THE THERMAL PERFORMANCE OF MONOCHLOROBENZENE AND BIPHENYL-BIPHENYL OXIDE AS WORKING FLUIDS IN RANKINE CYCLE SYSTEMS

By

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CONTENTS

SUMMARY

This thesis presents the results of an experimental investigation into the forced convection evaporation behaviour of two organic fluids, monochlorobenzene and the eutectic of biphenyl-biphenyl oxide which are suitable as working fluids for low output Rankine cycle systems. Details are given of a high pressure and temperature experimental loop which was constructed for the investigation which incorporated an electrically heated tube, 12.65 mm i.d. with a heated length of 1.83 m in which the test fluid flowed vertically upwards. The range of experimental conditions investigated were as follows:-

Test Variable and Units	Monochloro-benzene	Biphenyl-biphenyl oxide
System pressure, MN/m^2	.51 - 3.093	.225 - .521
Mass velocity, kg/m^2 sec.	296 - 886	195 - 743
Heat flux, kW/m^2	13 - 200	40 - 190
Inlet sub-cooling, kJ/kg.	12 - 201	25 - 191
Exit quality	.01 - .99	.02 - .99
Bulk fluid temperature, ^oC	146 - 326	232 - 344
Inside wall temperature, ^oC	176 - 575	252 - 503
Reynolds No.	18,000-86,900	15,500-47,600
Prandtl No.	2.9 - 3.7	4.0 - 5.8

It was found that the heat transfer in both the single-phase and sub-cooled boiling regimes could be described by existing correlations. In the net boiling region however this was not the case and none of five literature correlations considered for comparison purposes adequately represented the experimental data. A correlation of the net boiling data was derived using multiple linear regression analysis which employed the heat flux and liquid-vapour density ratio as the correlating variables. Heat transfer in the post dry-out region could be represented by a standard single-phase correlation

employing vapour phase thermophysical fluid properties. The heat flux at dry-out was correlated for a number of tests in terms of the mass velocity, latent heat and vapour quality at dry-out. The high wall temperatures caused by dry-out promoted thermal breakdown of the test fluids which served to highlight the prime importance of thermal stability considerations in Rankine cycle working fluid selection.

Included as Appendices are the data reduction computer program, a digest of the thermophysical properties of the test fluid, an error analysis and a listing of experimental and derived data for each test undertaken. Further Appendices give details of exploratory investigations concerning the thermal stability of monochlorobenzene employing a gas chromatographic method for the chemical analysis of fluid samples taken before and after heating, dissolved gas measurement and test section exit void fraction determination.

NOMENCLATURE

A	Test section flow area, m^2
A_m	Cross sectional area of test section wall, $\pi/4\ (D_o^2 - D^2)$, m^2
Bo	Boiling number, $\emptyset/(\lambda G)$
Cp_G	Constant pressure vapour specific heat, kJ/(kgK)
Cp_L	" " liquid " " "
Cp^o	Ideal gas specific heat , kJ/(kg.mole K)
D	Test section inner diameter, m
D_L	Equivalent hydraulic diameter of liquid film (Eq.3.16), m
D_o	Test section outer diameter, m
E	Thermocouple emf, mV
f	Fanning friction factor
f_{TP}	Two-phase friction factor
F_c	Convective heat transfer correction factor in Chen correlation (Eq. 3.14).
Fr_L	Froude number based on liquid portion of flow, $(G(1-x))^2/\rho_L^2 gD$
F_{NB}	Nucleate boiling correction factor in Guerrieri-Talty correlation
g	Acceleration due to gravity, 9.81 m/sec.^{2}
G	Mass velocity, m/A, kg/(m^2 sec.)
h	Heat transfer coefficient at tube wall, kW/(m^2C).
Δh	Liquid sub cooling i.e. saturation enthalpy - liquid enthalpy at test section inlet, kJ/kg.
h_L	All-liquid heat transfer coefficient, kW/(m^2C)
h_{mac}	Convection component (macroscopic)of heat transfer coefficient in Chen correlation (Eq. 3.14), kW/(m^2C)
h_{mic}	Nucleate boiling component (microscopic) of heat transfer coefficient in Chen correlation (Eq. 3.15), kW/(m^2C)
h_o	Combustion gas - tube wall heat transfer coefficient, kW/(m^2C)

I	Test section current, amperes
k	Thermal conductivity cal/(cm.s.K)
k_G	Vapour thermal conductivity, mW/(m.C)
k_L	Liquid " " "
k_m	Thermal conductivity of test section material, W/(m.C)
k^o	Low pressure thermal conductivity, cal/(cm.s.K)
k_{TP}	Two-phase mixture thermal conductivity, mW/(m.C)
L	Test section heated length, m
m	Mass flow rate, kg/s.
M	Molecular weight
Nu	Nusselt number, hD/k
Nu_L	Nusselt number based on liquid thermal conductivity, hD/k_L
p	Pressure, MN/m^2 or kN/m^2
p_c	Critical pressure, MN/m^2
p_r	Reduced pressure, p/p_c
P	Parachor
Pr	Prandtl number, $\mu Cp/k$
r	Test section inner radius, m
r_o	" " outer " "
r^*	Radius of minimum size thermodynamically stable bubble (Eq. 3.10), m
R	Test section resistance, ohms
R	Universal gas constant, 8.3143 kJ/(kg-mol K)
Re	Reynolds number, $\rho uD/\mu$ or GD/μ
Re_L	Liquid-phase Reynolds number, $(1-x)\ GD/\mu_L$
S_c	Nucleate boiling suppression factor in Chen correlation (Eq. 3.15)
T	Temperature, ^oC
T_b	Bulk fluid temperature, ^oC
T_c	Critical temperature, K
T_f	Film temperature, $(T_w + T_b)/2$, ^oC

T_L	Fluid temperature in sub-cooled region, ^oC
T_r	Reduced temperature, T/T_c
T_{sat}	Saturation temperature, ^oC
T_w	Inner wall temperature, ^oC
T_{wo}	Outer wall temperature, ^oC
u	Velocity , m/s.
U	Overall heat transfer coefficient, $kW/(m^2C)$
v_L	Liquid specific volume, m^3/kg.
v_{LG}	Difference in specific volumes of saturated liquid and vapour, m^3/kg.
V	Test section voltage drop, volts
V_c	Critical volume, m^3/kg
x	Vapour phase mass flow faction or quality
X_{tt}	Lockhart-Martinelli parameter (Eq. 3.8)
Z_c	Critical compressibility.
γ	Parameter defined by Eq. A3.9
δ	Thickness of laminar sub-layer (Eq. 3.11) m
Δp	Pressure drop or pressure difference, kN/m^2
ΔT	Temperature difference, ^oC
ΔT_{sat}	Wall superheat, $T_w - T_{sat}$, ^oC
ΔT_{sub}	Degree of sub-cooling, $T_b - T_{sat}$, ^oC
ε	Two-phase flow parameter in Chawla correlation (Eq. 3.16).
λ	Heat of vaporisation (Latent heat), kJ/kg.
μ	Viscosity, centipoises.
μ_G	Vapour viscosity, $mN\ s./m^2$
μ_L	Liquid viscosity, "
μ^o	Low pressure viscosity, centipoises.
μ_w	Viscosity at wall, $mN\ s./m^2$
ξ	Parameter defined by Eq. A3.5
ρ_c	Critical density, kg/m^3

ρ	Density kg/m^3
ρ_e	Electrical resistivity, µ.ohm-cm.
ρ_G	Vapour phase density, kg/m^3
ρ_L	Liquid " " "
ρ_r	Reduced density, ρ/ρ_c
σ	Surface tension, mN/m
τ_o	Wall sheer stress, N/m^2
ϕ	Wall heat flux, kW/m^2
dp_F/dz	Frictional component of pressure gradient, kN/m^3

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1. INTRODUCTION

1.1 The Rankine cycle is the most widely used thermodynamic system for electrical power generation. The cycle is shown in Fig. 1 for an elementary system employing water as the working fluid and in a modified form in Fig. 2 for an organic system incorporating a de-superheater/feed heater. In the former system high pressure water fed by the feed pump is vaporised to steam in the boiler through the addition of heat. The high pressure and temperature steam passes to the turbine where it is expanded down to a low pressure and temperature, in so doing producing work, before being condensed and circulated around the system again. Whilst water is the conventional working fluid for such a cycle it does have thermodynamic and turbomachinery deficiencies which have led to consideration being given to the use of alternative fluids such as liquid metals and organics. In particular during the past decade or so the advantages of organics as the working fluid for low power output Rankine cycle systems which employ a turbine as the prime mover have been clearly demonstrated.

1.2 There is a large market for low power output systems of say up to 200 kW and the prime movers currently fulfilling this demand are the petrol and diesel engines. Whilst the latter in particular have a high thermal efficiency, reciprocating engines in general have high maintenance costs, are noisy and can cause a lot of atmospheric pollution. Rankine engines employing turbines on the other hand are simple, being not subject to high vibratory forces they have lower maintenance costs and a longer life, are relatively silent in operation and by having a more controllable combustion process cause less atmospheric pollution. Additionally since the combustion is external a wide variety of heat sources can be used.

1.3 The advantages of organic fluids over water for low power output turbine systems arise from the much lower nozzle efflux velocities and

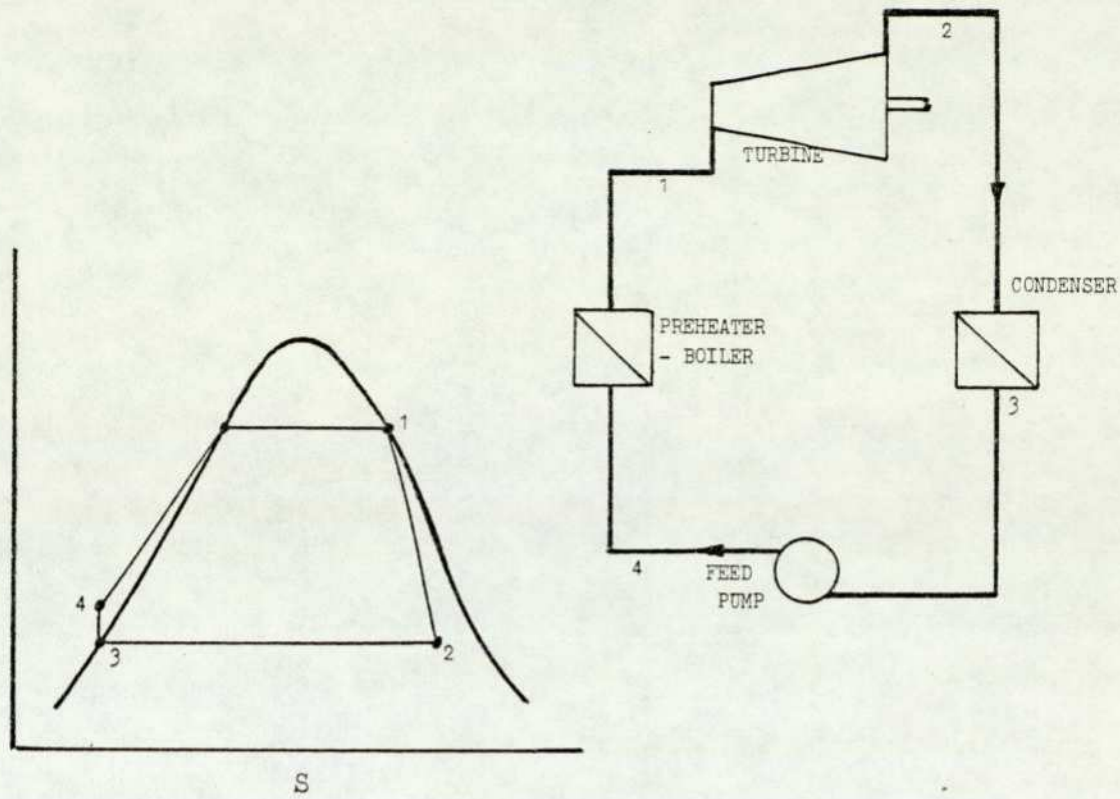


Fig. 1 ELEMENTARY RANKINE CYCLE SYSTEM

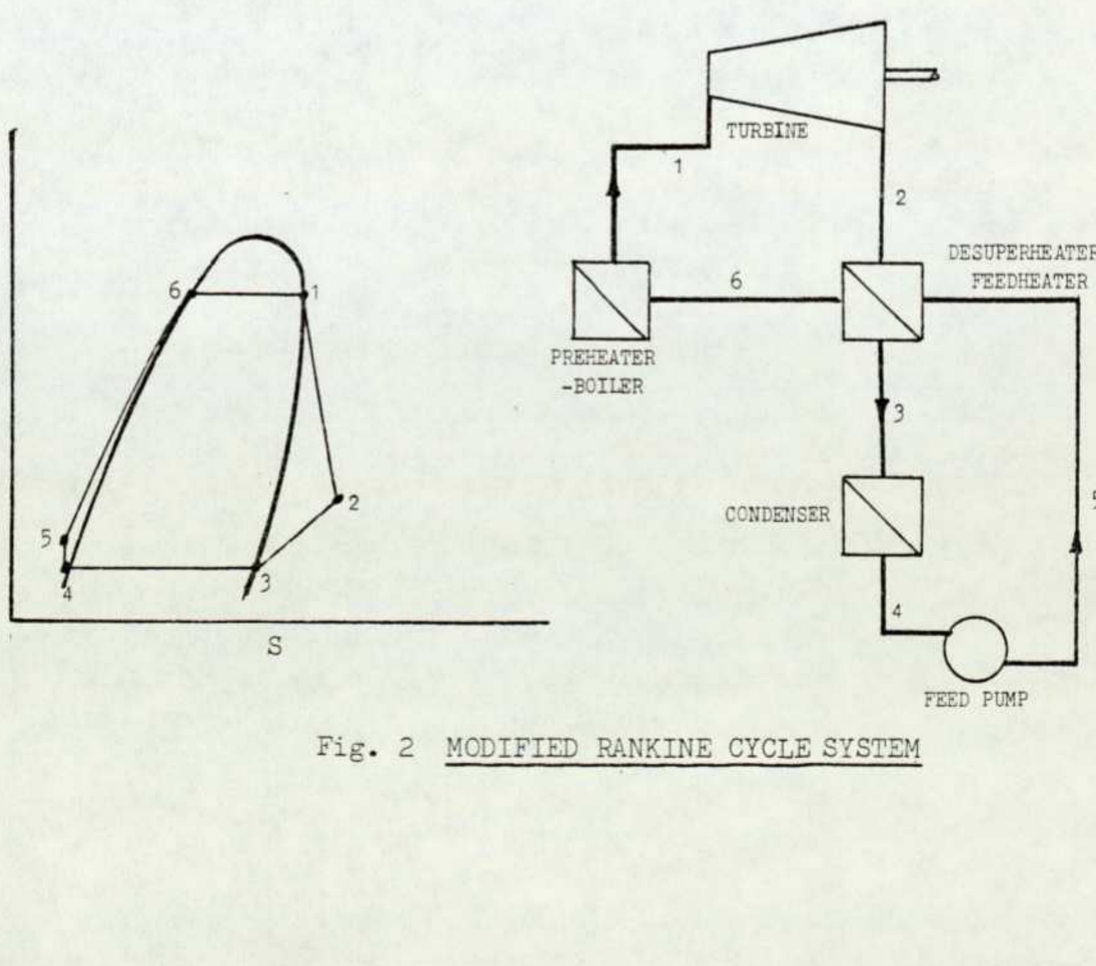


Fig. 2 MODIFIED RANKINE CYCLE SYSTEM

enthalpy drops associated with high molecular weight fluids. With steam as the working medium efflux velocities are very high. Hence a corresponding and impractically high blade speed is required to achieve a good turbine efficiency with a small diameter rotor. This together with the large losses arising from employing small blade heights and partial admission rules out steam as a candidate working fluid for high efficiency vapour turbine systems. In comparison, the low nozzle efflux velocities obtained with organics enable a turbine to be designed to operate at the optimum nozzle efflux-blade velocity ratio. Further a single stage construction is often possible since the available enthalpy drop is low. These factors promote mechanical simplicity and minimum cost. Because the enthalpy drop across the turbine stage is much lower than in the case of steam larger mass flow rates are required for a given power output permitting the use of full admission and relatively large blade heights, which are desirable design features.

1.4 An unusual feature of some organic fluids compared with water, is the positive slope of the saturated vapour line of the temperature-entropy diagram. This is illustrated for the fluids used in the experimental programme, viz: Monochlorobenzene and Biphenyl-Biphenyl oxide, in Fig. 3. A consequence of this difference is that superheated vapour exists after expansion at the turbine exit. Thus blade erosion problems are absent, unlike the case with steam where superheat turbine inlet conditions are often necessary so as to limit steam wetness to an acceptable amount. This latter characteristic can however be a drawback with some candidate organic fluids which have a temperature-entropy diagram with a very large positive slope. Expansion of such a fluid through a turbine would result in considerable superheat being present at the turbine exit which necessitates the incorporation of a regenerative heat exchanger to

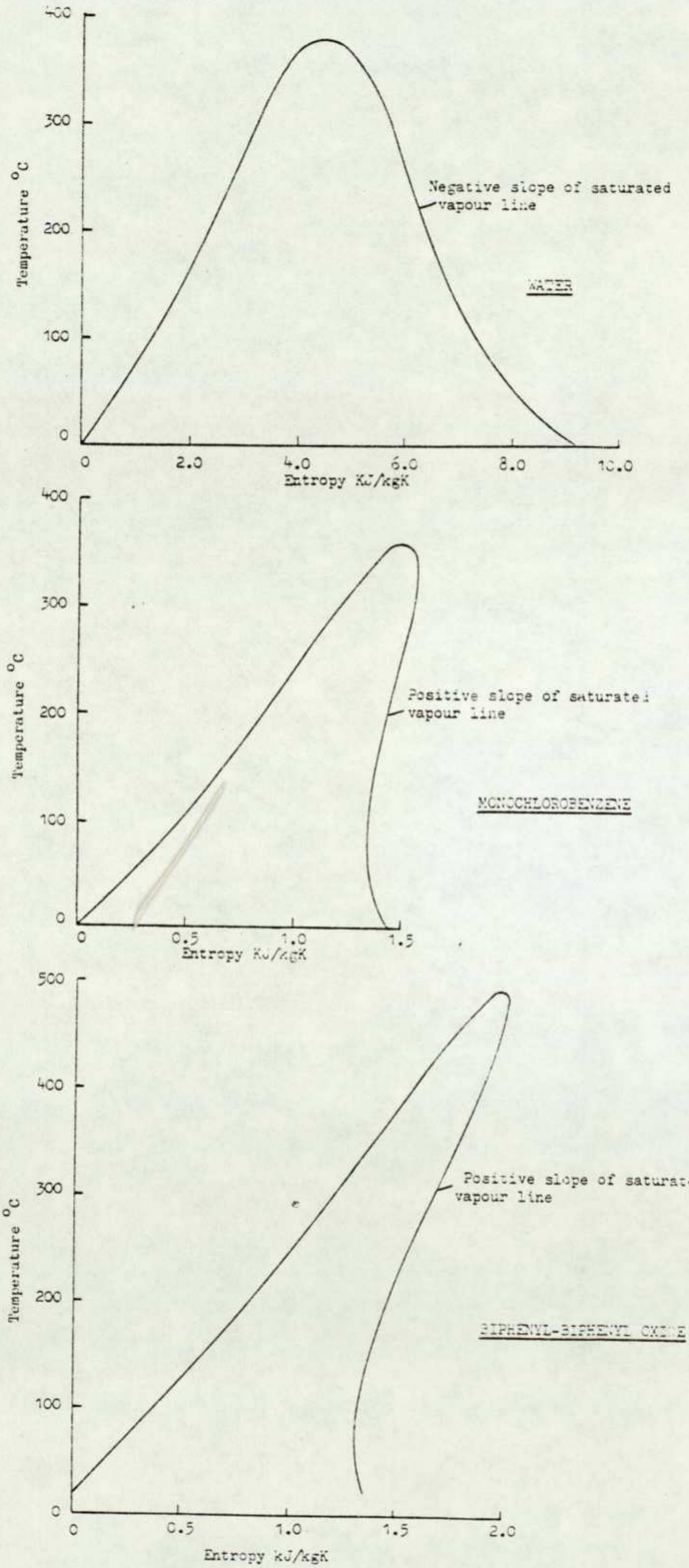


Fig. 3 Temperature-Entropy diagrams for water, monochlorobenzene and biphenyl-biphenyl oxide

recover it, prior to condensing, by feed heating so as to ensure a reasonable cycle thermal efficiency.

1.5 The selection of the best working fluid to use from amongst the large number of organic fluids in existence is not straightforward since many factors can influence this choice. A comprehensive review of factors affecting the choice of working fluid including details of applications of organic Rankine cycle systems with the various working fluids used covering the period 1850 to the present day has been previously given in Ref. 1.

The fluid selected should:-

(i) Possess high thermal stability with good materials compatibility.

(ii) Be non-explosive and non-poisonous.

(iii) Have a molecular weight above 50 and a near isentropic (vertical) slope of the saturated vapour line on the temperature-entropy diagram so as to avoid turbine blade erosion problems at the end of expansion.

(iv) Have a low freezing point.

(v) Have a higher than atmospheric vapour pressure at the cycle condensing temperature.

(vi) Possess good heat transfer properties.

(vii) Be cheap and readily available.

1.6 Only relatively few organic fluids meet sufficient of the foregoing criteria or have enough known about them to warrant serious consideration as candidate working fluids. Of these the 13 listed in Table 1 have been studied using computer programs to calculate their thermodynamic properties and perform cycle analyses of their use in air-cooled condensing systems to determine the most suitable one for a particular power range[(2)]. The results of this latter study showed

PROPERTY	UNITS	FLUID													
		Water	CP 9	CP 27	HFB	CP 32	DOW A	CP 34	O-XYL	CP 25	DOW E	PP 5	PP 9	FC 75	O-E-TOL
Chemical Formula		H_2O	$C_{15}H_{16}$	C_6H_5Cl	C_6F_6	C_5H_5n	-	C_4H_4S	C_8H_{10}	$C_6H_5CH_3$	$C_6H_4Cl_2$	$C_{10}F_{18}$	$C_{11}F_{20}$	$C_{18}F_{16}O$	C_9H_{12}
Molecular Weight		18	196.3	112.6	186	79.1	165	84.1	106.2	92.1	147	462	512	416	120.2
Critical Pressure	bar	221.2	24.45	45.2	33.04	56.34	32.04	54.59	37.4	42.1	41.06	17.53	16.59	16.07	30.59
Critical Temperature	^oC	374.2	522	354.2	243.6	347	497	307	358	318.9	423.8	292	313.4	227.1	380
Freezing Point	^oC	0	-50	-45.2	5.2	-42	12	-40	-29 to -25.2	-95	-22	?to +17.5	<-50	-62	<-17
Boiling Point at 1 atm.	^oC	100	110.6	132	80.3	115.3	257.7	84	144.4	110.6	180.2	142	160	102.6	165.2
Heat of vapourisation at boiling point.	kj kg^{-1}	2453.7	264	309	170.5	448	298	362	347	364	277	78.5	88.8	88.4	-
Liquid density	kg m^{-3}	1000(20)	979(25)	1110(20)	1618(20)	975	1061(25)	1058(25)	880	870(20)	1305(20)	1946(20)	1972(20)	1760(25)	882(20)
Liquid thermal conductivity	$mWm^{-1}\ ^oK^{-1}$	603(20)	121(93.5)	141(20)	97.5(20)	164(37.8)	140(25)	137(93.5)	119(80)	136(20)	121(20)	56.9(20)	56.9(20)	97.5(25)	-
Liquid specific heat	kj $kg^{-1}\ ^oK^{-1}$	4.183(20)	1.97(100)	1.335(20)	1.17(30)	1.5(25)	1.6(20)	1.43(37.8)	1.73(22.1)	1.69(20)	1.15(20)	1.05(30)	1.09(30)	1.05(30)	-
Liquid viscosity (Kinematic)	$m^2s^{-1} \times 10^6$	1.0(20)	4.5(37.8)	.729(20)	.56(25)	.82(25)	3.06(25)	.53(37.8)	.57(40)	.675(20)	1.065(20)	2.6(25)	3.32(25)	.82(25)	-
Surface Tension	mN m^{-1}	72.5(20)	38.1(22)	33(20)	22.6(20)	-	43(25)	33.9(20.6)	30(20)	28.5(20)	37.2(20)	15(25)	15(25)	15(25)	-

CP9 - Monoisopropylbiphenyl
CP27 - Monochlorobenzene
HFB - Hexaflurobenzene
CP32 - Pyridine
DOW A - Biphenyl-Biphenyloxide
CP34 - Thiophene
O-XYL - Ortho xylene
CP25 - Toluene
DOW E - O-dichlorobenzene
PP 5 - Perflurodecalin
PP 9 - Perfluoromethyldecalin
FC 75 - Perfluoro-2-butyltetrahydrofuran
O-E-TOL - O-ethyl toluene

Figures in brackets denote the temperature in ^oC at which the property applies.

TABLE 1 PARITAL LIST OF RANKINE CYCLE WORKING FLUIDS AND THEIR PROPERTIES that of the fluids considered the first 5 listed in Table 1 (excluding water) were most suited for various power ranges in the overall range from 0.5 to 200 kw_e. Of these monochlorobenzene (CP27) and the eutectic of biphenyl-biphenyl oxide (DOW A), known commercially as Dowtherm A (The Dow Chemical Co., USA), Thermex (Imperial Chemical Industries Ltd., U.K.), Diphyl (Bayer AG, W.Germany) or Gilotherm DO (Rhone-Poulenc, France) were selected for experimental study to determine their heat transfer characteristics, one of the fluid selection factors mentioned above.

1.7 Monochlorobenzene or chlorobenzene as it is sometimes termed having the chemical formula C_6H_5Cl is widely used as a starting material for the production of phenol, aniline, chloronitrobenzene, DDT etc. It is manufactured by the chlorination of benzene in the presence of a catalyst (usually ferric chloride, $FeCl_3$) to form a simple molecule where one chlorine atom has replaced one hydrogen atom around a single benzene ring. Some typical properties of monochlorobenzene are given in Table 2[(3)-(5)]. Unlike biphenyl-biphenyl oxide, monochlorobenzene has no history of use as a thermal fluid except in some of the development projects mentioned in Ref. 1. The eutectic mixture of biphenyl-biphenyl oxide has a history of use as a heat transfer fluid going back to the early 1930's. It is, as indicated in Fig. 4 a mixture of 26.5% biphenyl and 73.5% biphenyl oxide by weight. The boiling points of both these components are so close that the mixture evaporates azeotropically i.e. with the same composition in the liquid and vapour phases. An enrichment of the liquid with one of the components of the mixture thus does not occur on evaporation and its properties do not change. Typical properties of biphenyl-biphenyl oxide are also given in Table 2[(6)-(9)]. The saturation pressure-temperature and liquid-vapour density ratio characteristic for the two fluids are

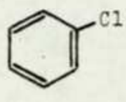
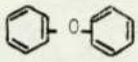
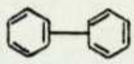
FLUID	CHLOROBENZENE SYNONYMS: MONOCHLOROBENZENE, CHLOROBENZOL, CHLORBENZOL, PHENYL CHLORIDE.	BIPHENYL-BIPHENYL OXIDE SYNONYMS: DIPHENYL-DIPHENYL OXIDE, DOWTHERM A, THERMEX, DIPHYL, GILOTHERM DO.
STRUCTURE		73.5% BIPHENYL OXIDE  26.5% BIPHENYL 
CHEMICAL FORMULA	C_6H_5Cl	
MOLECULAR WEIGHT	112.6	165
BOILING POINT AT 1.014 BAR, °C	131.7	257.7
FREEZING POINT, °C	-45	12
DENSITY AT 20°C, kg/m^3	1105 - 1107	1062
CRITICAL PRESSURE, BAR	45.2	32.04
CRITICAL TEMPERATURE, °C	359.2	497
CRITICAL VOLUME, m^3/kg	.00274	.00311
LIQUID SPECIFIC HEAT AT 20°C, kJ/(kgK)	1.36	1.15
LIQUID THERMAL CONDICTIVITY, mW/(mK)	141 (20°C)	140 (25°C)
LIQUID VISCOSITY (DYNAMIC), kNs/m^2	8 (20°C)	35 (25°C)
SURFACE TENSION AT 20°C, mN/m	32.0	43.0
LATENT HEAT OF VAPOURISATION AT BOILING POINT, kJ/kg	309.0	298.0
HEAT OF FUSION, kJ/kg	85.8	98.2
FLASH POINT, °C	32.0	116.0
FIRE POINT, °C	52.0	128.0
AUTO IGNITION TEMPERATURE, °C		615.0
LOWER EXPLOSIVE LIMIT IN AIR, % v/v	1.4	1.0
UPPER " " " " " "	7.1	3.5
THRESHOLD LIMIT VALUE, ppm v/v	75	
DIELECTRIC CONSTANT	5.7 (20°C)	3.26 (23.9°C)
SPECIFIC RESISTIVITY AT 20°C, OHM-CM	2×10^9	6.4×10^{11}
REFRACTIVE INDEX	1.5215 (25°C)	

TABLE 2: Summary of characteristic data for Monochlorobenzene and the eutectic of Biphenyl and Biphenyl oxide.

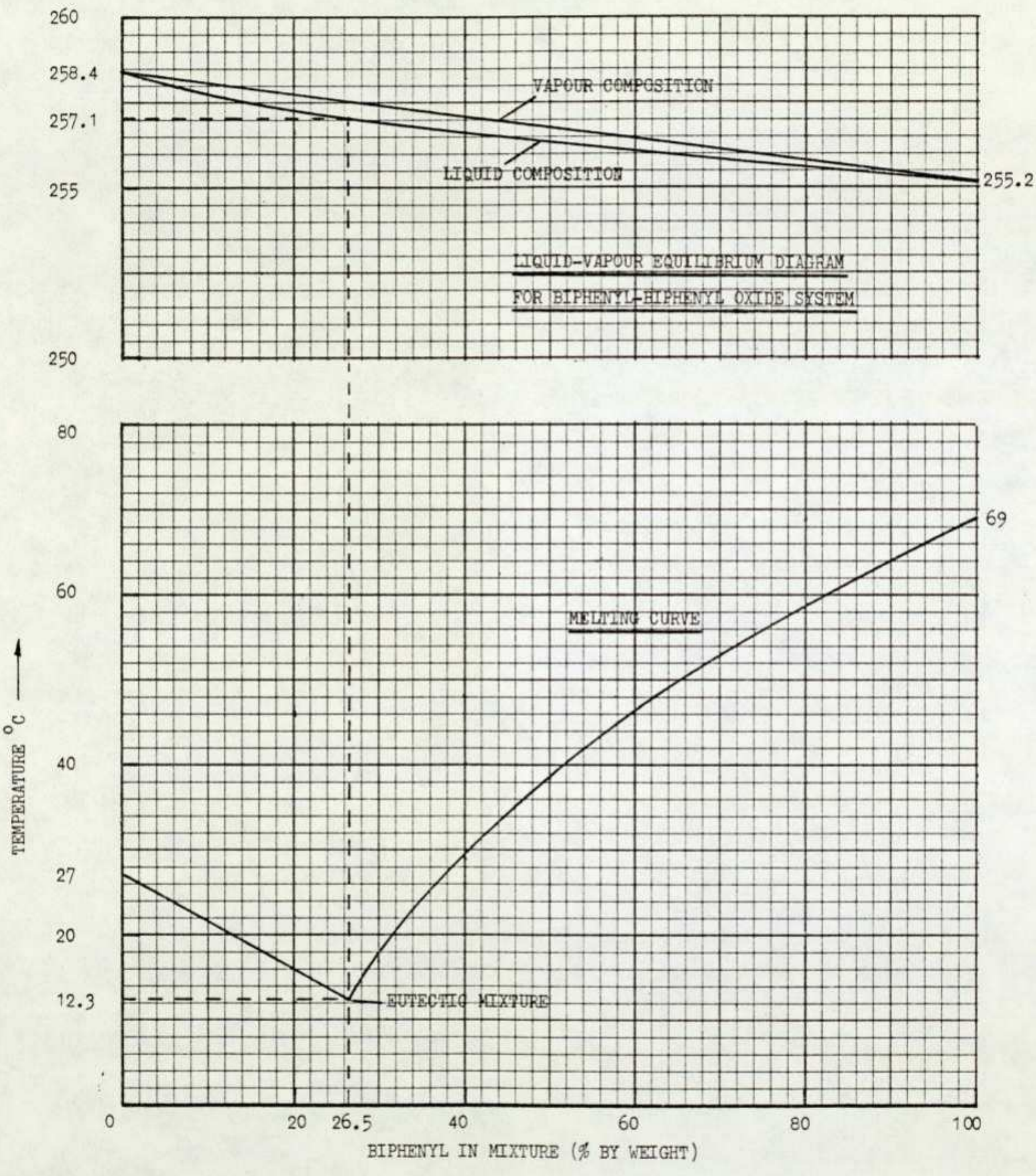


Fig. 4 CRYSTALLISING POINTS AND LIQUID-VAPOUR EQUILIBRIUM DIAGRAM FOR BIPHENYL-BIPHENYL OXIDE MIXTURES

shown in Figs. 5 & 6 along with those for water as well as for some of the other fluids mentioned in Table 1. Fig. 6 which presents the pressure-temperature characteristics as a plot of saturation pressure versus reciprocal of absolute temperature further illustrates the advantages of organic fluids vis a vis water. For a particular temperature the system pressures are lower which leads to lower stresses in the pressurised components such as evaporator tubes which operate at maximum cycle temperatures enabling lighter, lower cost materials to be used.

1.8 An organic Rankine cycle system such as shown schematically in Fig. 2 incorporates several heat exchangers viz. preheater/boiler or evaporator, desuperheater/feed heater and condenser. It has been estimated that the cost of these heat exchangers comprises a large proportion, about 40%, of the overall cost of a low power output system[(10)] with boiler costs accounting for up to half of this latter figure[(11)]. It is thus evident that reliable heat transfer information on the fluids under consideration is required to provide the basis for the economic design of the heat exchange components. It was to provide such heat transfer data that the investigation described in this thesis was instigated. For this purpose a test loop was constructed and heat transfer measurements undertaken on two fluids which were subject to the pressure and temperature conditions expected in an organic Rankine cycle system evaporator. The data required could not be obtained by calculation since boiling heat transfer theory is not sufficiently advanced. Obviously the main interest of the experimental research has been on boiling heat transfer since heat transfer laws for single phase systems are by comparison well established. The prime objectives of the investigation were:(i) to obtain data for monochlorobenzene and biphenyl-biphenyl oxide for the several distinct

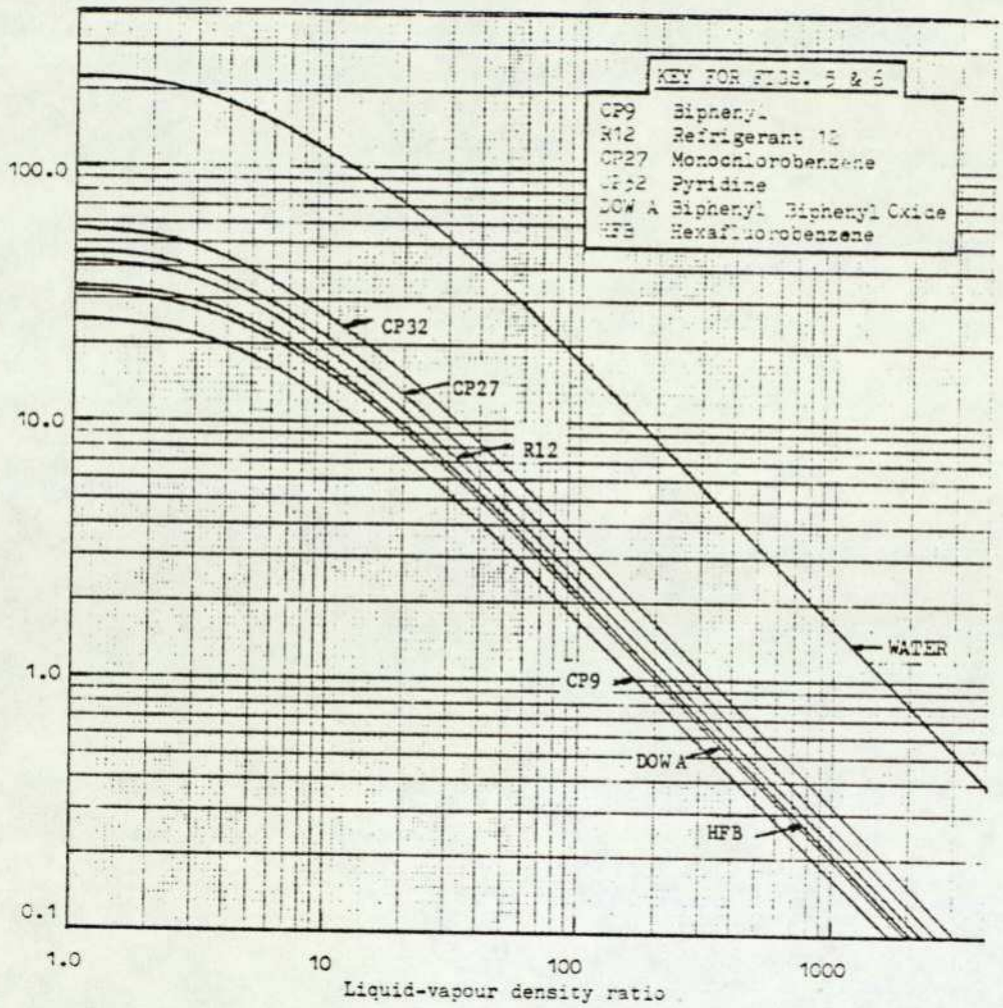


Fig. 5 Vapour pressure v density ratio for Rankine cycle working fluids

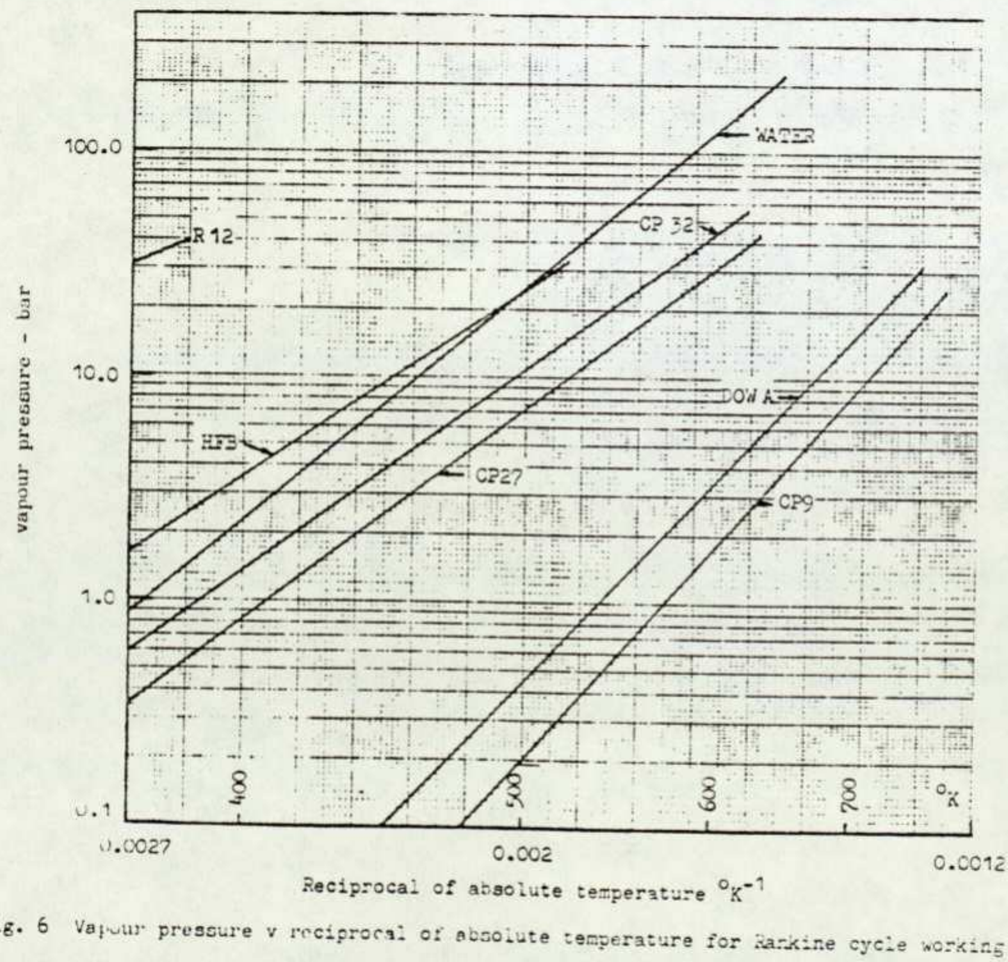


Fig. 6 Vapour pressure v reciprocal of absolute temperature for Rankine cycle working fluids.

modes of heat transfer existing within a vertical electrically heated test section and (ii) to subsequently correlate these data either by means of existing correlations or by means of relationships derived from the analysis of the experimental results.

1.9 One of the essential differences between water and organic fluids is the good thermal stability of the former compared with the generally poor thermal stability of the latter. Water is considered to be completely stable up to quite high temperatures, say 600 C, when dissociation begins to occur. Organics have a much lower limit of thermal stability i.e. the temperature above which unacceptable decomposition of the fluid occurs. The latter governs the temperature to which the fluid can be heated in the system, which in turn largely determines the thermal efficiency of the cycle. It is thus essential that the selected fluid should have acceptable thermal stability in the presence of commercially available materials under the repeated cyclic conditions appertaining in Rankine cycle systems and this factor can be considered to be the most important of all the fluid selection criteria[12] [13]. Quantitative information on the thermal stability of biphenyl-biphenyl oxide obtained from long term endurance loop testing is available in the literature[14][15]. No similar information however could be found for monochlorobenzene and thus a preliminary investigation on thermal stability aspects was undertaken on fluid samples used in the heat transfer tests. This latter work which employed a gas chromatographic method of chemical analysis is reported in Appendix 5.

2. HEAT TRANSFER IN ONCE-THROUGH EVAPORATOR SYSTEMS

2.1 A low power output organic Rankine cycle system would in all probability employ a once-through boiler rather than the recirculating type used in most conventional steam plants. For a small power plant a single tube of a once-through boiler would have sufficient vapour generation capacity to meet the total requirements of the power plant. Such single tube units are usually called monotube boilers or vapour generators in which sub-cooled fluid entering from the feed pump is completely vaporised and superheated in a single pass.

2.2 A monotube boiler is preferred to a recirculating type for an organic fluid application for the following reasons:

(i) The high temperature working fluid inventory is minimised.

(ii) The boiler is compact due to the absence of a vapour drum, liquid separator and recirculating pump.

(iii) The boiler has a low thermal inertia which consequently produces a rapid response to control equipment,

(iv) There is greater safety if there is an over-pressure incident.

(i) above is particularly important for organic systems where fluid thermal decomposition is always present to a greater or lesser extent. Thermal decomposition is primarily a function of temperature and the fluid residence time at temperature. Thermal decomposition will thus be very much less with a once-through design, where the hot-cold mass ratio can be as low as 1:100 [16], than with a recirculating system where a relatively large amount of fluid is being continuously heated at maximum cycle temperatures. A once-through design also minimises the likelihood of the formation of stagnant regions which could lead to accelerated thermal decomposition of the working fluid. In addition to reducing the system cost the absence of a large primary pressure vessel eliminates the possibility of catastrophic boiler explosions occurring in accident situations, a particularly desirable feature where mobile power plants are concerned.

2.3 The amount of heated surface area required for a given thermal duty and temperature difference can be determined from a knowledge of the overall heat transfer coefficient between the combustion gas and the working fluid flowing within the tube. The overall heat transfer coefficient at any point along the boiler tube, referred to the tube i.d. is the reciprocal of the combined thermal resistances of the combustion gas, the tube wall and the working fluid viz.:-

$$U = \frac{1}{\frac{1}{(D_o/D)\,h_o} + \frac{D}{2k_w}\log_e (D_o/D) + \frac{1}{h}}$$

where:

- U = overall heat transfer coefficient referred to tube i.d.
- h_o = heat transfer coefficient from the flue gas to the tube material.
- h = heat transfer coefficient from the tube wall to the working medium.
- k_w = thermal conductivity of the tube material.

2.4 The combustion gas heat transfer coefficient h_o for a monotube boiler is generally one or two orders of magnitude smaller than the equivalent tube wall and working fluid heat transfer coefficients and thus its magnitude largely determines the heat transfer area required. The working fluid side heat transfer coefficient however determines the boiler tube wall temperature, larger heat transfer coefficients leading to lower tube temperatures. Since the boiler tube operating temperature places an upper limit on the performance and compactness possible with a boiler a knowledge of the heat transfer process within the monotube is essential for design purposes.

2.5 The various regimes of heat transfer occurring during the once-through forced convection evaporation of a fluid flowing vertically upwards in a tube having a uniform wall heat flux are illustrated in Fig. 7. During vaporisation the nature of the flow changes from pure liquid to pure vapour via a number of two-phase flow patterns or regimes ranging from discreet bubble flow to mist flow. The fluid enters the tube in a sub-cooled state i.e. the bulk temperature is below the saturation temperature corresponding to the inlet pressure level and heat transfer from the heated wall is by single-phase forced convection. The fluid temperature is progressively raised until a point is reached, termed the 'onset of sub-cooled boiling' where the liquid becomes sufficiently superheated to form bubbles at preferred nucleation sites on the wall of the tube. Initially these bubbles are very small and are restricted to the wall in a thin boundary layer and any that are swept out into the stream rapidly condense in the colder bulk fluid and the net increase in void fraction, i.e. the ratio of the vapour phase volume to the total volume at a particular cross-section of the tube, is negligible. Some investigators have termed this the 'highly sub-cooled' region. As the bulk sub-cooling further decreases up the tube a rapid increase in the bubble population occurs and these begin to grow and depart into, but not condense, in the main stream. The location where the rapid increase in voidage occurs is known as the 'point of net vapour generation' and the distance from this point to the bulk boiling boundary occupies the so called 'slightly sub-cooled' region.

2.6 The bulk temperature and void fraction continue to increase through the slightly sub-cooled region until the bulk boiling boundary is reached when sufficient heat has been added to the fluid to raise its average bulk or mixed mean enthalpy to the saturation value corresponding to the local pressure. Another name for this location is the 'zero quality' point, quality being defined as the weight fraction of the

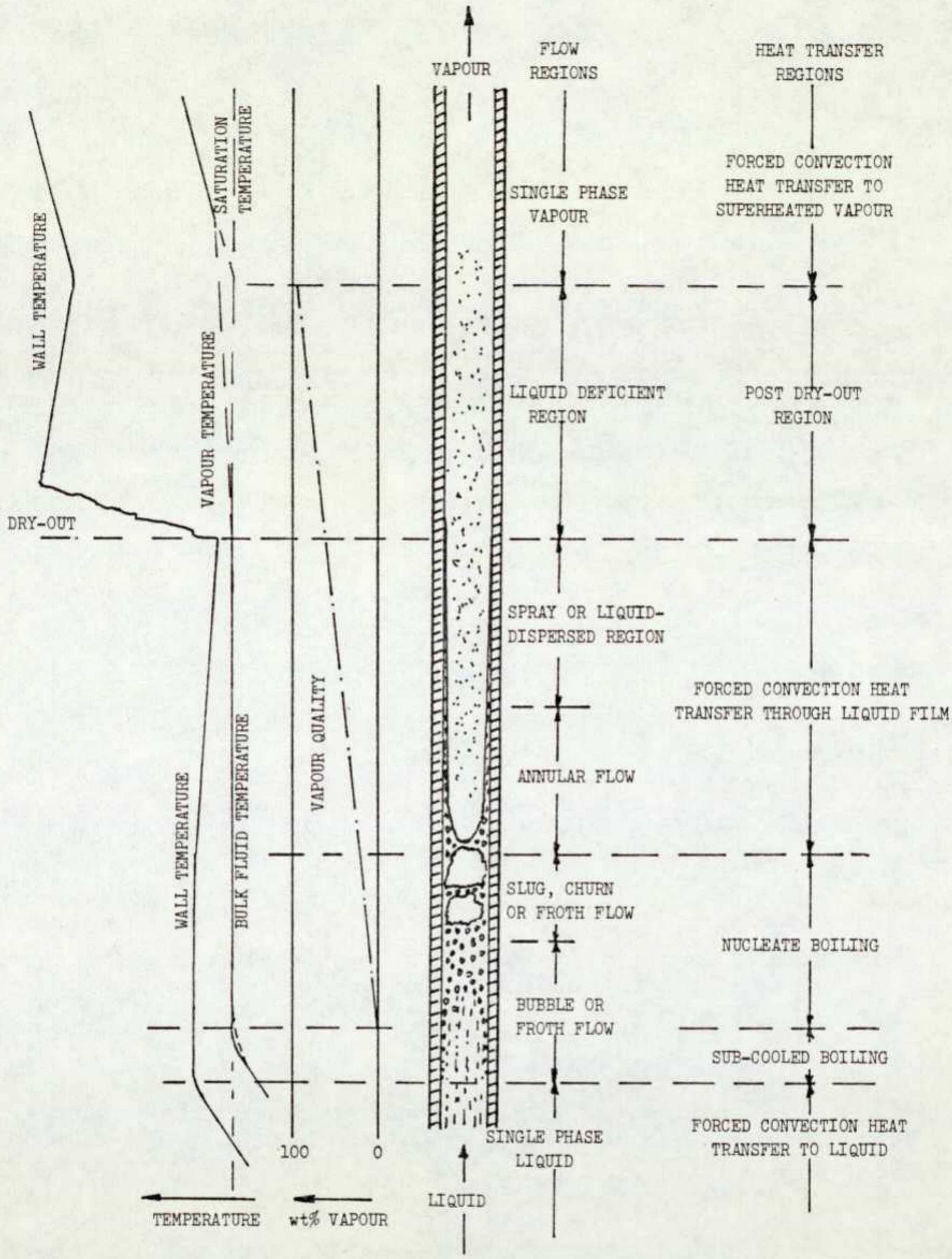


Fig. 7. <u>Schematic representation of 'once-through' boiling</u>

flow vaporised at any particular point along the duct. Vigorous nucleate boiling of the fluid is taking place at this stage and in this nucleate boiling region the heat flux to the liquid may be increased considerably without any significant increase in the wall temperature, which is generally only slightly higher than the liquid saturation temperature. Further up the tube into the positive quality regime the bubbles agglomerate to form vapour slugs surrounded by saturated liquid in a region variously termed turbulent slug, churn or froth flow. Nucleate boiling still occurs at the wall and bubbles continue to feed the vapour slugs until the vapour flow rate becomes so high that the majority of the liquid is forced into an annular film on the wall with the remainder of the liquid being carried as entrained droplets in a turbulent vapour core, the so-called 'annular flow' regime. Generally nucleate boiling will continue to take place in the liquid film to a diminishing extent in low quality annular flow until it is eventually suppressed by the increasing flow velocity leading to too small a temperature difference across the liquid film to support nucleation.

2.7 As the flow continues up the tube the annular flow pattern persists with heat transfer taking place by conduction and convection through the thin liquid film and evaporation occurring at the liquid-vapour interface. The liquid film thus progressively decreases in thickness due to the effects of evaporation and entrainment and eventually at the so-called 'dry-out point' there is insufficient liquid left in the film to wet the wall at all points around its circumference. A dry patch thus forms at the heated surface at which point the vapour now adjacent to the tube wall acts as a partial insulant which, with a heat flux controlled system such as a radiantly heated tube, gives rise to a sudden increase in wall temperature. There can be relatively large surface temperature oscillations present at this point which are indicative of the unstable conditions which appertain at dry-out, however these soon decrease and conditions stabilise, assuming the effect is not catastrophic, with higher temperature gradients than existed previously. Catastrophic conditions arise when the temperature rise is such that the tube overheats to beyond the melting point of the material, or to a temperature which in combination with the pressure conditions within the tube causes a failure of the tube wall. These critical conditions of heat transfer and fluid flow are variously referred to as dry-out, boiling crisis, critical or peak heat flux or burn-out conditions. An important distinction between a similar situation caused by vapour blanketing in a sub-cooled nucleate boiling system is that with the latter the temperature transient is extremely rapid and it invariably results in tube failure, whereas that occurring on dry-out is by comparison very slow and often, as in this work, produces tolerable wall temperatures. Indeed, since it is inevitable in a once-through boiler operating at saturation conditions that the dry-out transition has to be experienced it is an over-riding design condition that its occurrence should not cause failure of the boiler tube wall. The flow pattern after dry-out becomes one of liquid droplets entrained in vapour over a so-called 'liquid deficient' flow region. Liquid droplet vaporisation occurs by conduction and convection to the superheated vapour. The tube wall temperature after its precipitous rise at dry-out decreases slightly as a result of liquid droplet evaporation, producing higher vapour velocities and corresponding greater heat transfer coefficients. Finally, all the liquid is evaporated and heat transfer is by single-phase convection to a superheated vapour.

2.8 The foregoing description of once-through boiling can be summarised for design purposes by the variation of the fluid side heat transfer coefficient as shown for a steam system in Fig. 8[17]. The major disadvantage of this process as applied to organic fluids is that a dry wall condition exists for a significant portion of the evaporator tube which with a radiant heat source could result in high wall temperatures enhancing fluid decomposition. This region of high metal temperatures is thus of particular concern to the once-through boiler designer since it effectively constitutes a practical design limitation both from tube material stress and fluid breakdown considerations. The major factor influencing the magnitude of the wall temperature rise at dry-out is the value of the applied heat flux. There is however little quantitative information in the open literature which makes recommendations on the maximum heat fluxes to use with organic systems of the type being discussed, which with the absence of a reliable prediction theory makes recourse to experiment a necessity even for the simplest geometries.

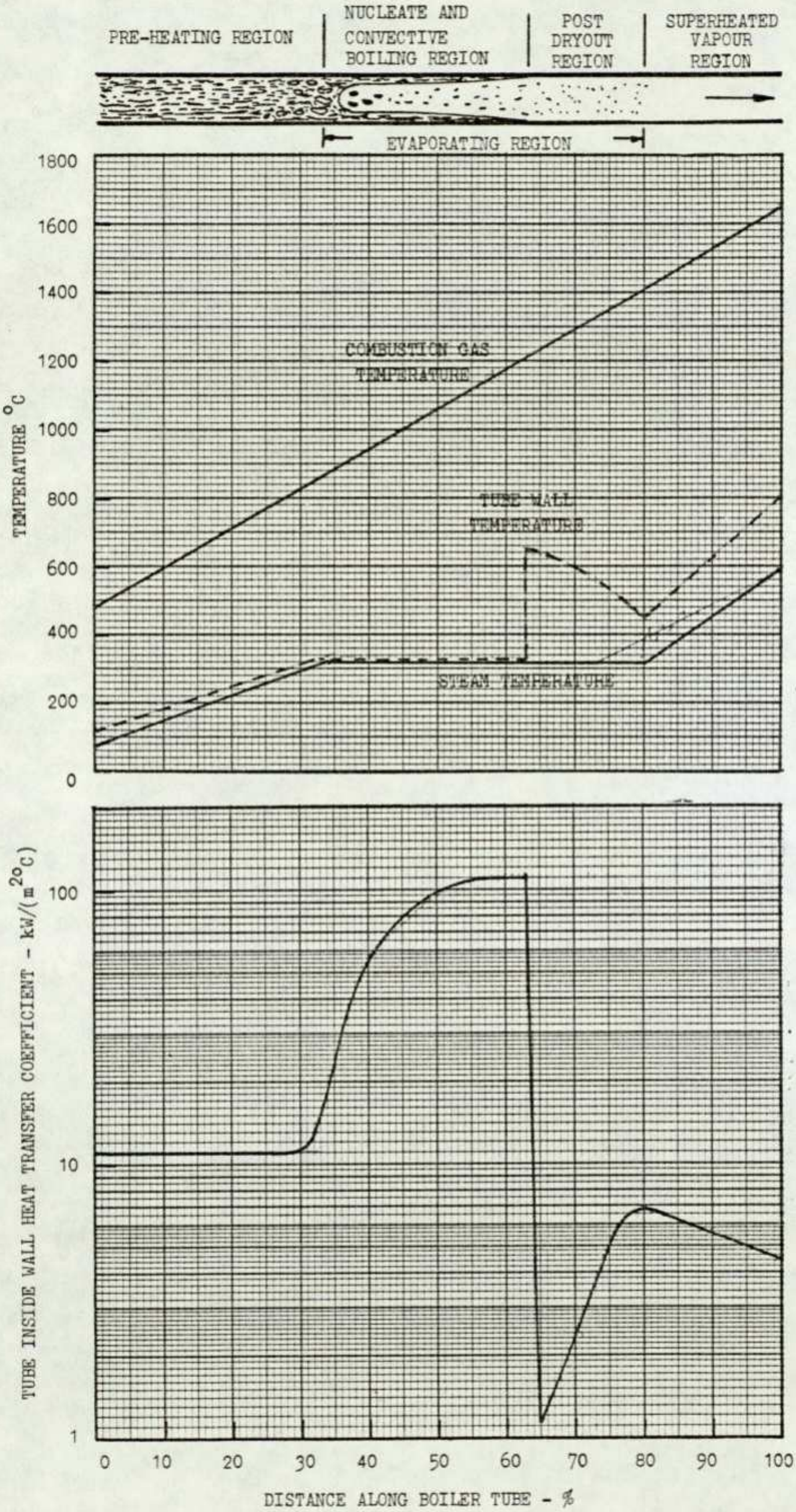


Fig. 8 Typical local conditions in a monotube steam generator.

3. REVIEW OF HEAT TRANSFER CORRELATIONS FOR THE SINGLE PHASE, SUB-COOLED BOILING & SATURATED BOILING REGIMES UP TO THE ONSET OF WALL DRYOUT.

3.1 From the foregoing chapter it is evident that once-through boiling or evaporation as it occurs in a monotube vapour generator is quite complex. In particular the presence of the various two-phase flow patterns seriously complicates the task of predicting heat transfer into the flowing fluid. Each of these flow regimes, which can vary significantly in detail for various combinations of pressure, flow rate and vapour quality etc. suggests a different model for the calculation of heat transfer rates etc. Because the physical phenomena associated with boiling in two-phase mixtures are not fully understood at the present time, design equations for the various flow regimes are based upon empirical or semi-empirical correlations. The purpose of this Chapter is to review the literature correlations which were used for comparison purposes with the experimental results in the data reduction phase of this investigation. Only a brief summary of these correlations will be made here since comprehensive discussions concerning them can be found in the various books on boiling heat transfer which have been published in recent years[(18)-(23)].

3.2 Single phase forced convection heat transfer correlations.

In this regime the temperatures of the wall and fluid are both below the fluid saturation temperature for the local pressure. A laminar sub-layer exists next to the wall which provides the primary resistance to heat transfer. With an increase in fluid velocity, the sub-layer thickness decreases and the mainstream turbulence increases which causes a corresponding increase in heat transfer. Three of several single-phase correlations for turbulent flow in pipes are given overleaf:-

Dittus and Boelter[(24)] in their correlation equation:-

$$\left(\frac{h_L D}{k_L}\right) = .023 \left(\frac{\rho_L u D}{\mu_L}\right)^{0.8} \left(\frac{\mu_L Cp_L}{k_L}\right)^{0.4} \qquad \text{(Eq. 3.1)}$$

evaluated all fluid properties at the bulk temperature of the fluid. Sieder & Tate(25) added a viscosity ratio factor to a similar expression as Eq.3.1 viz.:-

$$\left(\frac{h_L D}{k_L}\right) = .027 \left(\frac{\rho_L u D}{\mu_L}\right)^{0.8} \left(\frac{\mu_L Cp_L}{k_L}\right)^{0.333} \left(\frac{\mu_b}{\mu_w}\right)^{.14} \qquad \text{(Eq. 3.2)}$$

where again all fluid properties were evaluated at the bulk fluid temperature except μ_w which was evaluated at the wall temperature. The dynamic viscosity ratio term was added to account for the fact that the boundary layer at the wall is strongly influenced by the temperature dependence of the viscosity.

As a conclusion from the analysis of a large amount of experimental data on forced convection on a variety of liquids the Engineering Sciences Data Unit recommended the following equation(26) with the fluid properties all evaluated at the bulk temperature:-

$$\left(\frac{h_L}{\rho_L u Cp_L}\right) = \exp\left(-3.796 - .205 \log_e Re - .505 \log_e Pr - .0255 (\log_e Pr)^2\right) \qquad \text{(Eq. 3.3)}$$

which can be written in the form of Eq. 3.1 as:-

$$\left(\frac{h_L D}{k_L}\right) = E.\ Re^{.795}.\ Pr^{.495} \qquad \text{(Eq. 3.4)}$$

where $E = .0225 \exp\left(-.0225 (\log_e Pr)^2\right)$

3.3 Sub-cooled boiling heat transfer correlations.

In the case of sub-cooled boiling heat transfer the tube wall temperature is above the local fluid saturation temperature. When this excess temperature or wall superheat exceeds a certain value bubbles form at nucleation sites on the tube wall which cause the heat transfer coefficients to be substantially increased beyond their previous single phase values. Correlations for this regime range from completely empirical or semi-empirical dimensionless group ones to the more fundamental superposition type which employ pool boiling correlations with added terms to account for liquid motion.

Moles & Shaw[27] have summarised the dimensionless group and superposition type correlations for sub-cooled flow boiling. From an analysis of experimental sub-cooled flow boiling covering different fluids and geometries the latter investigators have proposed the following dimensionless group correlation:-

$$\frac{h}{h_L} = 78.5 \left(\frac{Cp_L \mu_L}{k_L}\right)_f^{0.46} \left(\frac{\phi}{\lambda \rho_G u}\right)^{0.67} \left(\frac{\lambda}{Cp_L \Delta T_{sub}}\right)^{0.5} \left(\frac{\rho_G}{\rho_L}\right)^{0.7} \qquad \text{(Eq. 3.5)}$$

In the above expression all properties are calculated at the saturation temperature corresponding to the relevant system pressure with the exception of the Prandtl group which is evaluated at the film temperature (the arithmetic mean of the wall and bulk temperatures). The all-liquid heat transfer coefficient h_L in Eq. 3.5 was recommended to be calculated using the ESDU correlation (equation 3.3 or 3.4). The foregoing expression is similar to that developed by Papell[28] for the sub-cooled flow boiling of water viz:-

$$\frac{h}{h_L} = 90 \left\{ \left(\frac{\phi}{\lambda \rho_G u}\right) \left(\frac{\lambda}{Cp_L \Delta T_{sub}}\right)^{1.2} \left(\frac{\rho_G}{\rho_L}\right)^{1.08} \right\}^{0.7} \qquad \text{(Eq. 3.6)}$$

Both Eqs. 3.5 and 3.6 are restricted to sub-cooled boiling since the parameter containing the degree of sub-cooling of the fluid ($\Delta T_{sub} = T_b - T_{sat}$) becomes infinite at zero sub-cooling.

3.4 Saturated flow boiling heat transfer correlation.

3.4.1 Heat transfer correlations for the net boiling region can be separated out under two general headings (i) the wet wall correlations and (ii) the dry wall or liquid deficient correlations with the dividing line between the applicability of each being the wall dryout point. Only the correlations relevant to heading (i) will be discussed here since rig operating difficulties prevented reliable heat transfer data from being obtained in the post-dryout region.

3.4.2 A large number of empirical or semi-empirical correlations have been developed to correlate boiling heat transfer data for a variety of fluids[29]. One of the earliest correlations of data for the local heat transfer coefficients in evaporation is that given by Guerrieri & Talty[30] from experiments undertaken with organic fluids in a single tube natural circulation vertical boiler. In a similar manner as in the work of Dengler & Addoms[31] published at the same time, the existence of two contributions, namely forced convection effects and bubble nucleation effects, to the overall heat transfer process in flow boiling was recognised. For the case when nucleation effects were assumed to be absent Guerrieri & Talty related the boiling heat transfer coefficient to the single phase all-liquid heat transfer coefficient by the following expression:-

$$\frac{h}{h_L} = 3.4 \left(\frac{1}{X_{tt}}\right)^{0.45} \qquad \text{(Eq. 3.7)}$$

where X_{tt} is the parameter used by Lockhart & Martinelli[32] to correlate two-phase pressure drop measurements when both phases were in turbulent flow viz:-

$$X_{tt} = \left(\frac{\mu_L}{\mu_G}\right)^{0.1} \left(\frac{\rho_L}{\rho_G}\right)^{0.5} \left(\frac{1-x}{x}\right)^{0.9} \qquad \text{(Eq. 3.8)}$$

The single-phase liquid coefficient h_L is calculated by the following Dittus & Boelter relation which only considers the unvaporised part of the mass flow i.e. G(1-x) in the calculation of the Reynolds number term:-

$$h_L = .023 \frac{k_L}{D} \left(\frac{DG(1-x)}{\mu_L}\right)^{0.8} \left(\frac{Cp_L \mu_L}{k_L}\right)^{0.4} \qquad \text{(Eq. 3.9)}$$

At low values of $1/X_{tt}$, i.e. at low qualities the heat transfer coefficient given by Eq. 3.7 must be multiplied by a 'nucleate boiling augmentation factor' F_{NB} to account for the increased heat transfer due to nucleate boiling. The value of F_{NB} was empirically found to be:- $F_{NB} = 0.187\,(r^*/\delta)^{-.555}$ where r^* was defined as the minimum radius of a thermodynamically stable bubble corresponding to the wall superheat:-

$$r^* = \frac{2\,R\,T_{sat}^2\,\sigma}{M\,p\,\lambda\,\Delta T_{sat}} \qquad \text{(Eq. 3.10)}$$

and δ the thickness of the lamina layer at the wall given by:-

$$\delta = \frac{10\mu_L}{\rho_L} \left(\frac{\rho_L}{\tau_o}\right)^{0.5} \qquad \text{(Eq. 3.11)}$$

where τ_o is the wall shear stress, $D/4.(-dp_F/dz)$.

The nucleate boiling correction term F_{NB} cannot be less than unity which corresponds to a value of r^*/δ of 0.049 and thus nucleation suppressed conditions are present for any r^*/δ value greater than this latter figure.

3.4.3 In an attempt to obtain a single equation to cover both the nucleate boiling and the forced convective regions Schrock & Grossman(33) suggested the use of the 'Boiling Number', $\emptyset/\lambda G$ to characterise the nucleate boiling region and the Lockhart-Martinelli parameter to characterise the forced convective region. Their correlation, derived from experiments with water and steam in vertical tubes can be expressed as follows:-

$$\frac{h}{h_L} = 7390 \left[\left(\frac{\emptyset}{\lambda G}\right) + 1.5 \times 10^{-4}\left(\frac{1}{X_{tt}}\right)^{.67}\right] \qquad \text{(Eq. 3.12)}$$

where h_L is calculated using the Dittus-Boelter equation (Eq. 3.1). The correlation is based on the assumption that at low heat fluxes the flow is annular and thus convective effects are dominant and there is a strong dependence on X_{tt}. As the heat flux is raised nucleate boiling augments the forced convection effect until, when the heat flux becomes sufficiently large, the heat transfer process becomes independent of the two-phase flow characteristics of the system. At this stage the heat transfer coefficient becomes independent of X_{tt} and can be correlated by the Boiling Number.

3.4.5 Lavin & Young[34] provided several correlations for evaporation as a function of the local flow regime from experiments undertaken with Refrigerants 12 and 22 in short horizontal and vertical electrically heated copper tubes. The form of the equation chosen to correlate the data in the annular flow regime which excluded any nucleation contribution can be expressed as:-

$$\frac{h}{h_L} = C\left(\frac{1 + x}{1 - x}\right)^{1.16}\left(\frac{\phi}{\lambda G}\right)^{-0.1} \qquad \text{(Eq. 3.13)}$$

where C = 3.79 and 6.59 for the vertical and horizontal tubes respectively with h_L being calculated using the Sieder-Tate correlation (Eq. 3.2), with the Reynolds number term defined in an identical manner as in Eq. 3.9.

3.4.6 Chen[35] utilised the data for water and organic fluids of several previous investigators to produce a correlation for saturated flow boiling that has subsequently gained widespread acceptance. The correlation was based on a superposition principle where effects due to bubble nucleation and forced convection are added to arrive at the overall heat transfer coefficient.

The heat transfer contribution associated with forced convection effects was termed the 'macroconvective' component and defined as:-

$$h_{mac} = 0.023 \quad \frac{k_{TP}}{D} \left(\frac{G(1-x)D}{\mu_L}\right)^{0.8} \left(\frac{\mu_L Cp_L}{k_L}\right)^{0.4} F_c \qquad \text{(Eq. 3.14)}$$

As a simplification it was assumed that the Prandtl numbers of the liquid and vapour were equal and that k_{TP}, the two-phase mixture thermal conductivity was equal to the liquid value on the basis that the main resistance to heat flow was the annular liquid film adhering to the tube wall. F_c is a flow-dependent Reynolds number factor which was assumed to be a function of the Lockhart-Martinelli parameter X_{tt}. The actual dependence of F_c on X_{tt} was derived by Chen from the test data of several independent sources and is reproduced here in Fig. 9. The nucleation heat transfer additive effect was defined by Chen as the 'microconvective' component which was calculated employing the nucleate pool boiling correlation of Forster & Zuber[36] multiplied by a nucleate boiling suppression factor S_c ($S_c > 1$), viz:-

$$h_{mic} = 0.00122 \left(\frac{k_L^{.79} \, Cp_L^{.45} \, \rho_L^{.49}}{\sigma^{.5} \mu_L^{.29} \, \lambda^{.24} \rho_G^{.24}}\right) . \Delta T^{.24} \, \Delta p^{.75} S_c \qquad \text{(Eq. 3.15)}$$

where $\Delta T = T_w - T_{sat}$ (wall superheat) and Δp is the vapour pressure difference corresponding to ΔT. The suppression factor S_c which was also determined by Chen from experimental data is similarly reproduced in Fig. 9 and this reflects the decreased nucleation effects as the vapour flowing quality increases (i.e. as F_c increases). At zero flow-rates S_c becomes unity and the microscopic heat transfer component reduces to that given by the pool boiling value of Forster & Zuber. At the opposite extreme of high two-phase mixture velocities the value of S_c decreases towards a minimum value of about 0.1. There is thus always a nucleate boiling component with the Chen correlation unlike other correlations which assume complete suppression of nucleation effects

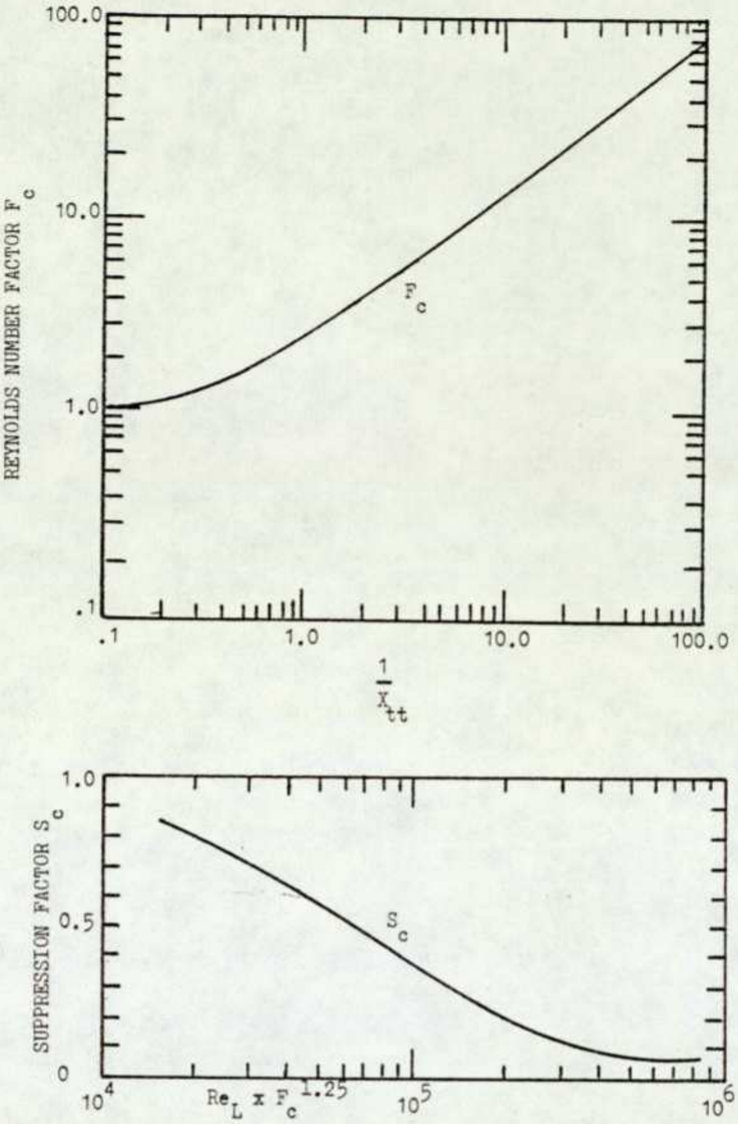


Fig. 9 Reynolds Number and Nucleate Boiling Suppression Factors for Chen correlation.(35)

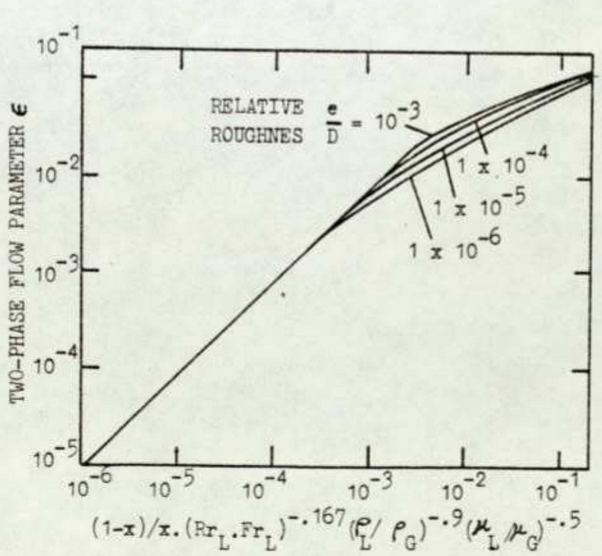


Fig. 10 Two-phase Flow Parameter ε for Chawla correlation(37)

at higher Reynolds numbers. As previously stated the two components are added to give the total heat transfer coefficient i.e.:-

$$h = h_{mic} + h_{mac}$$

3.4.7 A saturated flow boiling correlation covering the complete vapour quality range which incorporates a number of dimensionless groups has been proposed by Chawla[3.7]. A 'two-phase flow parameter' ε , the ratio of the mean liquid velocity to the mean vapour velocity was introduced to define a Nusselt number $(h.d_L/ \ k_L)$ based on the equivalent hydraulic diameter D_L of the liquid flowing as a film around the tube wall. This equivalent hydraulic diameter was given as:-

$$D_L = D \left\{ 1 - \left(1 + \frac{1-x}{x\varepsilon \rho_L/\rho_G} \right)^{0.5} \right\} \qquad \text{(Eq. 3.16)}$$

The two-phase flow parameter ε was empirically correlated as a function of the liquid Reynolds & Froude numbers, quality, density and viscosity ratios of the liquid and vapour phases and the relative roughness of the tube wall as shown in Fig. 10.

The final correlation for the heat transfer coefficient was derived from an analysis of experimental heat transfer data for both water and organics for two ranges of the product of the liquid Reynolds & Froude numbers viz.:-

for $(Re_L.Fr_L) < 109$

$$N_u = \frac{hD_L}{k_L} = 0.0066\ (Re_L.Fr_L)^{.475}\ (x/1-x)(\rho_L/\rho_G)^{.3}(\mu_L/\mu_G)^{.8}.Re_L^{.35}.Pr_L^{.42}$$

(Eq. 3.17)

and $(Re_L.Fr_L) > 109$

$$Nu = \frac{hD_L}{k_L} = 0.015(Re_L Fr_L)^{.3}\ (x/1-x)(\rho_L/\rho_G)^{.3}\ (\mu_L/\mu_G)^{.8}\ Re_L^{.35} Pr_L^{.42}$$

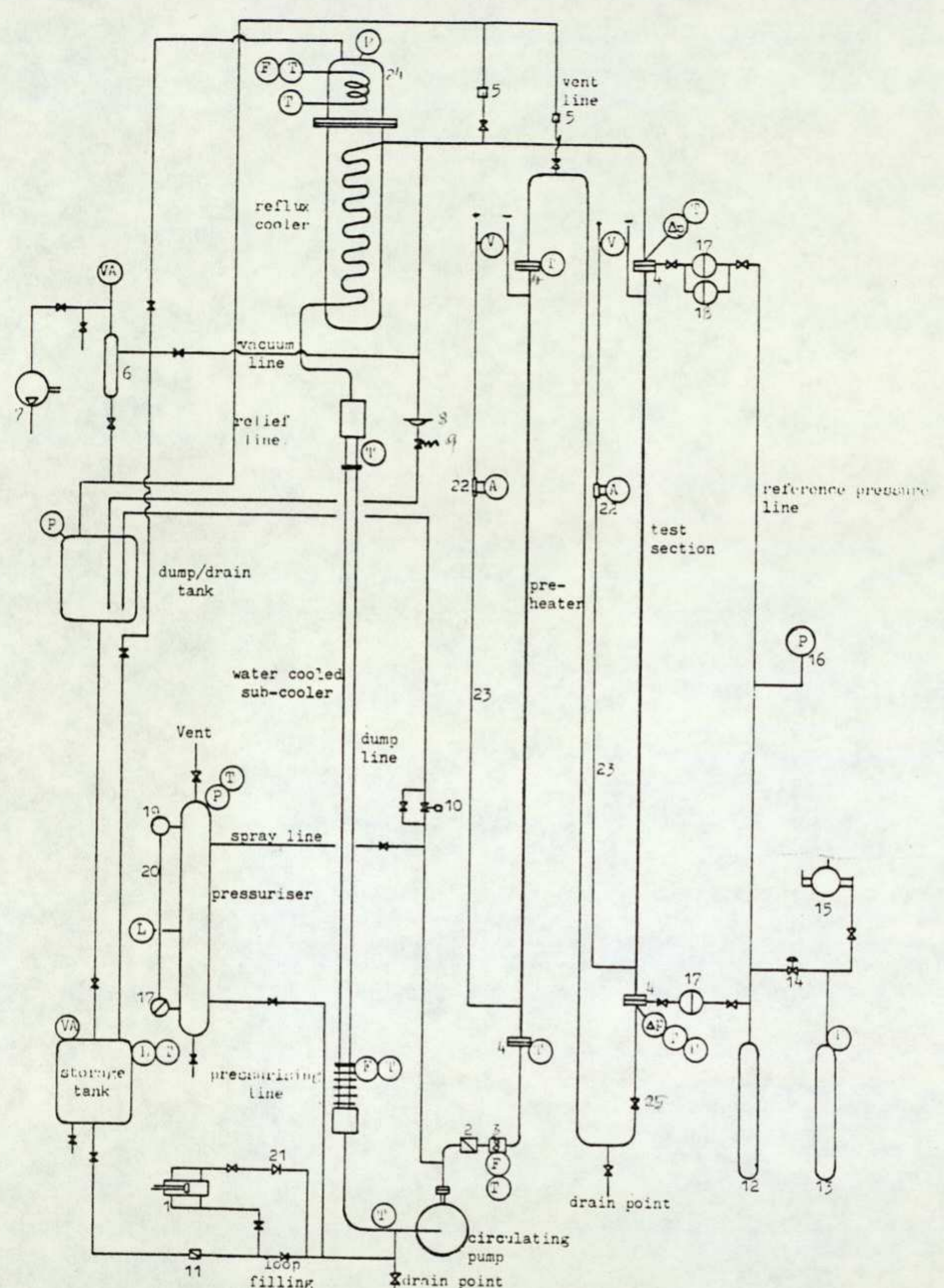
(Eq. 3.18)

4. DESIGN, CONSTRUCTION AND OPERATION OF THE LOOP USED IN THE EXPERIMENTAL HEAT TRANSFER INVESTIGATION.

4.1 Introduction

4.1.1 Over the past 25 years wide use has been made of loop facilities for investigating the mechanism of heat transfer to the fluids used in thermal power systems. The most common type of loop used in such studies has been the closed loop system as shown schematically in Fig. 11 for the rig employed here. The function of the loop system is to provide controlled fluid conditions over a suitably instrumented test section. These fluid conditions i.e. flow rate - pressure and temperature are usually controlled at the test section inlet although some investigators have preferred to control exit conditions instead. Control of fluid temperature prior to entry to the test section can be affected by the amount of heat input from a pre-heater situated upstream of the test section. Sufficient heat input should be available to provide any desired test section inlet temperature up to the saturation value. It is usual with such rigs however to have a certain amount of sub-cooling at the test section inlet so that the thermodynamic state at this point can be determined. It is also desirable to have an all-liquid inlet if burnout data are to be obtained with the so-called 'hard inlet' condition[38]. There are several methods available to control loop pressure utilising hydraulic accumulators, pressurisers or pressurising reciprocating pumps. Control of the flow is normally effected by a valve situated upstream of the test section; however other methods of control include variation of circulating pump speed or regulating the amount of pump by-pass flow.

4.1.2 The test section geometries used in loop studies have varied enormously from the single uniform bore tube as used here to the complex rod and cluster arrangements employed in nuclear reactor



1	reciprocating make-up pump	12	ref. pressure damping vessel	23	busbar
2	primary filter	13	h.p. ref. gas storage vessel	24	condenser cooling cool
3	turbine flowmeter	14	ref. pressure regulating valve	25	flow control valve
4.	electrically insulated flange	15	3 stage h.p. air compressor	P	Pressure
5	sight glass	16	Heise precision pressure gauge	Δ P	differential pressure
6	cold trap	17	diff. pressure transducer	T	temperature
7	vacuum pump	18	diff. pressure indicator	F	flow
8	bursting disc assembly	19	condensation pot	L	level
9	relief valve	20	water cooled reference leg	VA	vacuum
10	solenoid operated valve	21	non-return valve	V	volts
11	filling line filter	22	power shunt	A	amps

Fig. 11 SCHEMATIC OF HEAT TRANSFER LOOP

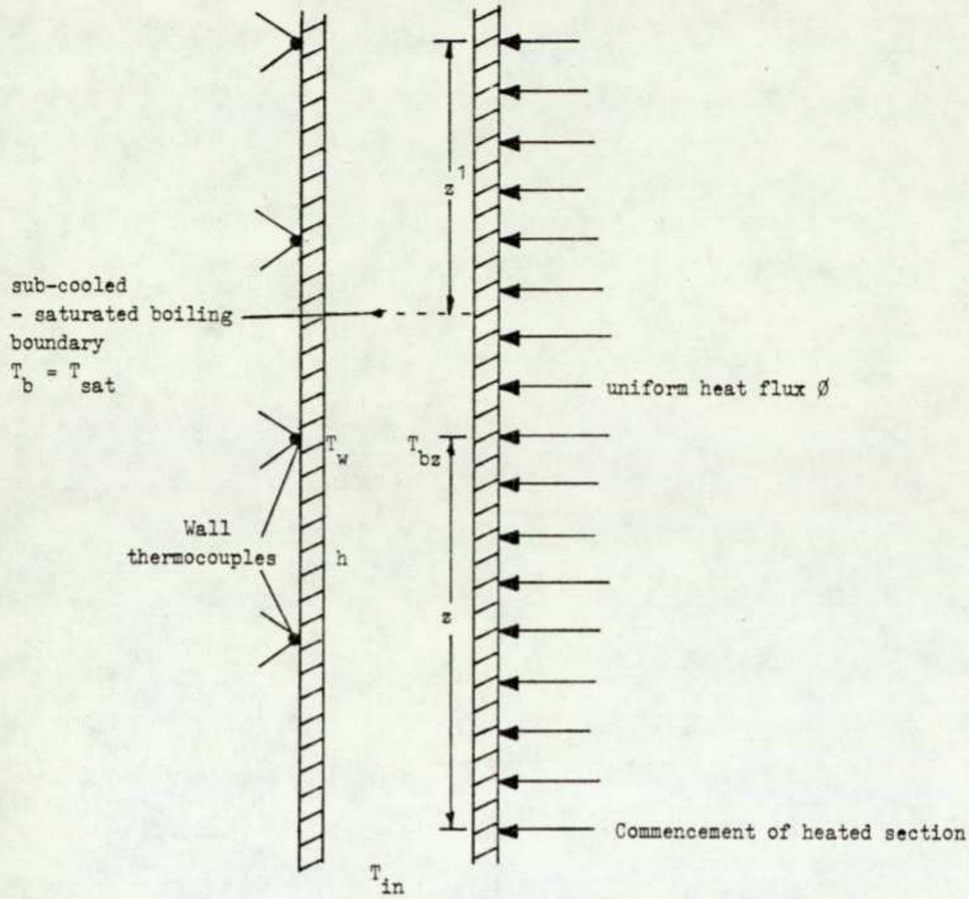
development work. The most extensively used method of supplying heat to the test section is by resistance heating of the test section wall using low voltage, high current a.c. or d.c. electrical power. This type of constant heat flux heating enables local heat transfer coefficients to be measured at intervals along the test section as indicated in Fig. 12. The inner wall temperature of the test section T_w is arrived at by subtracting the wall temperature drop from the measured outer surface temperature T_{wo}. The wall temperature drop is calculated using the Fourier heat conduction equation for a cylinder with a known amount of internal heat generation and material thermal conductivity. The bulk fluid temperature, T_b, adjacent to a wall thermocouple is calculated from a measured temperature at the test section inlet and the known amount of heat added up to the particular wall thermocouple position in question. Thus the only unknown in the heat transfer equation:-

$$\emptyset = h/(T_w - T_b)$$

is the heat transfer coefficient 'h' which can be determined at each wall thermocouple position. In the remainder of this Chapter a description will be given of the heat transfer loop which was designed and constructed incorporating the foregoing general principles together with the experimental techniques employed and some of the problems encountered during the course of the investigation.

4.2 Experimental Heat Transfer Loop Design.

4.2.1 It was envisaged at the outset of the investigation that the rig should simulate as far as possible an organic Rankine cycle system operating under both steady state and transient conditions as part of a joint project with another University department who were interested in the dynamics of closed loop systems using on-line computer control. In the event however this collaborative project was not undertaken and becuase of time limitations the rig, originally designed to study



REGION	BULK FLUID TEMPERATURE	VAPOUR QUALITY	HEAT TRANSFER COEFFICIENT
SUB-COOLED (Single-phase and sub-cooled boiling)	$T_{bz} = T_{in} + \frac{4\, Ø\, z}{G\, Cp_L\, D}$ z = distance from commencement of heating	-	$h = \frac{Ø}{(T_w - T_b)}$
SATURATED (net vapour generation)	$T_{bz} = T_{sat}$	$x_z = \frac{4\, Ø\, z^1}{G\, D\, \lambda}$ z^1 = distance from net boiling boundary	$h = \frac{Ø}{(T_w - T_{sat})}$

Fig. 12 Heat transfer to a fluid in a uniformly heated tube.

boiling, desuperheating/feed heating and condensation, was progressively modified to being a system suited only for the investigation of forced convection boiling. The following parameters were selected for design purposes which covered the extreme conditions for the fluids considered in the parallel computer simulation studies[2] :-

Maximum	operating pressure	6.9 MN/m^2
"	fluid temperature	350°C
"	test section temperature	600°C
"	flow rate	545 kg/hr.
"	test section power input	40 kW.

4.2.2 The rig as constructed had a height of about 4.6 m. and was sited within a partitioned off area in room A304 of the main University building. This partitioned off area had two levels for access purposes and its own ventilation extraction system. The loop constructional material was stainless steel with the exception of a Nimonic 75 test section (Nimonic 75 is a trade mark of H.Wiggin & Co. Ltd., Hereford). It was designed in accordance with relevant pressure vessel design standards for operation at the maximum pressure and temperature conditions given in 4.2.1.

4.3 Primary Loop.

4.3.1 As shown in Fig. 11 the loop consisted of a closed primary circuit with several auxiliary systems. Fluid was circulated by a glandless type pump through a flow meter and pre-heater prior to flowing vertically upwards through the test section. From the test section the fluid, either a liquid or liquid-vapour mixture, passed to a series combination of a reflux cooler/condenser and a water-cooled concentric tube sub-cooler where heat was removed to condense any vapour and reduce the temperature to a suitable value at the circulating pump inlet. Connections were made to the primary loop for filling, venting, pressurising, pressure relief and dumping, spraying down, vacuuming out and drainage.

4.3.2 The primary loop construction material was type 321 austenitic stainless steel and it was assembled using compression type fittings. The type of compression fittings employed were supplied by Betabite Hydraulics Ltd. and they gave satisfactory service under the severest combination of pressure and temperature conditions employed i.e. 3 MN/m^2 and 325°C with monochlorobenzene as the circulating fluid. The primary pipework bore ranged between 12.7 mm and 19 mm for various sections of the circuit with the connecting lines to the auxiliary circuits being 6.35 mm bore. The valves in contact with the test fluid were 6.35 mm Hoke 2100 Series with the exception of the 12.7 mm flow control valve. The latter valves had a PTFE based stem packing which gave no problems with either leakage or seizure with the very searching fluids used in the test programme.

4.3.3 Primary circulating pump. The circulating pump used was supplied by HMD Pumps Ltd. and was of the glandless type employing a magnetic drive coupling (Fig.13). The pump had a single open impeller and gave a head of 12 m. over the range of flow rates used in the test programme. Whilst no serious loop stability problems were encountered a pump having a greater head would have allowed a larger range of flow conditions to be investigated than was the case. During the test programme the pump performed satisfactorily with suction fluid temperatures of up to 207°C although it was nominally rated for only 150°C.

4.3.4 Primary fluid flow meter. A turbine flow meter was used to measure the volumetric flow rate through the system. A flow meter of this type is insensitive to changes in the density of the flowing fluid and they have a dynamic flow metering range of 10:1 or more. The flow meter was manufactured by Electronic Flo-Meters Ltd., type B/^{1}/4/2 and had a linear metering range of 54-540 kg/hr (water at 20°C). The body of the magnetic pickup of the flow meter was fitted

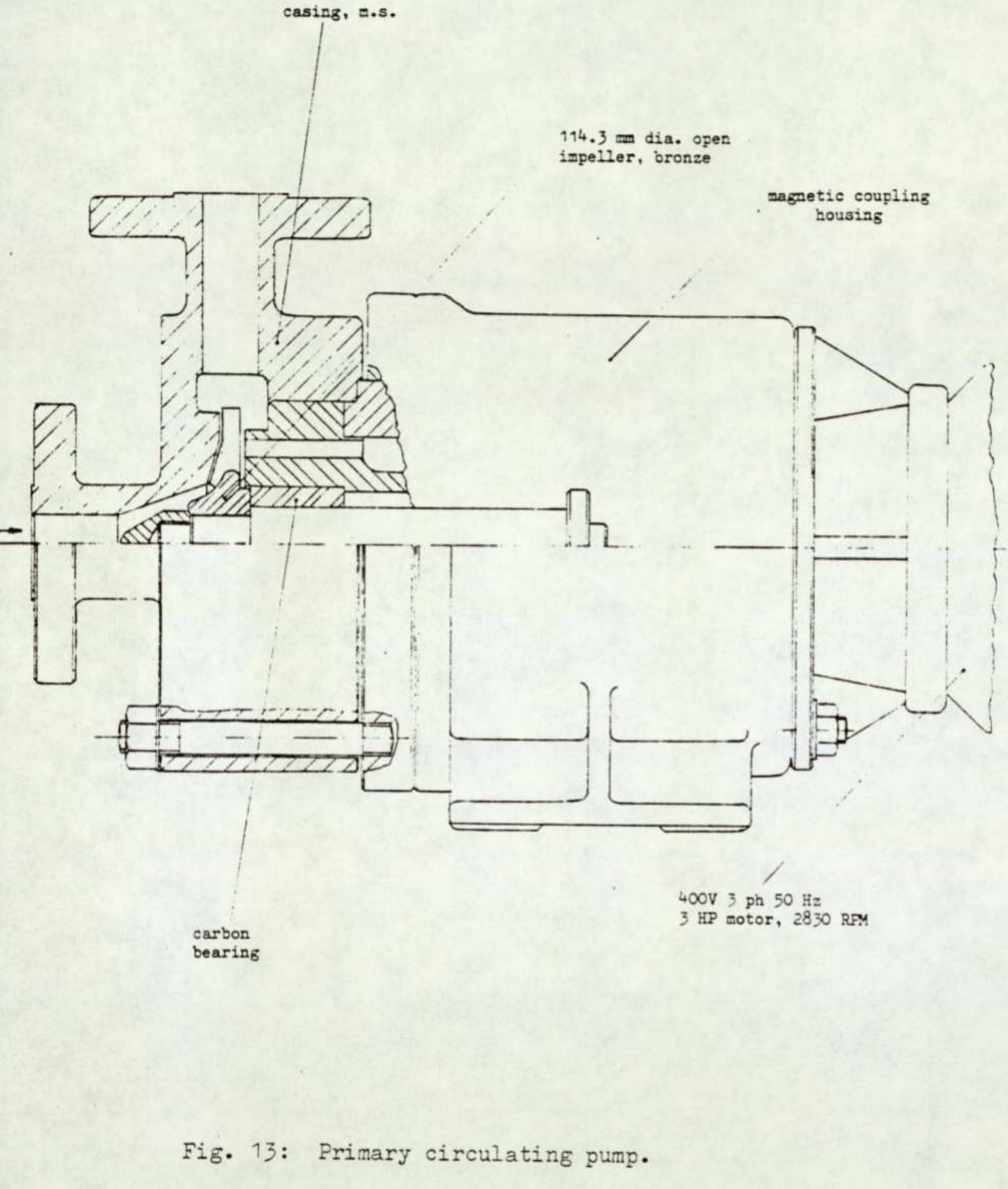


Fig. 13: Primary circulating pump.

with a coiled copper tube heat exchanger to limit the temperature of the electronics to below the manufacturers recommendation of 70°C maximum. A full flow filter was fitted upstream of the flow meter to remove particulate matter from the loop fluid.

4.3.5 Pre-heater. The temperature of the fluid at the test section inlet was regulated by the amount of heat input from an electrically heated pre-heater. The pre-heater was formed of a type 321 stainless steel tube, through which the fluid flowed vertically, and was heated as a resistance element by low voltage, high current electrical power. This power, which was d.c. was provided by a Simpson variac-controlled three-phase transformer feeding a three-phase bridge rectifier supplying up to 1,000 Amps at a potential of 12 volts with a maximum output voltage ripple of 5% peak to peak. The pre-heater dimensions were 15.87 mm outside diameter, 12.7 mm inside diameter with a heated length of 2.13 m. The pre-heater was electrically isolated from the adjacent loop components by insulated flanges. Flexible heavy-duty braids (Head Braiding Ltd., type HB186) were used to connect the power clamps fixed to the pre-heater and the power supply busbars. The 6.35 mm x 50.8 mm section busbars which connected the power supplies of both the pre-heater and the test section from the output terminals to the flexible braids were manufactured of electrolytic grade copper. Both the braids and clamps were plated to prevent oxidation.

4.3.6 Flow control valve. A 12.7 mm Hoke 2100 series needle valve was fitted upstream of the test section for flow control purposes. Although the valve stem packing was only rated by the manufacturer for up to 230°C the valve satisfactorily operated at maximum temperatures and system pressures of 297°C and 3.0MN/m^2 and 332°C and .47MN/m^2 with monochlorobenzene and biphenyl-biphenyl oxide respectively.

4.3.7 Reflux cooler - condenser. A reflux type heat exchanger was employed for initial cooling of the primary fluid after it left the test section. This consisted of a mild steel shell having the primary loop formed as a coil within it as shown in Fig. 14. This coil was immersed in an intermediate heat transfer fluid, water or Thermex, which was boiled up by heat from the primary fluid, the vapour so produced being condensed on a water cooled copper coil situated in the upper half of the vessel. Heat removal was thus to the cooling water circulating in the condenser cooling coil and because the boiling and condensing heat transfer coefficients were large the unit was relatively compact. Based on a heat transfer rate of 126 kW/m^2 of primary coil area the heat removal capacity was approximately 15 kW. A sight glass holder for a 100 mm diam. x 12.7 mm thick ground Pyrex glass sight glass (Quadrant Glass Co.) was fitted to the shell for observing whether refluxing was in progress, which with the vessel itself was hydraulically pressure tested up to 2.5 MN/m^2.

4.3.8 Sub-cooler. Prior to entering the circulating pump and completing the primary circuit the fluid was further reduced in temperature in a water cooled heat exchanger or sub-cooler. The heat exchanger was of the concentric tube type with the cooling water flowing upwards, in counterflow to the primary fluid, in an annulus between the tubes. The central tube through which the primary fluid flowed was 15.87 mm i.d. having a cooled length of 2.43 m.

4.4 Auxiliary Loop Systems.

4.4.1 Pressurisation. Under absolutely steady-state conditions with a closed loop system of the type discussed the heat input will equal the heat output and there will be no need for an external pressuriser for pressure-control purposes since the amount of fluid in the loop, monitored by say the condenser level, will determine the system pressure. In practice, however, such steady state conditions are

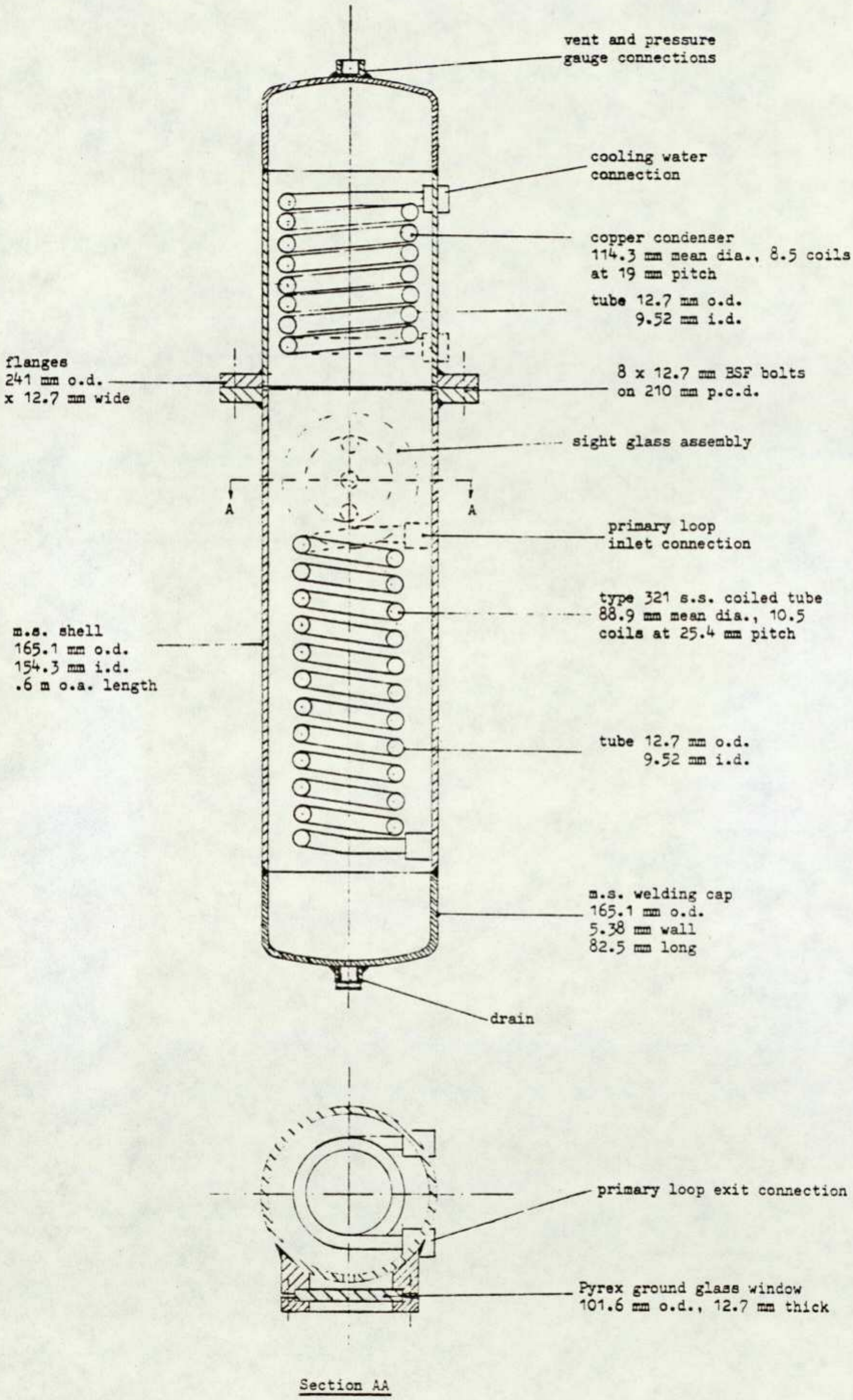


FIG. 14: Reflux cooler/condenser

difficult, if not impossible, to achieve so that there will be some inflow and outflow of primary fluid which must be stored in an accumulator system directly connected to the loop. Such an accumulator may also be used for accommodating the increase in fluid volume which occurs upon evaporation and during initial heating on loop start-up without having to dump excess fluid outside the high pressure part of the system. A further advantage provided by such an accumulator or pressuriser is that the rig remains at pressure when there is no power to the test section. This minimises the amount of pressure cycling involved when the power supply is cut off for any reason, which limits the additional stresses to couplings, valves etc. which is induced by pressure cycling which could lead to failure of loop components.
A pressuriser also reduces the time involved in getting the loop system back on-line when the test programme has been interrupted.
Closed loops usually employ one of the following types of pressuriser system:-

(i) A hydro-pneumatic accumulator where a pressurising gas, usually nitrogen, is loaded over the loop fluid in the vessel to provide the partial pressure to give the required pressure in the test section.

(ii) As in (i) but with the pressurising gas separated from the fluid in the vessel by an elastic membrane or piston.

(iii) A vapour pressuriser which employs immersion heaters to maintain a vapour bubble over the loop fluid in the pressuriser vessel.

A pressuriser such as (i) or (ii) would maintain pressure stability but it would produce severe temperature reductions in the circuit since make-up from it would be cold. It would also be much larger than an equivalent vapour pressuriser for the same stored energy in the pressurised fluid. For good pressure stability a large stored energy is required and the stored energy of a fluid at saturation temperature is an order of magnitude or more greater than the stored energy in a gas at the equivalent pressure. A vapour pressuriser is also the preferred system when it is desired to maintain a low gas content in the loop fluid since with the other types there is the likelihood of gas absorption from the pressurising gas, even if it is separated from the loop fluid by a membrane, as in the hydro-pneumatic accumulator commonly found in hydraulic systems.

The immersion heated closed in vessel shown in Fig. 15 was employed for pressurising the loop system under discussion here. It was connected to the primary loop via a 6.35 mm bore line and an isolating valve and was teed in on the suction side of the circulating pump. The volume of the vessel between its high and low working levels was about 1400 cm^3 which was sufficient to accommodate the changes in the loop fluid inventory which occurred during start up and in operation. In the automatic operation mode the pressuriser heaters (3 x .825 kW) were switched on and off by an indicator-controller (Ether type 991D) which monitored the temperature in the pressuriser vapour space. A 6.35 mm i.d. spray line connected the discharge side of the circulating pump to the pressuriser vapour space via a manually operated isolating valve. Operation of the spray line would cause a reduction of the vapour space temperature on the spraying-in of colder fluid and this in turn would produce a fairly rapid reduction in the primary loop pressure. Although not used for this purpose to a great extent in the present study, degassing of the loop fluid could be effected by the spraying operation. Non-condensible gases were stripped out of the loop fluid during the spraying process and these accumulated in the pressuriser vapour space which could be periodically vented off to atmosphere.

The amount of liquid in the pressuriser was monitored during all phases of loop operation. The determination of the liquid level inside a vessel at high pressure and temperature is not an easy task. High

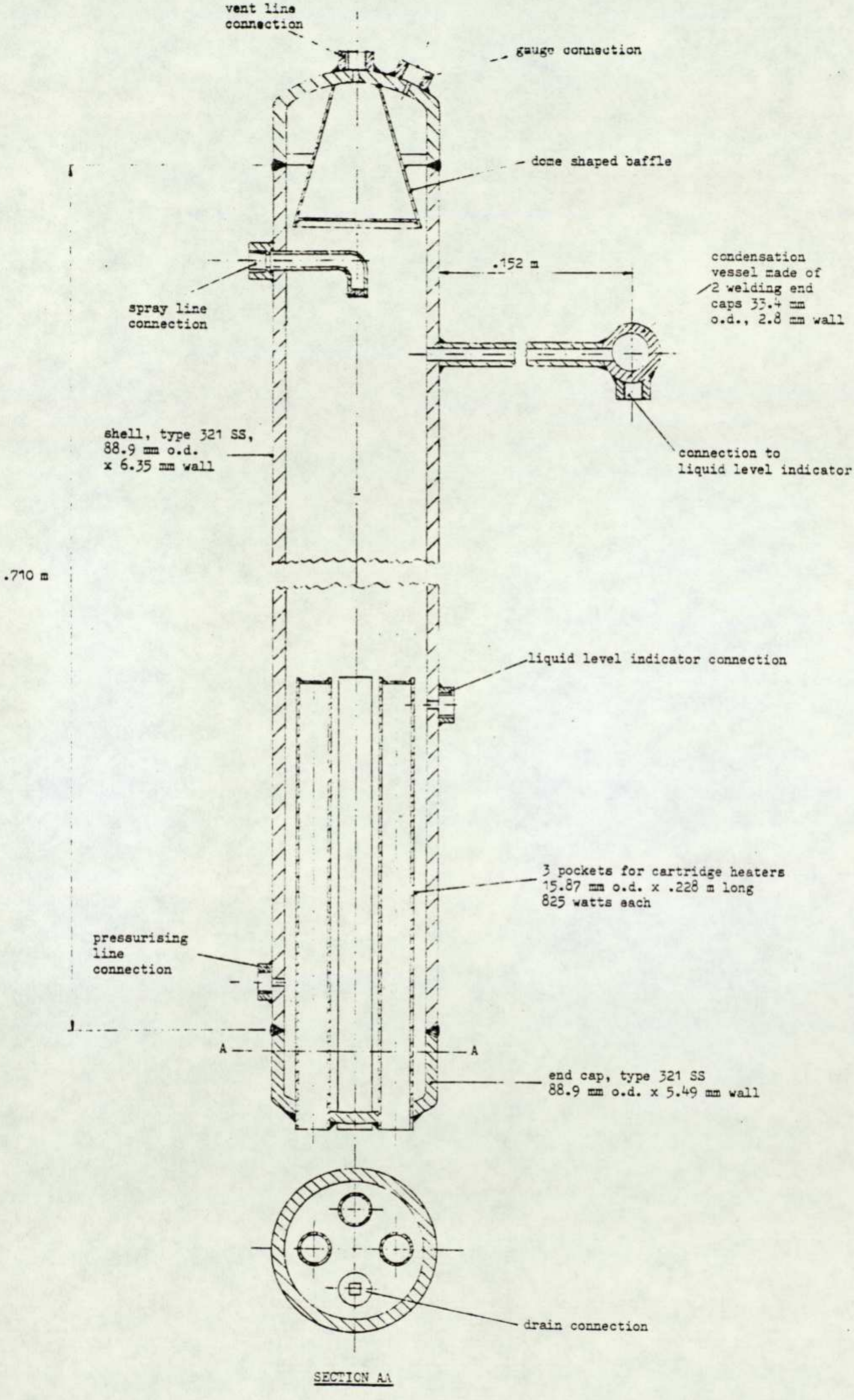


Fig. 15 Pressuriser

pressure sight glasses connected across the vessel can be used, but are not easily read and if the liquid is hot the different temperatures in the vessel and the sight glass result in an unknown error due to density differences. The level measurement system adopted in this work utilised a differential pressure transducer. One side of this transducer was connected to the vapour space via a condensation pot and a water-cooled line which constituted a reference leg. The other side of the transducer was connected to the lower half of the vessel just below the lowest permissible level. The differential pressure across the transducer was proportional to the level of liquid in the vessel, provided the reference leg was maintained at a constant temperature.

4.4.2 Filling and make-up. The loop fluid was stored when not in use in a 0.133 m^3 stainless steel tank. The tank was fitted with pockets for two cartridge heaters (Hedin 0.7 kW each) for boiling up the loop fluid at the commencement of a day's rig operation. The tank was also connected to a vacuum line which was used during degassing of the fluid prior to loop filling. A sight glass and thermometer pocket were fitted to the tank for monitoring the level and temperature respectively. Only sufficient fluid for two or three loop charges was held in the storage tank and it took about half an hour to boil it up from cold. A transfer-under-vacuum system was normally employed for filling the primary loop.

Make-up fluid for when the loop was operating at pressure was supplied by an air-actuated reciprocating pump as shown in Fig. 16. The delivery pressure of this pump was directly proportional to the air supply pressure, i.e. an air supply pressure of 0.3 MN/m^2 enabled it to pump against a pressure of 6.89 MN/m^2 based on the air cylinder to barrel area ratio of 19:1. In the original loop design which envisaged the inclusion of condensation studies with associated low pressures on

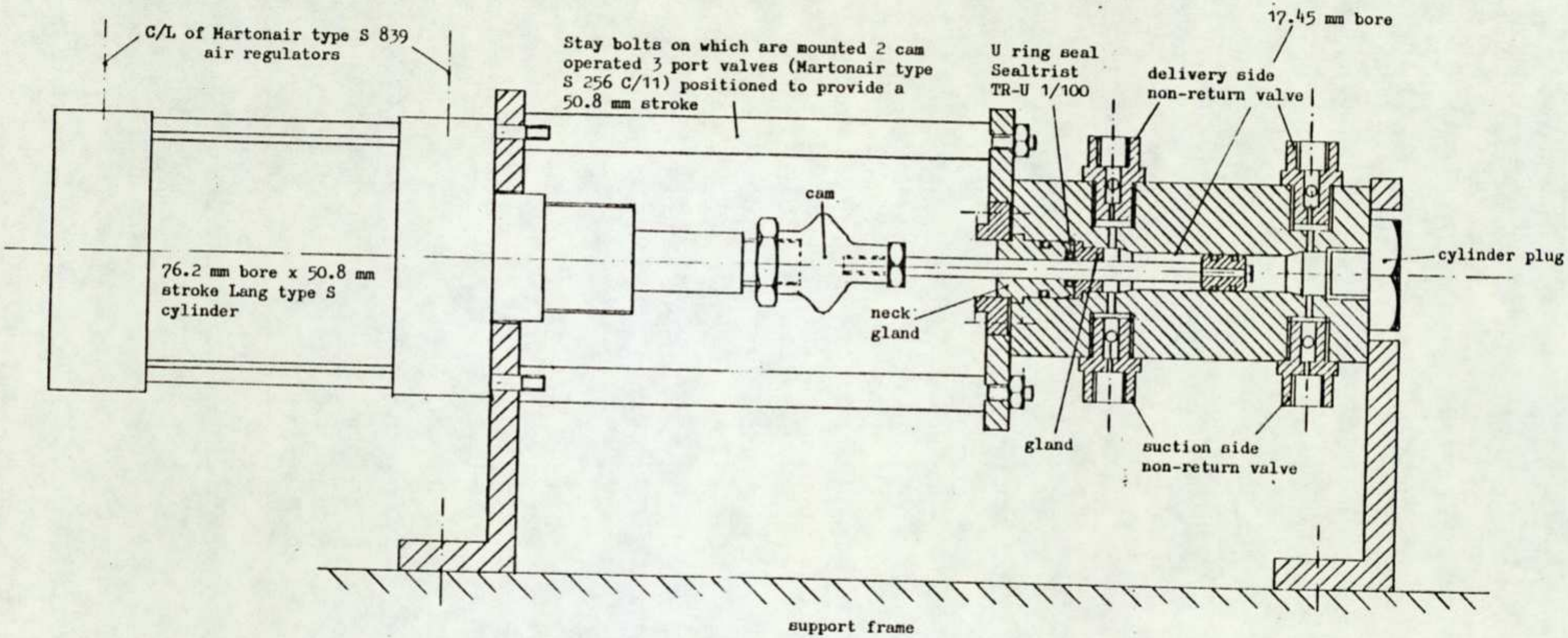


Fig. 16 Air-operated reciprocating pump.

the suction side of the pump this reciprocating pump was intended to be used for primary fluid circulation. According to Associated Engineering Ltd. who designed a similar unit for use in a steam car engine rig the pump was capable of delivering about 3.6 l/min. (150 double strokes/min at 12 cm^3/stroke) against a pressure of 10.35 MN/m^2.

4.4.3 Vent and drain system. Two 6.35 mm i.d. lines with isolating valves and sight glasses connected the primary loop high points and the dump/drain tank for venting purposes during loop filling. Loop drainage connections with isolating valves were fitted to the two lowest points of the loop for drainage of the system on completion of a day's operation.

4.4.4 Pressure relief and dump line. A pressure relief line was connected to the primary loop between the test section exit and the reflux cooler/condenser. To protect the system from over-pressurisation a bursting disc assembly was set in this line, the bursting pressure of the disc (F.A.Hughes & Co., type S½BPD) being 8.79 MN/m^2 $\pm$ 5%. Since it was undesirable to lose all the contents of the system should the disc have ruptured a relief valve was fitted downstream of the bursting disc assembly. This relief valve was set to lift at a pressure of 8.3 MN/m^2, somewhat above the maximum working pressure of 6.89 MN/m^2. In the event of an over-pressure incident rupturing the bursting disc the loop contents would be discharged until the pressure in the primary system fell below 8.3 MN/m^2.

The relief valve was connected on its downstream side to a dump/drain tank which had a volume of 0.133 m^3. A few litres of cold loop fluid were permanently stored in this tank for the purpose of quenching out the high pressure hot loop contents which would enter in the event of a bursting disc rupture. The dump tank was also connected to the primary loop by an extension of the spray line which was fitted with both hand and solenoid operated isolating valves. Operation of either of the foregoing valves caused loop fluid to be dumped out of the primary system and provided a means whereby rapid depressurisation of the entire system could be effected in an emergency.

4.4.5 Vacuum system. Vacuum lines with isolating valves were connected to the loop pressure relief line, reflux cooler/condenser shell and fluid storage tank. A portable two-stage rotary vacuum pump (Metrovick Ltd.) and a cold trap for vapour condensation /collection could be connected to either of these lines for evacuating the loop prior to filling, for control of pressure in the reflux cooler shell during operation or for promoting degassing of the fluid during storage tank heating.

4.4.6 Reference pressure and other gas systems.

The test section inlet and exit pressures were measured by a method which employed low range pressure transducers backed by a reference gas (air). A schematic of this reference pressure circuit is shown in Fig. 17. The reference gas pressure was controlled by a precision regulating valve (IV Pressure Controllers, Type 133/140/ER/V) mounted near the loop control panel. A gas bottle was used as a reservoir for the reference gas which was periodically charged up by a 3-stage high pressure air compressor (G.Radaelli, Milan). The reference pressure manifold downstream of the regulating valve was connected to a second gas bottle which acted as a damper for pressure fluctuations caused by the floating of the regulating valve.

A line was connected to the loop storage tank for introducing low pressure nitrogen gas from a storage bottle. This was used during loop filling when there was an insufficient pressure difference at the end of the transfer under vacuum process to completely fill the loop system. An air compressor and receiver located outside the loop enclosure provided compressed air for operating the reciprocating make-up pump.

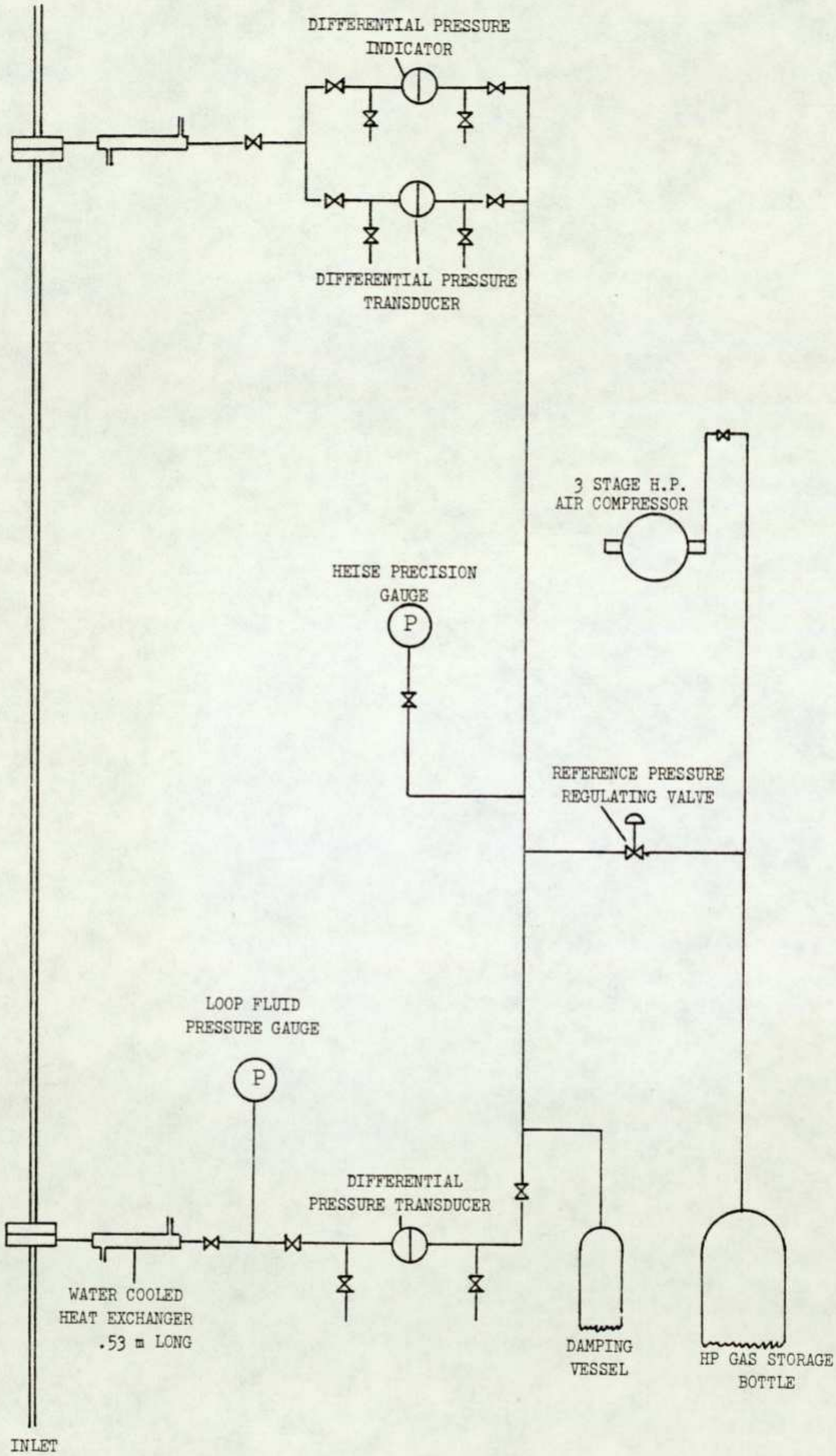


Fig. 17: Schematic of reference pressure circuit.

4.4.7 Water cooling services. In addition to the cooling water requirements for the reflux cooler/condenser and sub-cooler, operating experience with the loop showed that cooling of the following instruments and loop components was necessary, either to protect electronic equipment from high temperatures or to cool sealing features to prevent primary fluid leakage:-

(i) Test section and pre-heater inlet and exit thermocouple glands.

(ii) Pressuriser vapour space thermocouple gland.

(iii) The lines connecting the test section pressure tappings and the differential pressure transducers.

(iv) Pressuriser level reference leg and condensation pot.

(v) The pick up casing of the turbine flow meter.

4.4.8 Ventilation extract system. The rig enclosure was provided with a ventilation extract system consisting of a forced draught fan and .3 m diameter flexible ducting led to outside the building.

4.4.9 Photographic illustrations of the loop. A selection of photographs of the loop complex is given in Appendix 1.

4.5 Test Section.

4.5.1 A straight uniform bore seamless tube vertically orientated in the loop circuit was used as the test section for the experimental programme. The material selected for the test section was Nimonic 75 (% composition - Ni75, Cr19, Fe5, Mn1, C.1, Si1.0, Ti0.4) on account of its very low temperature coefficient of electrical resistivity[39] as indicated in Fig. 18. This latter property is important in maintaining constant heat flux conditions along the length of the test section when there are large axial temperature variations present such as occur on wall dry-out. Stainless steel, the more commonly used test section material has a rather large temperature coefficient[40] of electrical resistivity, as also shown in Fig. 18 and thus large heat flux variations can exist in once-through evaporation type tests.

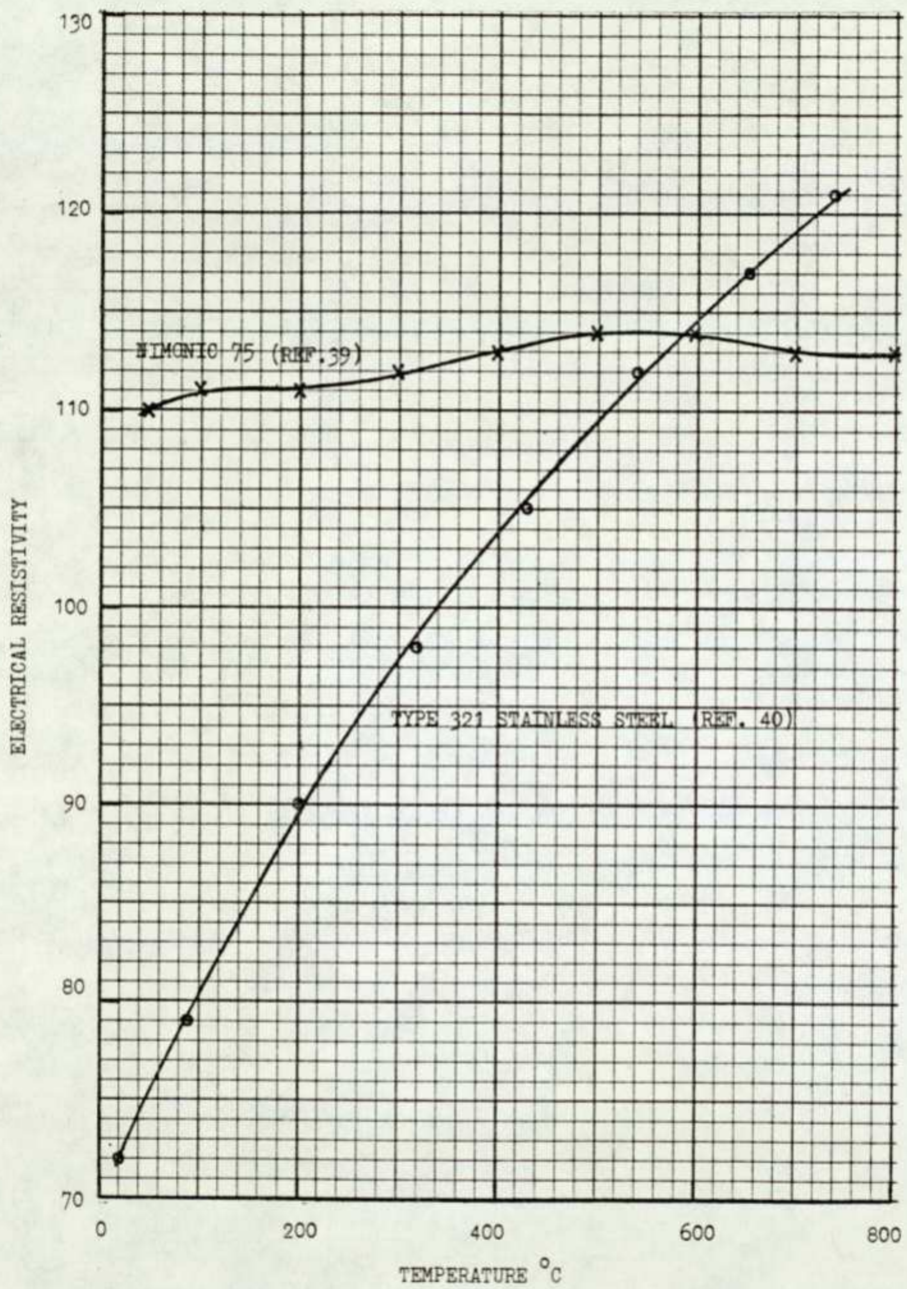
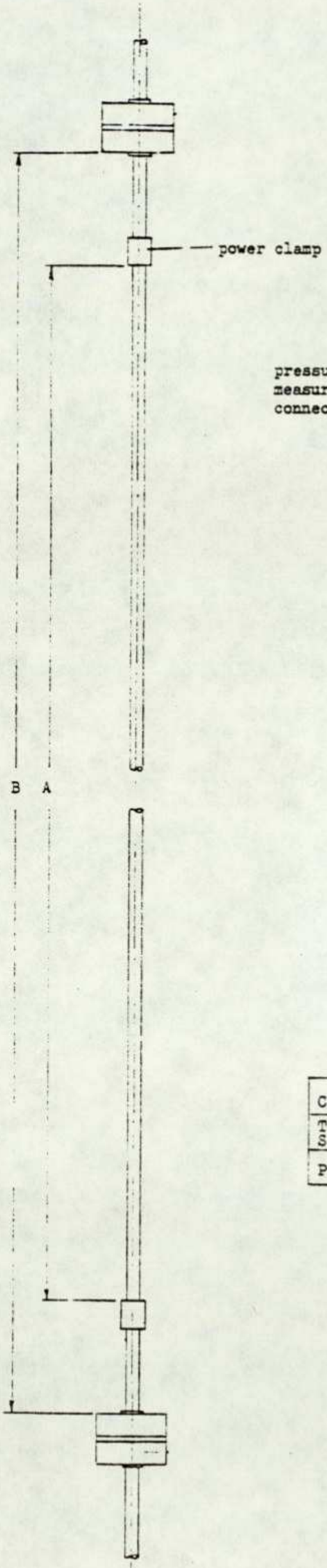
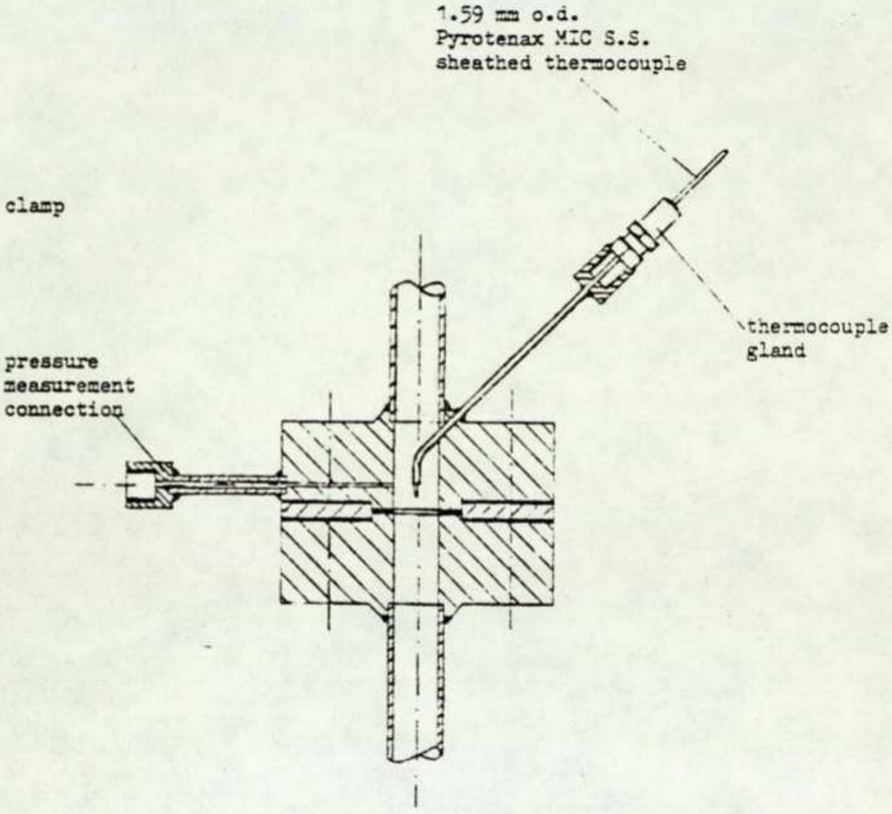


FIG. 18 Electrical resistivity variation with temperature for Nimonic 75 & type 321 stainless steel

4.5.2 The nominal dimensions selected for the test section, summarised in Fig.19 (15.88 mm o.d., 12.7 mm i.d., 1.83 m heated length) were a compromise choice involving several factors which will be briefly elaborated on. The length and diameter of the test sections are interdependent and determine the heat flux, mass velocity and the pressure gradient. A restriction on the minimum i.d. was that the bore should be such to be representative of the size that would be employed in an actual system, whilst the heated length was largely dictated by the headroom available in the rig area. The remaining geometrical dimension, wall thickness, together with the material being considered determined the test section resistance (from $R = \rho_e L/Am$) which had to be compatible with the available power supply. In practice experiments are usually limited by the capacity of the power supply i.e. for short lengths of tube there can be a current limitation with a voltage limitation for longer lengths. The wall thickness is also an important parameter in material stressing calculations. Ideally the test section should be as thin as can be allowed by internal pressure and thermal stress considerations so as to minimise the temperature drop through the wall and thus improve the accuracy of inner wall temperature determination.

4.5.3 The test section bore was checked for ovality at intervals along its length using an air gauging technique[41][42]. This method, used for inspection purposes in the production industry, employed an air jet impinging on the measuring surface from a nozzle in the gauging head which was inserted in the tube bore. The air pressure, measured on a water manometer, between this nozzle and an upstream control orifice was by a suitable choice of nozzle dimensions and operating pressures, a linear function of the separation distance between the gauging head and the tube wall. With this method, after first calibrating the set-up with a gauging ring of known bore, the separation distance between the sensing head and the tube wall could be





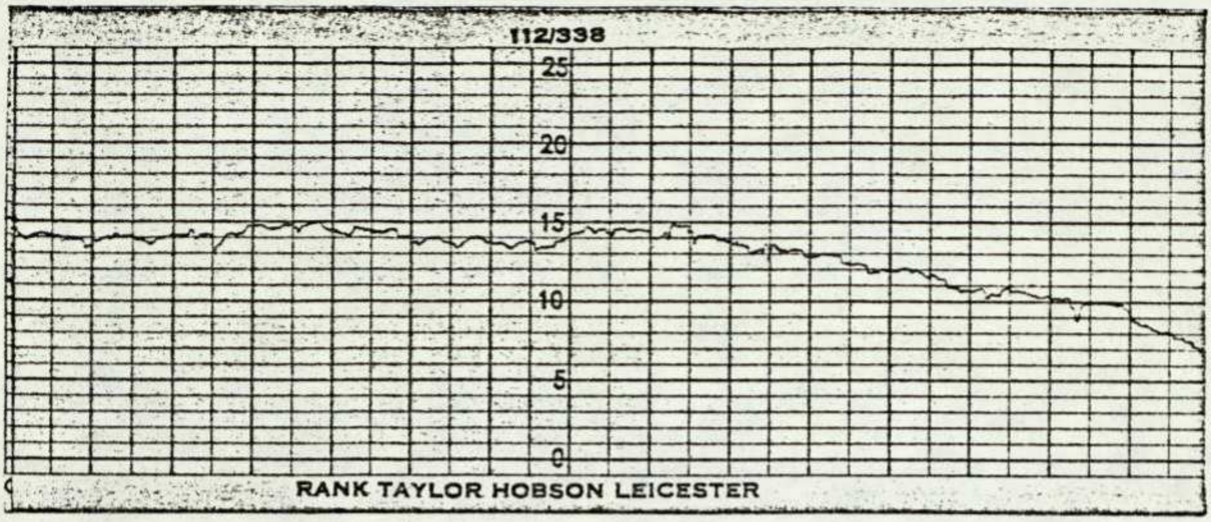
Cross-section Through Insulated Test Section Flange Showing Pressure and Temperature Tappings

Component	o.d.	i.d.	Dimension A	Dimension B
Test Section	15.87 mm	12.65 mm	1.83 m	2.183 mm
Pre-heater	15.87 mm	12.7 mm	2.13 m	2.49 m

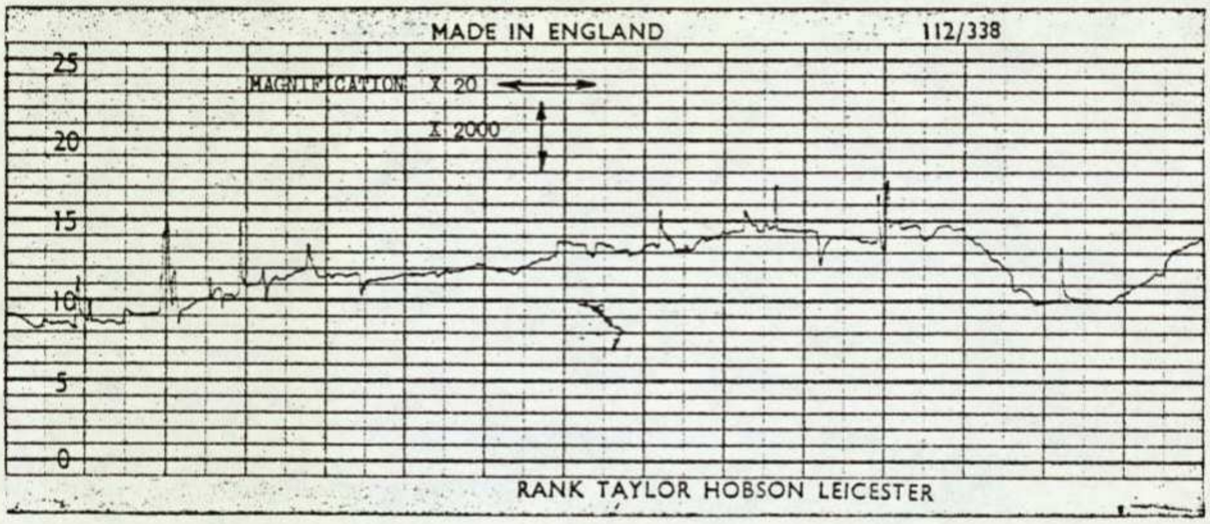
Fig. 19: Dimensions of test section and pre-heater.

accurately determined since changes in the manometer level were several thousand times greater (approximately 2,500) than variations in the separation distance. The bore as measured at around 100 locations using the foregoing method was 12.65 ± .01 mm. The outside diameter of the test section was also measured at intervals along its length using a micrometer and found to be 15.905 ± .01 mm. The bore of the test section was left in the as-drawn condition for the heat transfer tests. The surface finish of the tube wall was measured using a Talysurf meter which computed the centreline average (CLA) value of the surface roughness together with the production of surface roughness profiles. Typical surface profiles and CLA values for new and used tube samples are shown in Fig. 20 . The latter samples were taken from the inlet and exit regions of the tube on the completion of testing.

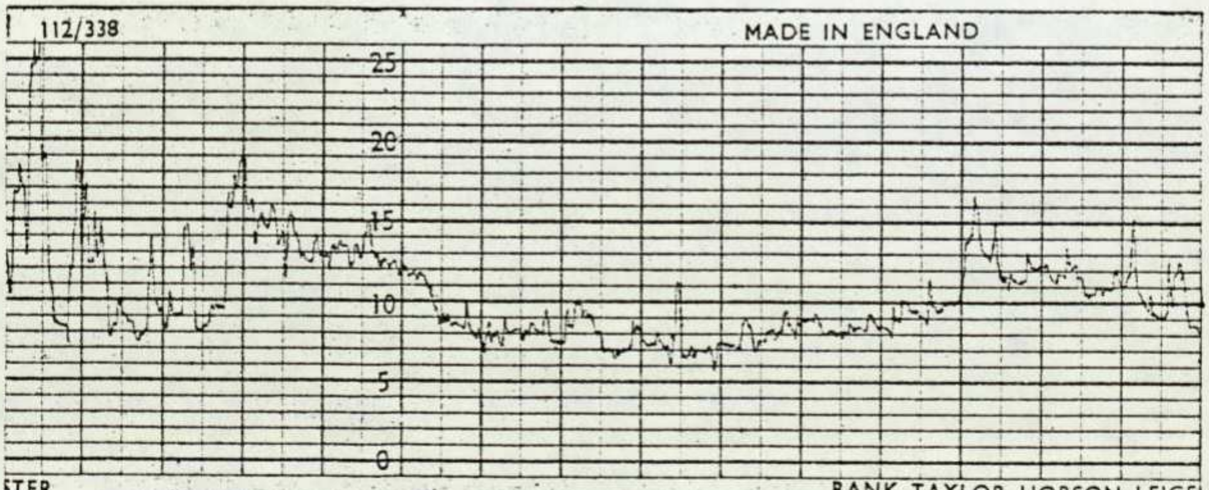
4.5.4 The test section was orientated vertically in the loop circuit and was electrically isolated from the adjoining upper and lower components by stainless steel flanges with insulating gaskets, washers etc. as shown in Fig. 21 . The material used for electrical insulation purposes was 1.59 mm thick Klingerite (R. Klinger Ltd.), an asbestos-based pipe-flange jointing product recommended for use up to 13.8 MN/m^2 and 550°C. The non-insulated halves of the test section flanges at inlet and exit were provided with pressure and temperature tappings. Thermal expansion of the test section during loop operation was accommodated by the tensioning arrangement shown in Fig. 22 . The test section exit flange was rigidly fixed to the main loop support structure so that expansion was downwards and taken up by a pre-loaded Belleville washer stack. A characteristic of Belleville spring washers is that over a certain portion of their deflection they exert a force which is independent of the amount of deflection[43]. By a suitable choice[44] of washer dimensions a constant load of about 140 kg. was maintained on the test section throughout its working temperature range



UNUSED SAMPLE OF TUBE, AVERAGE C.L.A. VALUE = .25 μm



SAMPLE OF TUBE FROM INLET END ON CONCLUSSION OF TEST PROGRAMME.
AVERAGE C.L.A. VALUE = .275 μm



SAMPLE OF TUBE FROM EXIT END ON CONCLUSION OF TEST PROGRAMME,
AVERAGE C.L.A. VALUE = .97 μm

Fig.20 Test section 'TALYSURF' surface roughness profiles and average C.L.A. roughness values.

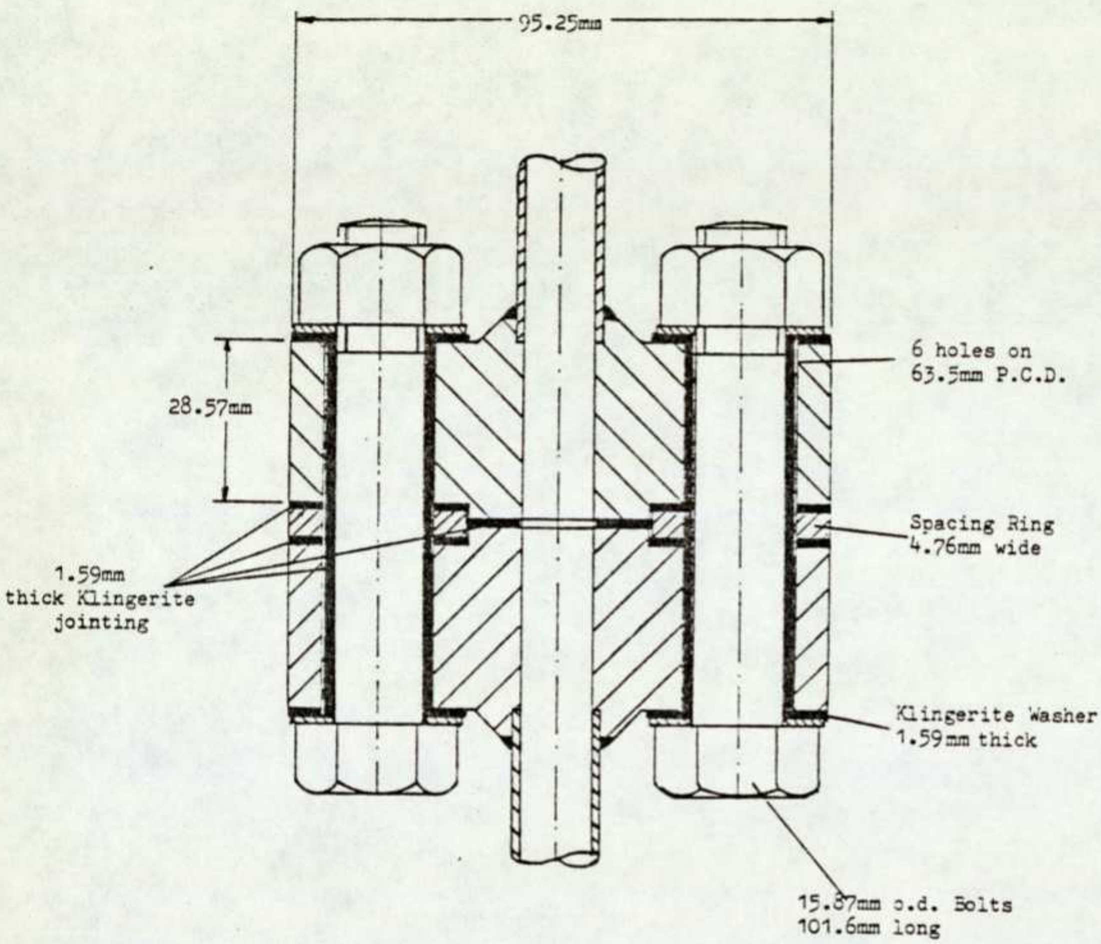


FIG.21 CROSS-SECTION THROUGH TEST SECTION ELECTRICALLY INSULATED FLANGE

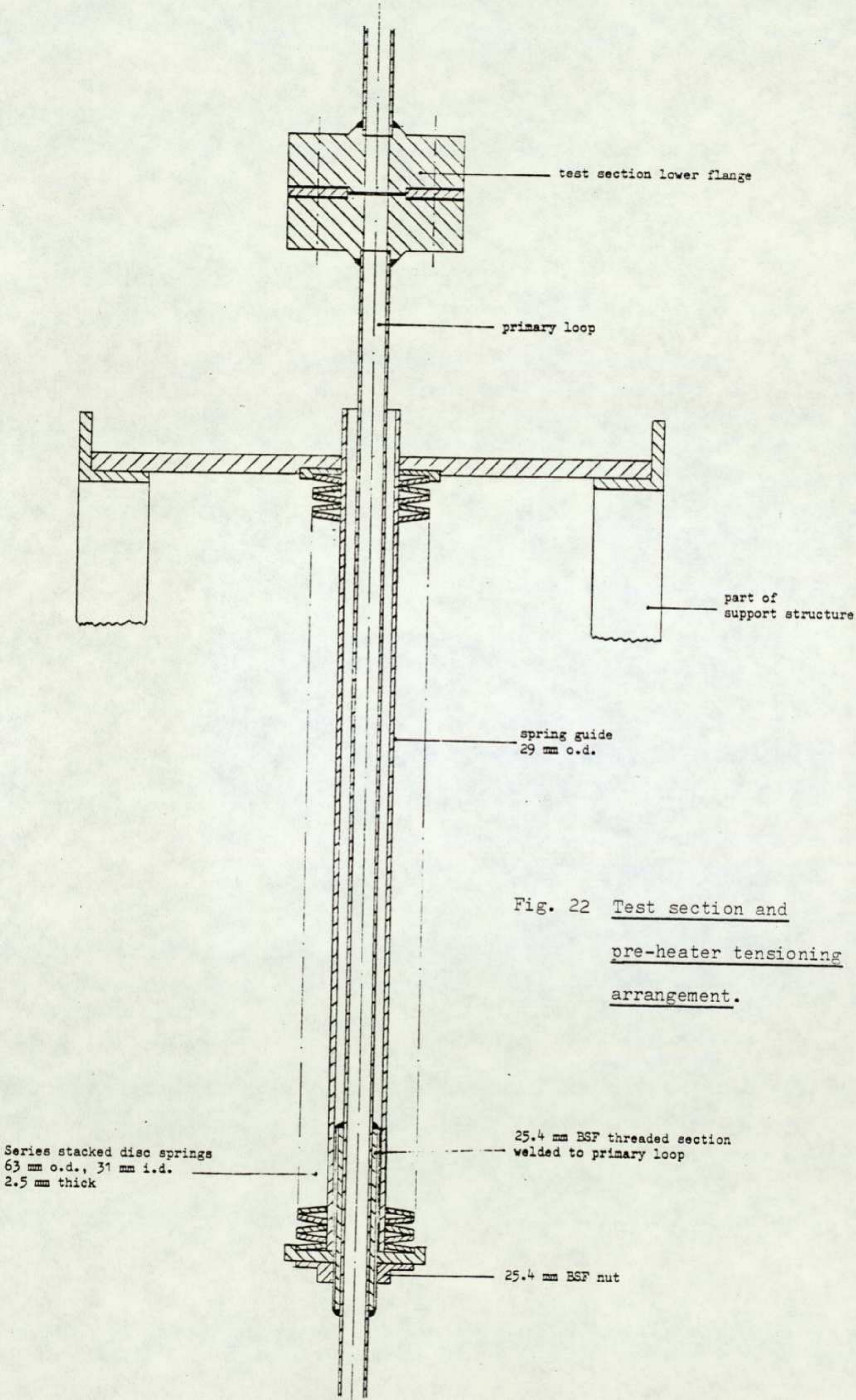


Fig. 22 Test section and pre-heater tensioning arrangement.

without any over-stressing or bowing occurring. A similar type of Belleville washer stack was also employed for allowing for the thermal expansion of the pre-heater.

4.5.5 The 1.83 m heated length of the test section was preceded by a .69 m calming length (L/D = 55) made up of .51 m from the flow control valve to the lower flange and .18 m from the flange to the top face of the lower power clamp. Direct current was supplied via busbars and flexible braids from a transformer-rectifier through the upper and lower power clamps which were bolted to the test section. Care was taken to ensure good electrical contact between the clamps and the test section by having the centre hole in the clamp blocks reamed out .025 mm smaller in diameter than the tube outside diameter with the tube being lapped over the clamping region. The test section power supply unit was a 415 V, 3-phase, 50 Hz. input Ferranti silicon rectifier, (Ferranti, Hollinwood No. 20/10061) having a separate motorised Berco voltage regulator (Model M3743AI No. 65803) giving a 0-40 volts output at 750 amps. The voltage output of the rectifier set was limited in the present work to 21.7 V at 760 amps (16.5 kW) by the non-optimum value of the test section resistance. The input on the primary side of this transformer-rectifier set could be switched to be regulated by an automatic power control circuit. In this latter mode of operation a constant heat input into the test section could be maintained during periods when there were fluctuations in the line supply voltage.

4.6 Loop Instrumentation.

4.6.1 The parameters which were either monitored and/or measured during operation of the loop system are indicated on the circuit schematic shown in Fig. 11. The instrumentation employed for this purpose is given in the schedule listed in Table 3. Further details concerning the system pressure, temperature and flow rate measurements are given overleaf. The test section wall temperature measuring instrumentation

PARAMETER	SENSOR	MANUFACTURER	TYPE	RANGE	ACCURACY
REFERENCE PRESSURE	PRECISION BOURDON TUBE GAUGE	HEISE	MODEL C, 21.6cm DIAL NO. 62641	0-10.34 MN/m^2 (0-1500 psi)	<0.1% FSR
REF.-FLUID PRESSURE AT TEST SECTION EXIT	BELLOWS ACTUATED INDICATOR	AEI AUTOMATION	BARTON MODEL 200 NO.600389	0-5.08 m. W.G. (0-48 kN/m^2)	0.5% FSR
REF.-FLUID PRESSURE AT TEST SECTION EXIT	VARIABLE RELUCTANCE TRANSDUCER	HONEYWELL	1028 + OD31 OSCILLATOR-DEMODULATOR	$\pm$ 34.5 kN/m^2	<1.5% NON-LINEARITY <1% FSR
REF.-FLUID PRESSURE AT TEST SECTION INLET	VARIABLE RELUCTANCE TRANSDUCER + O/D UNIT	S.E. LABORATORIES	SE42/L/V/BB NO. 1914	$\pm$ 69 kN/m^2	<1.5% NON-LINEARTY <1% FSR
FLUID PRESSURE AT TEST SECTION INLET	BOURDON TUBE GAUGE	HOPKINSONS		0-10.34 MN/m^2 (0-1500 psi)	INDICATION ONLY
PRE-HEATER INLET TEMPERATURE	MIC ST.STEEL SHEATHED CR-AL T/C	PYROTENAX	T041 HT7/NC-NA INSULATED HOT JUNCTION		AS CALIBRATED
PRE-HEATER EXIT TEMP.	"	"	"		"
TEST SECTION INLET TEMP	"	"	"		"
TEST SECTION EXIT TEMP.	"	"	"		"
PUMP INLET TEMP.	"	"	"		"
FLUID TEMP. BEFORE FLOW-METER	"	"	"		"
PRIMARY LOOP FLOWRATE	TURBINE FLOW-METER	ELECTRONIC FLO-METERS LTD.	B/¼/2 NO. 8193	54.5-54.5 kg/hr.	$\pm$.5% LINEARITY $\pm$ 1% FSR
	FREQUENCY METER	RACAL INSTRUMENTS	9520 NO. 2459	VARIOUS, USED ON 0-1000 Hz	0.1%
	AMPLIFIER	KEMO LTD.	GB2 NO. 14833		
	STABILISED POWER SUPPLY	FARNELL INSTRUMENTS	L 30/BT NO. 2043	0-30V DC	
TEST SECTION SURFACE TEMP. (INSULATED T/C's)	FOIL HOT JUNCTION & CU-CON T/C WIRE	AEE WINFRITH & SAXONIA	WIRE: TYPE IC 30 SWG (.314 mm)		AS CALIBRATED

TABLE 3 INSTRUMENTATION SCHEDULE

CONT....

PARAMETER	SENSOR	MANUFACTURER	TYPE	RANGE	ACCURACY
TEST SECTION SURFACE TEMP. (WELDED ON T/C's)	CR-AL INSUGLASS	SAXONIA	32 SWG(.274mm)		AS CALIBRATED
TEST SECTION VOLTS	DIGITAL VOLT-METER	SOLARTRON	LM 1402 NO. 200310	VARIOUS, USED ON 0-20V	.05%
TEST SECTION AMPS	POWER SHUNT			75 mV FOR 1000A	± 0.5%
TEST SECTION VOLTS	MOVING COIL PANEL METER (INDICATION ONLY)	CROMPTON INSTRUMENTS	300	0-40 V	CLASS INDEX 1.5 BS 89 (1970)
TEST SECTION AMPS	"	"	"	0-1200 A	"
PRE-HEATER VOLTS	"	"	"	0-15V	"
PRE-HEATER AMPS	"	"	"	0-1000A	"
PRESSURISER LEVEL	VARIABLE RELUCTANCE TRANSDUCER	HONEYWELL	1028 + OD31 OSS/DEMOD. UNIT	± 34.5 kN/m^2	<1.5% NON-LINEARITY <1% FSR
PRESSURISER VAPOUR SPACE TEMPERATURE	MIC ST. STEEL SHEATHED CR-AL T/C	PYROTENAX	T041 HT7/NC-NA INSULATED HOT JUNCTION		INDICATION ONLY
PRESSURISER HEATERS CONTROL	INDICATING TEMPERATURE CONTROLLER	ETHER	991D WITH ANTICIPATORY CONTROL NO. 11654	0-1200 C	± 1% .5% ON CONTROL BAND
PRESSURISER LOCAL PRESSURE INDICATION	BOURDON TUBE GAUGE			0-4.14 MN/m^2 (0-600 psi)	INDICATION ONLY
SUB-COOLER C.W. FLOWRATE	ROTAMETER	GEC-ELLIOT PROCESS INSTRUMENTS	2000, TUBE SIZE 18X, FLOAT TYPE S NO. 937040	0-10 l/min	± 2% FSR
SUB-COOLER C.W. INLET TEMPERATURE	MIC ST.STEEL SHEATHED THERMOCOUPLE	PYROTENAX	T041 HT7/NC-NA INSULATED HOT JUNCTION		AS CALIBRATED
SUB-COOLER C.W. EXIT TEMPERATURE	"	"	"	"	"
REFLUX COOLER	ROTAMETER	GEC-ELLIOT PROCESS INSTRUMENTS	2000, TUBE SIZE 14X, FLOAT TYPE S NO.937039.	0-5 l/min.	± 2% FSR

CONT.....

PARAMETER	SENSOR	MANUFACTURER	TYPE	RANGE	ACCURACY
REFLUX COOLER C.W.INLET TEMP.	MERCURY THERMOMETER	GALLENKAMP		0-100 C	± 1C
REFLUX COOLER C.W. EXIT TEMP.	"	"		0-150 C	± 1C
REFLUX COOLER SHELL LEVEL	SIGHT GLASS	QUADRANT GLASS CO.			INDICATION ONLY
REFLUX COOLER SHELL PRESSURE	BOURDON TUBE GAUGE			0-2.07 MN/m^2 (0-300 psi)	"
REFLUX COOLER SHELL VACUUM	BOURDON TUBE GAUGE	EDWARDS		0-760 TORR	"
DISPLAY PANEL mV INDICATION	DIGITAL VOLTMETER	MARCONI INSTRUMENTS	MULTIMETER TF 2670 NO. 6835	VARIOUS, USED ON 100 mV RANGE	"
STORAGE TANK TEMPERATURE	MERCURY THERMOMETER	GALLENKAMP		0-300C	"
STORAGE TANK LEVEL	SIGHT GLASS	CRANE LTD.			"
STORAGE TANK PRESSURE	BOURDON TUBE GAUGE			0-207 KN/m^2 (0-30 psi)	"
STORAGE TANK VACUUM	"			0-760 TORR (0-30"Hg)	"
DUMP TANK PRESSURE	BOURDON TUBE GAUGE			0-275 kN/m^2 (0-40 psi)	INDICATION ONLY
COLD TRAP VACUUM	"			0-760 TORR (0-30 "Hg)	INDICATION ONLY
REF. PRESSURE STORAGE BOTTLE PRESSURE	"			0-27.6 MN/m^2 (0-4000 psi)	INDICATION ONLY

is covered separately in section 4.7 of this Chapter. The remaining instrumentation was essentially provided for monitoring various parameters during operation of the loop. These parameters, most of which concerned the various auxiliary systems were not normally recorded during the data-taking operations. An exception to the foregoing were the respective flow rates and inlet and exit temperatures of the cooling water supplies to the reflux cooler and sub-cooler. The latter together with the test section and pre-heater power input measurements were used in drawing up a heat balance for the loop.

4.6.2 Primary fluid temperature. The primary fluid temperature at various points in the system was measured by 1.59 mm o.d. stainless steel-sheathed minerally-insulated Chromel-Alumel thermocouples. The thermocouples were directly immersed in the loop fluid through penetrations in the pressurised components which were sealed by a compression type thermocouple gland, (BICC Ltd.). Some problems with leakage were experienced with these latter fittings which were overcome by including an additional PTFE seal under the gland nut and by local cooling of the sealing points in cases where heat conduction from the high temperature loop components would have softened the PTFE seal and caused leakage.

4.6.3 System pressure. The absolute value of the fluid pressure at inlet and exit of the test section was determined from measurements of the reference pressure and the output signals of the differential pressure transducers. The reference pressure was measured by a Heise model C precision bourdon tube gauge. The full-scale reading of this gauge was 10.35 MN/m^2 (1500 psi) sub-divided into sectors of 13.8 kN/m^2 (2.0 psi). A knife-edged pointer and mirror-backed scale enabled the gauge to be read to within 3.4 kN/m^2 (0.5 psi).

A differential-pressure indicator (AEI Barton type 200) was fitted in parallel with the exit differential-pressure transducer to provide, in conjunction with the Heise gauge, a direct visual indication of the system pressure. This differential-pressure indicator had a full-scale range of 48 kN/m^2 (6.95 psi) sub-divided into hundredths and was used for fine control of the test-section exit pressure during data recording. Two further direct indications of system pressure were:

(i) A large Bourdon tube gauge (Hopkinsons Ltd.) sited adjacent to the loop control panel which was teed in to the test-section inlet-pressure tapping. This latter gauge served as a check on the system pressure during operation on occasions when the differential indicator moved off scale.

(ii) A Bourdon tube gauge connected to the pressuriser vapour space.

Water-cooled heat exchangers were fitted to the lines connecting the tappings on the test section flanges to the differential pressure transducers. This was undertaken in order to reduce the possibility of errors in the pressure-drop measurements which would be caused through compressibility effects by vapour collecting in the lines. These latter liquid lines to the transducers were also slugged with about 50 mm of 0.5 mm bore capillary tube to reduce pressure fluctuations.

4.6.4 System flow rate. The mass flow rate through the primary loop was determined from the output of the turbine flow meter (Electronic Flo-Meters Ltd.) and a thermocouple just upstream of the flow meter position. The former provided an electrical pulse output, the frequency of which was proportional to volumetric flow rate. The pulses were generated by the magnetic blades of the rotor when they passed a stationary pick-up assembly containing a magnet and coil mounted externally on the meter body. With each blade passage a voltage was induced in the coil which was amplified using a series combination of an operational amplifier (RS Components type FET-OPA) and a Kemo amplifier (Type GB2) for registering on a Racal digital frequency meter (type 9520).

4.6.5 Test section power input. The test section power input was calculated from the voltage drop between the power clamps as measured by a Solartron digital volt meter, and the current as determined from a precision power shunt which gave an output of 75 mV for 1,000 amps. A voltage-dividing circuit was utilised to enable the test section voltage drop to be recorded on the same range as the other parameters.

4.6.6 Data logger. A 100 channel DART system data logger, manufactured by Electronic Associates Ltd. was used to record the majority of observations taken in an actual test. A Data Dynamics ASR 33 teletype printer was employed as the output device which limited the maximum scanning speed to 1 channel every 0.8 seconds. The 100 mV range scale was employed for all the measurement channels on which the system was found to record with a sensitivity of 10 µV, approximately equal to .25 C with Chromel-Alumel thermocouples. The following parameters were recorded by the data logger:-

Parameter	No.	Channel Nos. on data logger
Test section electrically insulated thermocouples	77	00 to 76
Test section inlet temperature	1	77
" " exit "	1	78
Pre-heater inlet temperature	1	79
" " exit "	1	80
Fluid temperature before circulating pump	1	81
Fluid temperature before flow meter	1	82
Sub-cooler cooling water inlet temp.	1	83
Sub-cooler cooling water exit temp.	1	84
Reference-test section inlet differential pressure transducer	1	85
Reference minus test section exit differential pressure transducer	1	86

Pressuriser level differential pressure transducer	1	87
Test section voltage drop	1	88
" " current	1	89
Pre-heater voltage drop	1	90
" " current	1	91
Test section welded-on thermocouples	6	92-97
Spare channels	2	98-99
Total	100	

Channel number 00 of the data logger was connected to the uppermost thermocouple on the test section i.e. at the test section exit, with channel number 76 connected to the lowest.

4.6.7 Centralised display of instrumentation. The majority of the instruments and controls necessary for operating the loop and for data recording purposes were situated around the central display located on the upper working level of the loop enclosure. The following parameters were continuously displayed during rig operation:-

Turbine flow meter output frequency (Racal digital frequency meter)
Reference gas pressure (Heise gauge)
Reference minus test section exit pressure (Barton differential pressure indicator).
Test section volts (Crompton Instruments type 300 panel meter).
" " amps " " " " " "
Pre-heater volts " " " " " "
" " " amps " " " " " "

A selector switch was fitted which enabled the following parameters to be displayed, as required, for checking purposes during data recording on the 100 mV range of a digital volt meter mounted on the central display board:-

Reference - test section inlet differential pressure transducer output.
" - " " exit " " " "

Pressurieer level differential-pressure transducer outupt.

Test section volts.

" " amps.

Pre-heater volts.

" " amps.

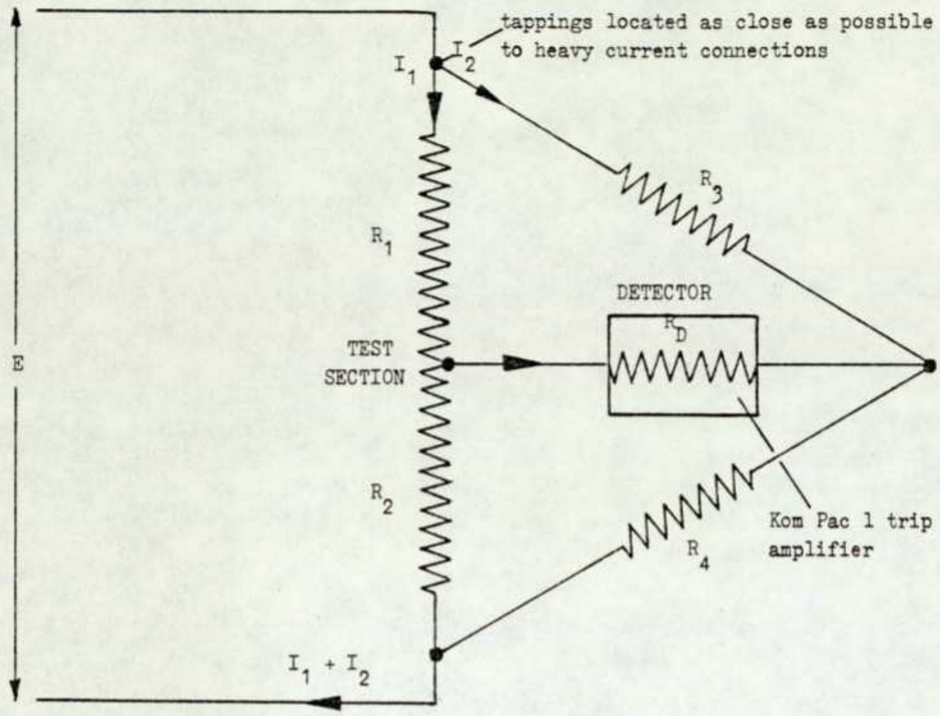
When not being used during data recording the pressuriser level was normally continuously displayed on the panel DVM so as to give an indication of any leakage of primary fluid.

4.6.8 Burn out detection system. At the outset of the investigation it was considered to be desirable to incorporate a test section protection system that would trip the test section power if an over-temperature incident occurred before a physical failure actually took place. As previously mentioned, with heat-flux controlled systems high wall temperatures can occur when there is an impairment to heat transfer between the tube wall and the fluid caused by vapour blanketing in sub-cooled boiling and by dry-out in saturated boiling. Operational experience with the loop however during the commissioning phase showed that dry-out, with the relatively low heat fluxes employed, produced tolerable test section temperatures so that the detection system produced was never actually employed and thus is mentioned here purely for record purposes.

The simplest type of burn-out detector is a thermocouple which measures the tube wall temperature, the output of which can be used to actuate a power trip system when the temperature reaches a pre-determined level. Such a system would however depend on the thermocouple hot junction being located within the burn-out zone which, as has been found, can be extremely localised so that a large number of thermocouples would be required to be sure of detecting the temperature rise. An alternative method which does not rely upon the fortuitous placement of a thermocouple is to utilise the change in test section resistance caused by a change in its temperature. A Wheatstone bridge was formed by the two halves of the test section and the centre and end wires which were spot welded to it during the thermocouple placement process. A sensitive trip amplifier detector (Kom-Pac 1 by MTE Electronics Ltd.) was incorporated in the bridge as indicated in Fig. 23. The theory(45)(46) was that any imbalance in the bridge caused by an increase in the test section temperature could be detected and the signal used to switch off the power to the test section. The sensitivity of the system was designed to be such so as to trip the power at a signal level from the bridge of 10 mV, corresponding to a resistance change of 0.25% of the test section resistance. In practice with the limited testing undertaken with the system the out of balance potential produced on dry-out was extremely small due to the low temperature coefficient of electrical resistivity of the material of the test section and the modest post dry-out temperatures experienced.

4.7 Test Section wall thermocouples.

4.7.1 The location of the test section instrumentation, consisting essentially of thermocouples for measuring the outer surface temperature, is shown in Fig. 24 . Initially Chromel-Alumel thermocouples (32 swg, .274 mm) were spot welded on the test section using a capacitor discharge technique at 25.4 mm intervals along its length. It was known that there would be pick-up by these directly attached thermocouples due to the potential gradient across the test section and a procedure was instituted for measuring the amount of pick-up during the thermcouple fixing process which could then be subtracted to or added to subsequent thermocouple readings to arrive at their true output. The pick-up problem is illustrated in Fig. 25 and it arises when the two wires of the thermocouple junction are not at points of equipotential on a current carrying surface. This gives rise to a potential gradient emf across the thermocouple junction which is in series with the true signal. This additional component can add



E - test section e.m.f.

R_1, R_2 - test section resistance

R_3, R_4 - external resistances

R_D - detector resistance

for a 1:1 ratio Bridge, i.e. $R_1 = R_2$, $R_3 = R_4$ the Bridge sensitivity can be shown [45] to be:-

$$\frac{E_D}{R_1} = \frac{-I_1}{(2 + \frac{R_3}{R_D})}$$

where E_D = out of balance potential at the detector

R_1 = increase in resistance R_1 due to dry-out temperature excursion

Fig. 23 Dry-out detection Bridge circuit

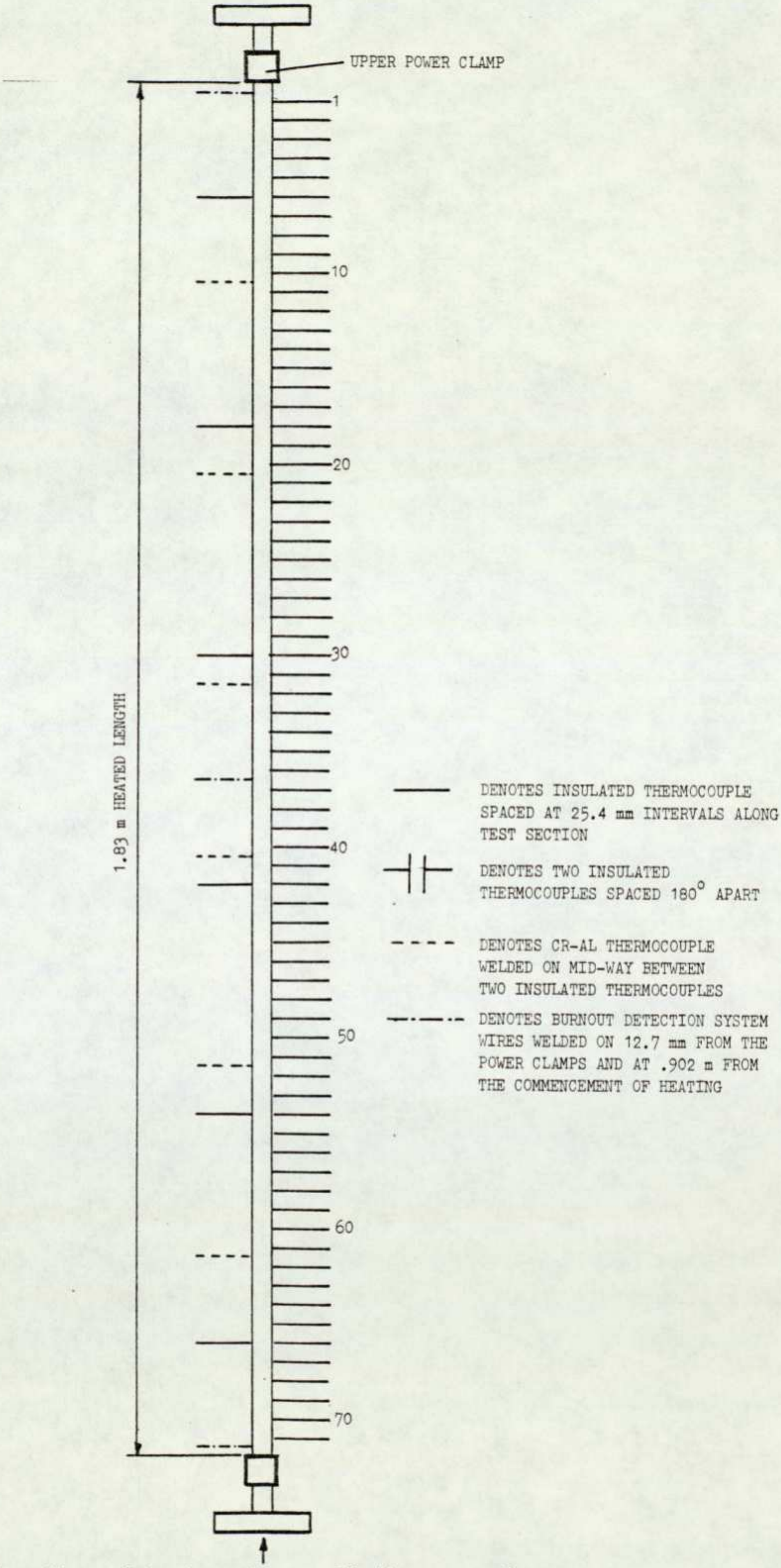
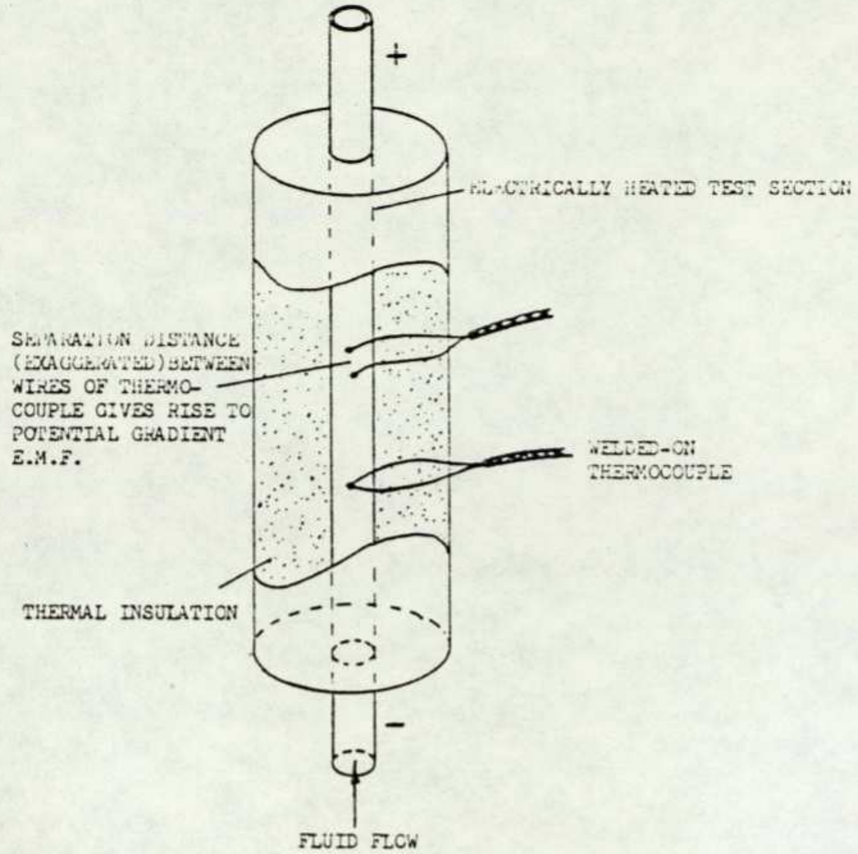


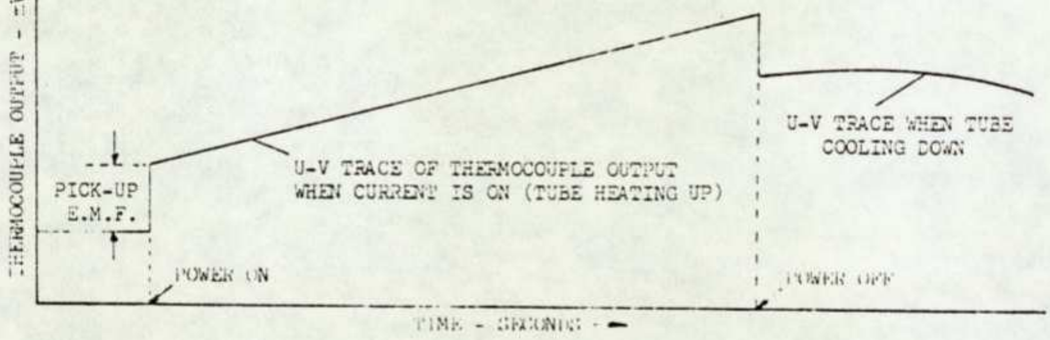
FIG.24 Location of test section wall thermocouples

to or subtract from the thermocouple emf according to its polarity. As an example of the magnitude of the error that could be caused if the potential gradient emf were unaccounted for; considering a volt drop across the test section of 1 volt per 25.4 mm length an axial displacement between the two wires of only .025 mm would create a pick-up of 1 mV, equivalent to 25°C with Chromel-Alumel thermocouples (~.04 mV/°C). In practice it was found to be difficult to eliminate entirely the potential gradient emf even by very careful positioning of one flattened wire on top of the other using a microscope prior to spot welding. The procedure adopted was to limit the amount of pick-up to .067 mV (~1.5°C) with 10 volts across the test section, by rewelding a particular thermocouple until it was within the permissible pick-up figure. With DC heating the pick-up problem is more serious than with AC where it can be readily identified as an oscillation about a mean level which can possibly be tolerated by the reading instrument or removed by a suitable filter.

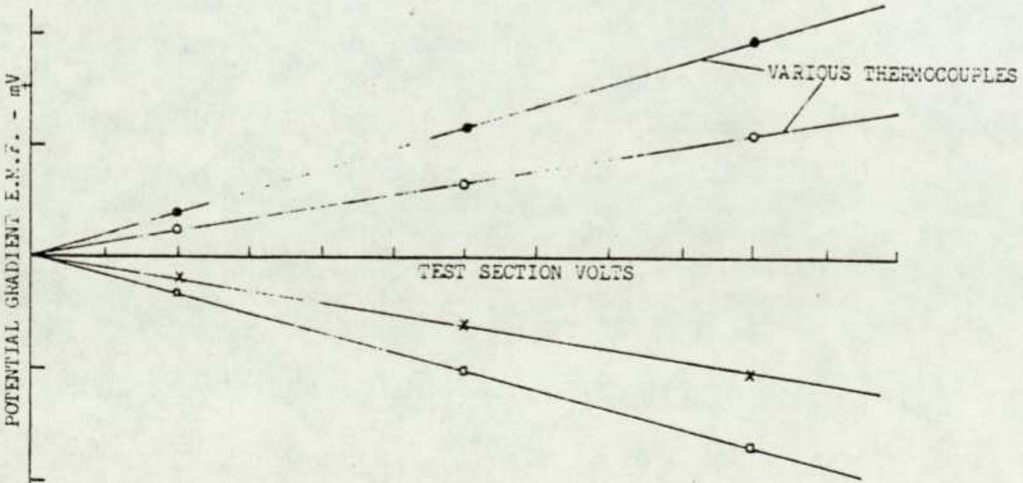
4.7.2 The amount of pick-up of a particular thermocouple was determined by connecting it to a UV recorder having a very sensitive galvanometer (.067 mV/cm) and applying a known voltage across the test section for a second or so (47)(48). At the instant of switching the current on and off the UV trace deflected an amount equal to the pick-up as indicated in Fig. 25. This procedure was repeated at several voltages for each thermocouple and a calibration graph produced as in Fig. 25 of pick-up against test section voltage. The thermocouples were checked for correct performance in monitoring test section wall temperatures up to around 175°C using only the pre-heater for heating the loop fluid, prior to testing them with the test section power on. This method of arriving at the true thermocouple output by adding or subtracting the pick-up for a particular test section voltage drop was found to be satisfactory for very low voltage drops of 1-2 volts. However the temperature distribution so derived became increasingly random as the



a) TEST SECTION WITH DIRECTLY ATTACHED THERMOCOUPLES



b) U.V. RECORDING OF THERMOCOUPLE OUTPUT



c) THERMOCOUPLE CALIBRATION GRAPH

FIG. 25 VOLTAGE PICK-UP WITH DIRECTLY ATTACHED THERMOCOUPLES ON A CURRENT CARRYING TEST SECTION.

voltage level was raised. This problem was unforeseen and considerable efforts were directed at finding a solution which did not entail disturbing the welded-on thermocouples. A current reversal changeover switch was installed to enable two readings of each thermocouple to be taken with opposite polarities across the test section. These readings were taken immediately following each other when the tube wall had reached a steady state temperature and the theory was that the summation of the two readings would cancel out the pick-up emf, provided it was of the same magnitude but of opposite sign for the two polarities. Tests with this current reversal system however demonstrated that this was not the case and that the pick-up was random and time varying and was probably attributable to common-mode interference converted to series-mode, caused by a voltage difference between the test section and data logger earths. As there was no ready solution to this problem without employing a three-wire type of thermocouple in a bridge circuit incorporating a high quality potentiometer for balancing out the pick-up signal[(49)(50)] a decision was made to abandon welded-on thermocouples in favour of ones which were electrically isolated from the test section surface.

4.7.3 The electrically isolated thermocouples installed in place of the welded-on ones incorporated a novel type of hot junction formed of an electroplated foil. These foil hot junctions were obtained from the Reactor Development Laboratory, Atomic Energy Establishment, Winfrith where they had been developed by specialists involved in test section instrumentation for large scale heat transfer loop experiments. Whilst primarily intended for dry-out detection[(114)] the foil type hot junction had shown advantages in overcoming the problems which arose, particularly at high temperatures, in securing a normal thermocouple junction to a test section when it was separated from the surface by a non-electrically conducting material such as a mica sheet.

4.7.4 The hot junctions supplied had been produced as a batch of several hundred from .051 mm thick annealed constantan foil using a photo-etching process similar to that employed for the manufacturing of printed circuits[115]. The identi cal constantan strips formed by the chemical etching process were each 2.0 mm wide and 30.2 mm long with a short end tag at either end. Half of each of the strips were plated by electro-deposition with silver to a thickness of 0.0063 mm on either side, indicated by the darker half of the foil shown in Plate 3. The silver plating was then covered with a 0.001 mm protective layer of nickel. The electro-deposition process followed at AEEW is not known to the writer however it was probably similar to that detailed by Wilson & Epps[116], Gier & Boelter[117] and Thomas[118] who describe thermocouple or thermopile construction by this process. For this type of thermocouple there is an optimum plating thickness, determined by Wilson & Epps[116] for silver to be between 20-30% of the constantan core cross sectional area. The plating thickness used here was equivalent to about 25% of the constantan core area. Since the silver plating has a low resistance compared with that of the constantan core it effectively shorts out the base metal underneath and a thermo-junction therefore exists at the extremity of the silver plating on the foil. The nickel flashing acts only to protect the silver from oxidisation and does not contribute to the thermo-electric effect at the junction[114]. The emf output of the silver-constantan thermocouple was found from the calibration exercise (reported in paragraph 4.8.3) to closely follow the copper-constantan tables[53] in confirmation of the findings of AEEW[115]. A close compliance with the copper-constantan tables was to be expected because copper and silver have a near identical thermo-electric emf[119].

4.7.5 The method employed for fixing the foil hot junction to the tube is illustrated by the series of photographs in Plates 1-8. Copper and constantan wires (30 swg, 0.314 mm) were first crimped to the end tags of the silver plated and constantan ends respectively using nickel sleeves 1.524 mm o.d., 1.27 mm i.d. and 6.35 mm long employing a made up crimping tool. Since these sleeves connecting the hot junction to the thermocouple wire were very small it was assumed that there was no temperature gradient along them which would have contributed to the measured emf. The foil was then placed on the adhesive side of a high temperature silicone varnish impregnated glass cloth tape 25.4 mm wide (Permacel No. 212) followed by a small sheet of .0025 mm thick mica (Attwater & Son, Preston) and the whole wrapped around the test section after first carefully locating the hot junction in the desired position. A single sheet of asbestos paper (Attwater) was positioned around the glass cloth tape and the whole tightly bound with glass fibre string (1 mm dia., .3 mm wall Vidaflex 99, an unvarnished fibre glass sleeving braided using E type glass yarn suitable for up to 700°C manufactured by Jones, Stroud & Co. Ltd.). Seventy-one such thermocouples were fixed to the test section in the same axial plane at equal intervals of 25.4 mm commencing at a distance of 25.4 mm from the start of the heated section. At distances from the start of heating of .152, .457, .762, 1.107, 1.137 and 1.168 m double foil thermocouples 180° apart were positioned to check on whether there was any circumferential variation in the tube wall temperature.

4.7.6 In order to check the insulated thermocouples six 32 swg (.274 mm) Chromel-Alumel ones were spot-welded to the test section mid-way between the insulated ones at distances of .267, .521, .8, 1.103, 1.131 and 1.156 m. These were used for comparison purposes with the insulated ones when steady state tube wall temperature conditions were established when only the preheater was being used to heat the circulating fluid.

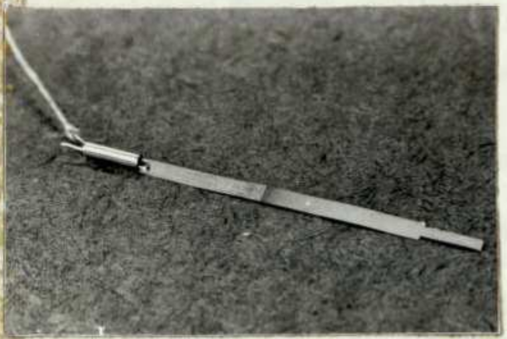


PLATE 1 FOIL THERMOCOUPLE WITH NICKEL SLEEVE AND WIRE POSITIONED ON END TAG PRIOR TO CRIMPING.

PLATE 2 CRIMPING THE THERMOCOUPLE WIRE TO THE END TAG.

PLATE 3 FOIL THERMOCOUPLE PLACED ON ADHESIVE SIDE OF PERMACEL TAPE WITH MICA SHEET ON TOP. THE DARKER HALF OF THE FOIL WAS THE SILVER PLATED ONE.

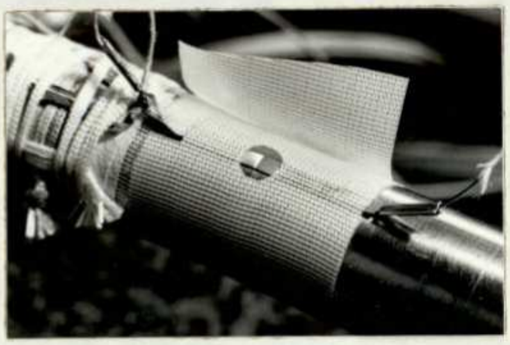


PLATE 4 PERMACEL TAPE WITH FOIL THERMOCOUPLE AND MICA WRAPPED AROUND TUBE. THE HOLE IN THE PERMACEL TAPE WAS FOR ACCURATELY POSITIONING THE HOT JUNCTION ON THE TUBE.

PLATE 5 ASBESTOS PAPER WRAPPED AROUND TUBE AND SECURED WITH VIDAFLEX GLASS FIBRE STRING.

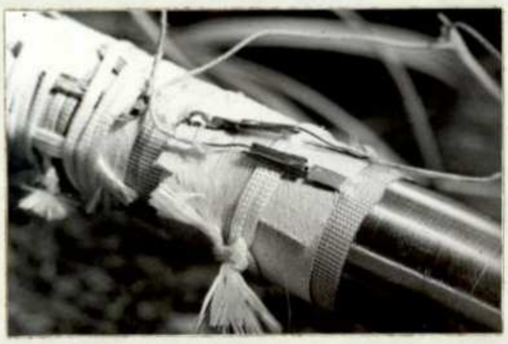


PLATE 6 POSITIONING OF THERMOCOUPLE END TAGS PRIOR TO FINAL BINDING WITH GLASS FIBRE STRING.

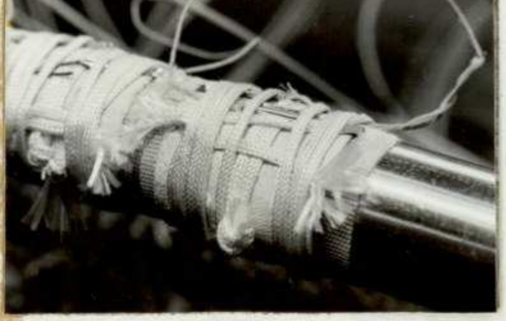


PLATE 7 THERMOCOUPLE JUNCTION AFTER FINAL BINDING WITH VIDAFLEX GLASS FIBRE STRING.

PLATE 8 VIEW OF INSULATED THERMOCOUPLES ON A PORTION OF THE TEST SECTION.

These welded-on thermocouples were fixed employing a capacitor-discharge spot welding technique. After spot-welding the hot junction on to the tube the thermocouple wire was wound once round the test section to minimise conduction losses at the thermocouple junction and then covered over with a high-temperature adhesive cement (Fortafix Ltd.) and allowed to cure. A similar procedure was also used for fixing the three burn-out detection system wires to the test section, one at the mid point of the tube, the other two each at 12.7 mm from the start and finish of heating respectively.

4.8 Loop System Check out and instrumentation calibration.

4.8.1 The primary loop circuit was cleaned and degreased after assembly by circulating a solvent, trichlorotrifluoroethane (Refrigerant 113). The system was then pressure-tested to 10.35 MN/m^2 utilising the air-operated reciprocating pump. Because of their very low surface tension refrigerant fluids are extremely searching and leaks could be readily detected using a Halide leak-detecting lamp. The latter was of the blow-lamp type, the flame of which changed from being nearly invisible to green or bright blue in the presence of a refrigerant leak.

4.8.2 Prior to installing the primary fluid turbine flow meter the makers' calibration was checked with water using the weigh tank and stopwatch technique. The results of this latter check and those of a repeat calibration exercise which was carried out several months later mid-way through the experimental programme confirmed the makers' figures for the flow meter as shown in Fig. 26.

On the system pressure measurement side the Heise gauge had been supplied by the manufacturer with a certificate which showed a nil deviation of the gauge reading from the deadweight tester figures at all calibration points up to 10.35 MN/m^2. The gauge was used as received from the manufacturer apart from the adjustment of the zero point of the scale each day in order for the subsequent readings to be

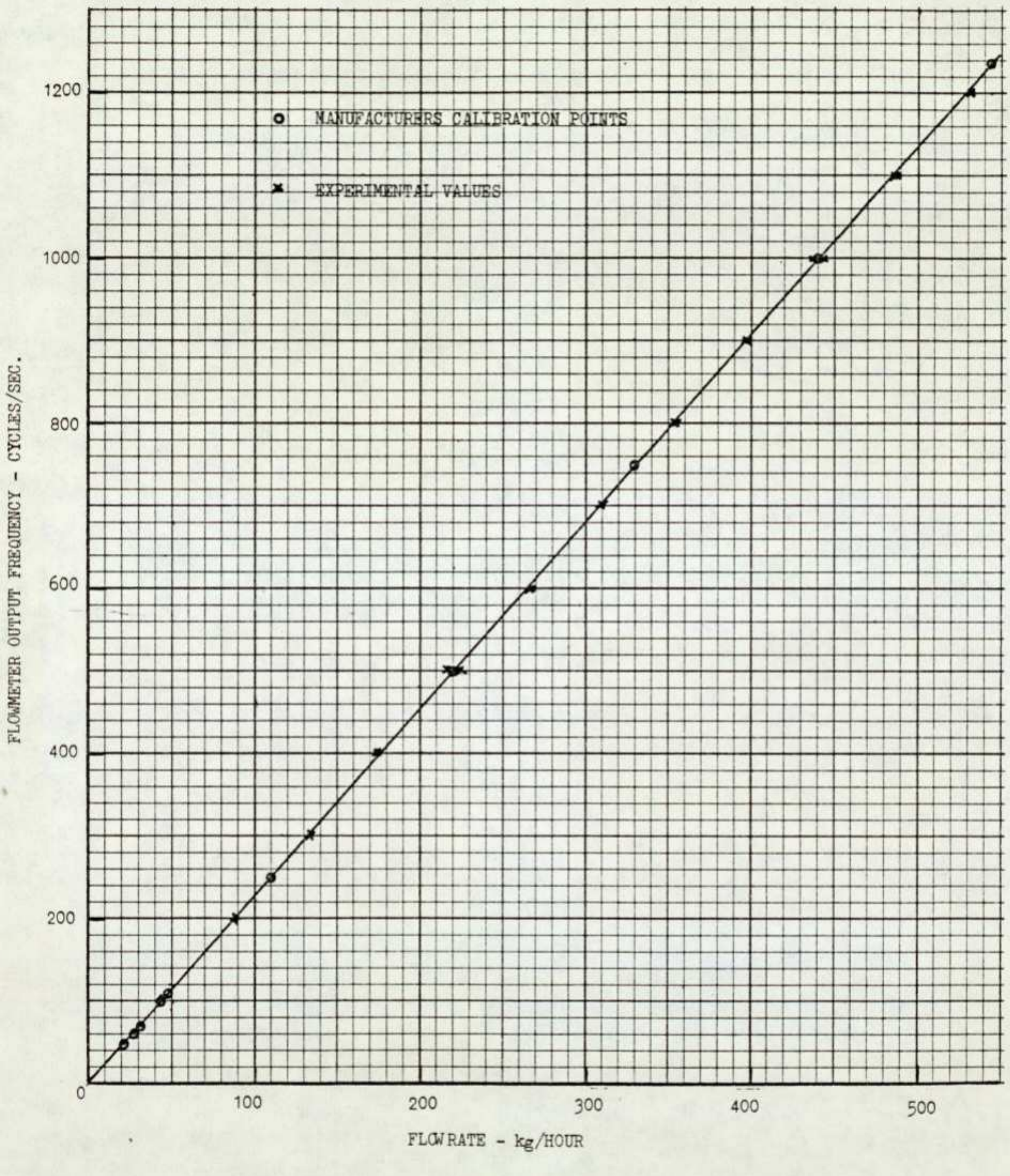


FIG.26 Calibration graph for turbine flowmeter

absolute pressure values. Although no recordings were taken from the other Bourdon tube type pressure gauges in the loop complex most of them were checked out prior to use with a Budenberg deadweight tester. The low range inlet and exit differential pressure transducers were initially calibrated at the outset of the investigation and on several other occasions during the course of the test programme using a constant pressure air supply and mercury manometer. Frequent calibration of these latter pressure transducers was considered to be necessary because of the possibility of a significant change in their calibration which could have been caused by excessive differential pressures. Such excessive differential pressures could have been caused by a leak of either loop fluid or the reference gas during start up and shut down when the loop pressure could rapidly alter. Whilst no serious incidents of this latter nature occurred, due to close visual monitoring of the test section exit-reference gas pressure as displayed by the Barton differential pressure indicator, a transducer protection system would have been desirable as a safeguard to limit differential pressures to less than the stated manufacturers maximum limit of ten times the transducers working range. No such problems existed with the similarly calibrated Barton differential pressure indicator which was designed to withstand differential overload up to its full static pressure rating of 17.2 MN/m^2 (2,500 psi).

A calibration was also undertaken of the remaining differential pressure transducer which was used to indicate the level of fluid in the pressuriser. The output of this variable-inductance transducer was noted under low and high level pressuriser conditions and this was periodically checked during loop shutdowns.

4.8.3 All three types of thermocouple i.e. stainless steel sheathed, electrically insulated and welded-on were calibrated prior to use in a constant temperature oil bath (up to 235°C) and/or an electrically heated furnace (up to ~600°C). The temperature of the oil bath or furnace was measured by a Platinum-13% Rhodium/Platinum thermocouple[51] in conjunction with a high accuracy potentiometer (Croydon Instruments, Cropico P3 No. 4481). Both of the two forms of Chromel-Alumel thermocouples used viz. the stainless steel sheathed ones for fluid temperature measurements and those which were welded to the test section were found to follow the table values of Ref. 52 up to within ± .5°C up to their calibration limit of 400°C. Except for below 100°C the output of the foil type thermocouples corresponded to within + .3, -.5°C of the values given in Ref. 53 up to 400°C. Since it was highly likely that the test section wall temperatures would exceed 400°C the calibration of the foil type thermocouples was taken up to about 600°C, which in the event was just high enough to cater for the maximum test section temperatures experienced in the test programme. The thermocouple calibration measurements are summarised in Table 4.

4.8.4 Several calibrations were undertaken in connection with the electrical power supply to the test section. Prior to installing the test section into the loop its electrical resistance was measured in an electrical standards laboratory at 20°C using a Kelvin bridge (Cropico Instrument Co. No. 22489). The measured resistance between the power clamps was .0275 Ω which compared favourably with the calculated value of .0283 Ω evaluated using a resistivity value of 113 μΩ-cm. The output of the voltage dividing circuits employed to enable the test section and pre-heater voltage drops to be recorded by the data logger were checked for linearity over the 0-100 mV range. A stabilised power supply was employed in these latter tests to simulate the test section and pre-heater voltage drops. Unfortunately no high amperage facility existed for checking the output of the precision shunt which was used for determining the test section current; its accuracy was quoted as ± 0.5% over a 0-75 mV (0-1,000 amps) range. To confirm the uniformity of voltage drop across the test section a check was made of the voltage

STANDARD THERMOCOUPLE PLAT 13% Rh-PLAT		CU-CON WALL THERMOCOUPLES			CR-AL SHEATHED THERMOCOUPLES		
EMF mV	TEMP(1) C	EMF mV	TEMP(2) C	DIFFERENCE FROM STANDARD C	EMF mV	TEMP(3) C	DIFFERENCE FROM STANDARD C
.4	65.7				2.64	65.2	-.5
.5	80.1				3.26	79.8	-.3
.6	94.1	3.97	94.1	0	3.84	93.8	-.3
.7	107.5	4.58	107.4	-.1	4.39	106.8	-.7
.8	120.5	5.19	120.3	-.2	4.94	120.2	-.3
.9	133.5	5.78	132.6	-.5	5.45	133.0	-.5
1.0	145.6	NR			5.96	145.8	+.2
1.1	157.7	7.02	157.8	+.1	6.43	157.6	-.1
1.2	169.6	7.60	169.4	-.2	6.91	169.3	-.3
1.3	181.3	8.18	180.7	-.6	7.38	181.4	+.1
1.4	192.9	8.79	192.6	-.3	7.85	193.0	+.1
1.5	204.1	9.38	203.8	-.3	8.31	204.3	+.2
1.6	215.4	9.98	215.2	-.2	8.76	215.8	+.4
1.7	226.5	10.57	226.2	-.3	9.20	227.0	+.5
1.8	237.4	11.17	237.2	-.1	9.65	237.5	+.1
1.9	248.3	11.76	248.2	-.1	10.09	248.7	+.4
2.0	258.9	12.33	258.5	-.4	10.53	258.9	0
2.1	269.6	12.93	269.3	-.3	10.95	269.5	-.1
2.2	280.1	13.53	280.0	-.1	11.38	279.6	-.5
2.3	290.5	14.12	290.4	-.1	11.82	290.4	-.1
2.4	300.8	14.72	300.9	+.1	12.24	300.8	0
2.5	311.1	15.31	311.2	+.1	12.68	311.4	+.3
2.6	321.3	15.91	321.6	+.3	13.11	321.3	0
2.7	331.4	16.50	331.7	+.3	13.51	331.2	-.2
2.8	341.4	17.09	341.7	+.3	14.00	343.0	-.4
2.9	351.4	17.68	351.7	+.3	14.34	351.2	-.2
3.0	361.3	18.26	361.4	+.1	14.75	361.0	-.3

STANDARD THERMOCOUPLE PLAT 13% Rh-PLAT		CU-CON WALL THERMOCOUPLES			CR-AL SHEATHED THERMOCOUPLES		
EMF mV	TEMP(1) C	EMF mV	TEMP(2) C	DIFFERENCE FROM STANDARD C	EMF mV	TEMP(3) C	DIFFERENCE FROM STANDARD C
3.1	371.1	18.84	371.1	0	15.17	371.1	0
3.2	380.9	19.43	380.9	0	15.57	380.4	-.5
3.3	390.6	20.04	390.8	+.2	15.97	390.1	-.5
3.4	400.3	20.60	400.1	-.2	16.39	399.8	-.3
3.5	409.9	21.22			NR		
3.6	419.5	21.86					
3.7	429.1	22.45					
3.8	438.6	23.04					
3.9	448.0	23.62					
4.0	457.4	24.21					
4.1	466.7	24.79					
4.2	476.0	25.38					
4.3	485.3	25.97					
4.4	494.5	26.55					
4.5	503.6	27.13					
4.6	512.8	27.72					
4.7	521.9	28.30					
4.8	531.0	28.88					
4.9	540.1	29.46					
5.0	549.1	30.00					
5.1	558.1	30.60					
5.2	567.1	31.19					
5.3	576.0	31.78					
5.4	584.9	32.34					
5.5	593.7	32.93					
5.6	602.5	33.51					
5.7	611.3	34.09					

NOTES:

NR denotes 'not recorded'
(1) As given by BS 1826 (1952)
(2) " " " BS 1828 (1961), limited to 400 C
(3) " " " BS 1827 (1952)

TABLE 4 Results of calibration exercise on wall and fluid temperature measurement thermocouples at several positions along the test section using the welded-on thermocouples and burn-out detection system wires as voltage tappings. The result of this exercise for nominal potential drops of 5, 10, 15 and 20 volts across the test section are shown in Fig. 27 . This latter check was undertaken after the loop had been in operation for some time. It is evident from Fig. 27 that despite the care taken to ensure a good contact between the power clamps and tube a high resistance oxide film had in fact built up at the interface of the tube and upper power clamp.

4.8.5 System dynamic checks and calibrations. Apart from the check on the linearity of voltage drop across the test section the foregoing calibrations were essentially checks undertaken prior to the initial filling of the loop for commissioning and test purposes. After filling the loop and during the test programme several other calibrations or dynamic checks were undertaken to establish confidence in the instrumentation associated with the test section. These tests were:-

(i) The determination of the test section single-phase heat transfer and pressure drop characteristics for comparison with standard correlations.

(ii) A comparison of the test section wall temperatures as given by the insulated and welded-on thermocouples as a check on the likely accuracy of the former type.

(iii) The determination of the heat loss from the test section at various operating temperatures so that appropriate correction factors could be applied to the heat flux as calculated from the voltage and current readings.

4.8.6 Single-phase heat transfer and pressure drop tests. Heat transfer data was obtained under single-phase flow conditions prior to and at intervals during the test programme for comparison with established single-phase heat transfer correlations. A good agreement with the

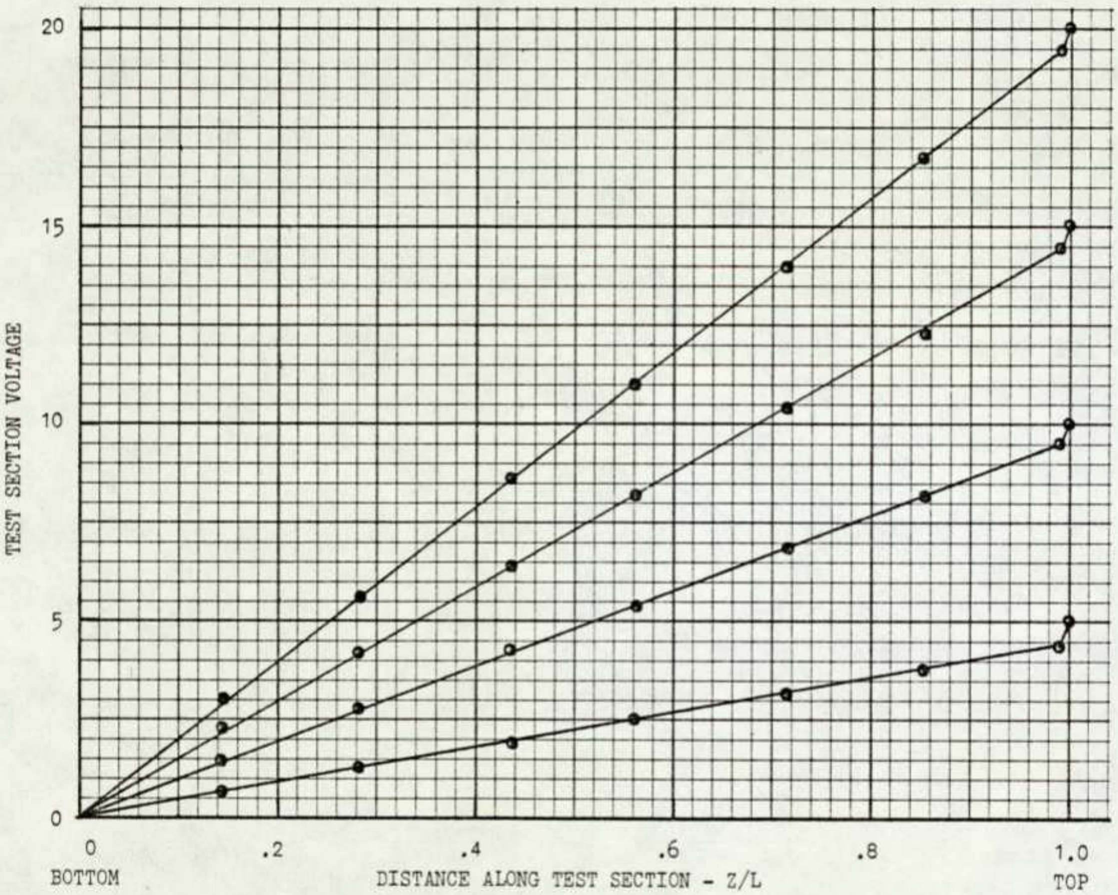


FIG. 27 Voltage drop along the test section

latter would indicate that a high degree of confidence could be placed in the reliability of the two-phase results obtained subsequently. A typical result of one of these check runs is shown in Fig. 28 from which it can be seen that the standard correlation is followed to within a few percent. It should be noted that these tests were always undertaken with highly sub-cooled fluid or a low heat flux to avoid any heat transfer enhancement effects due to sub-cooled bubble formation. Tests were carried out under adiabatic flow conditions to determine the single-phase pressure drop characteristic of the test section for comparison with that predicted by a standard correlation. The experimental frictional pressure-drop component was determined by subtracting the gravity component from the measured total pressure drop between the tappings on the test section for various primary loop flow rates. The tube friction factor was calculated employing the experimental frictional pressure drop value from the Fanning expression:-

$$f = \frac{2\Delta p\ g\ D}{4Lu^2}$$

Representative results of these latter tests are shown in Fig. 29 . As shown in Fig. 29 tests were conducted with two fluids, Refrigerant 113, which was the solvent employed for loop cleaning, and the first of the two test fluids, Monochlorobenzene over the Reynolds number range 9,000-25,000. For comparison purposes the standard Nikuradse correlation for the frictional pressure drop component in smooth tubes is also presented in Fig. 29 according to the relation (54):-

$$1 / f^{0.5} = 4.0 \log_{10} (Re.f^{0.5}) - 0.4$$

Considering that the frictional pressure drop component was only a maximum of around 8% of the gravity component for these single phase runs there is reasonable agreement between the experimental and predicted friction factors.

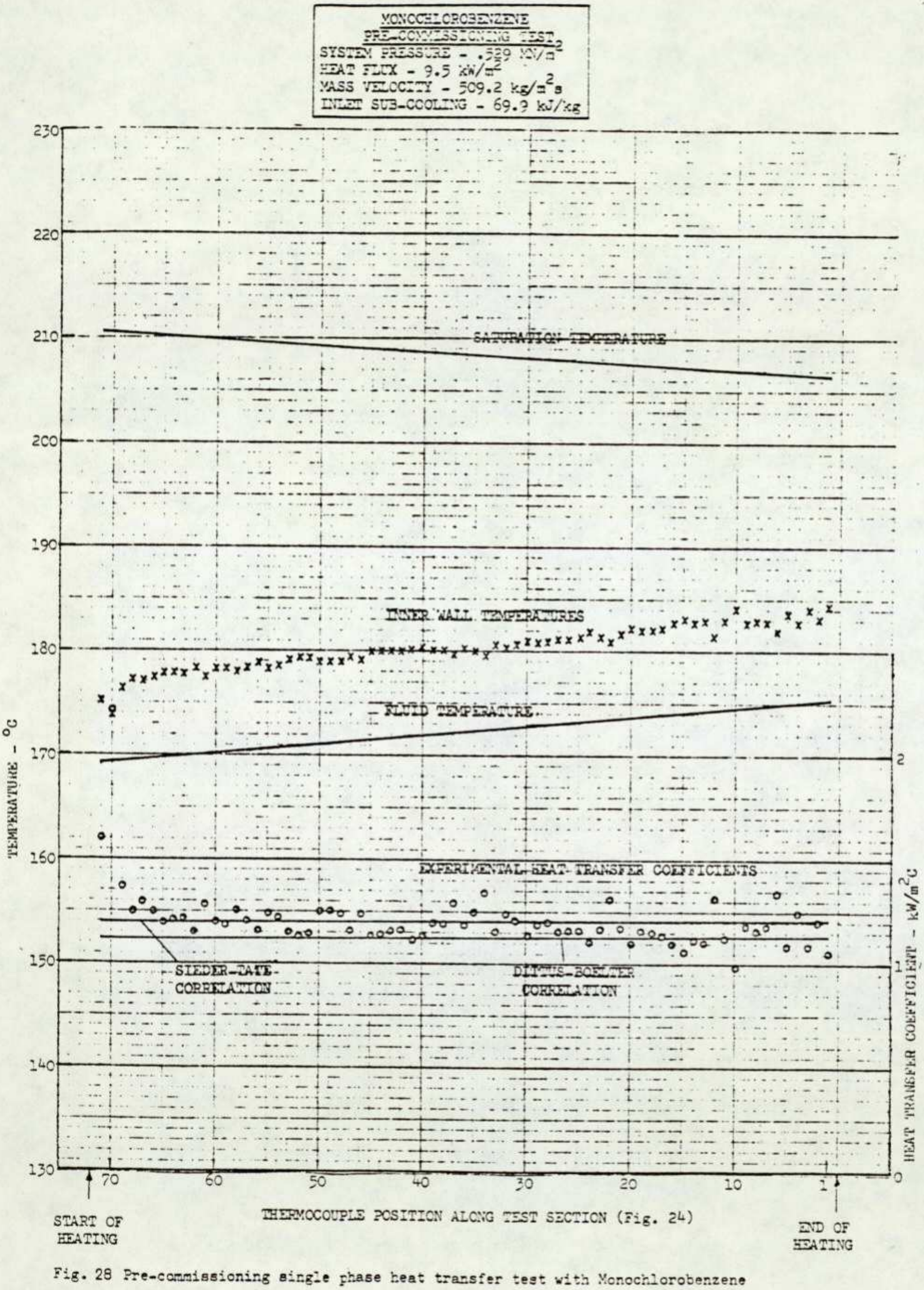


Fig. 28 Pre-commissioning single phase heat transfer test with Monochlorobenzene

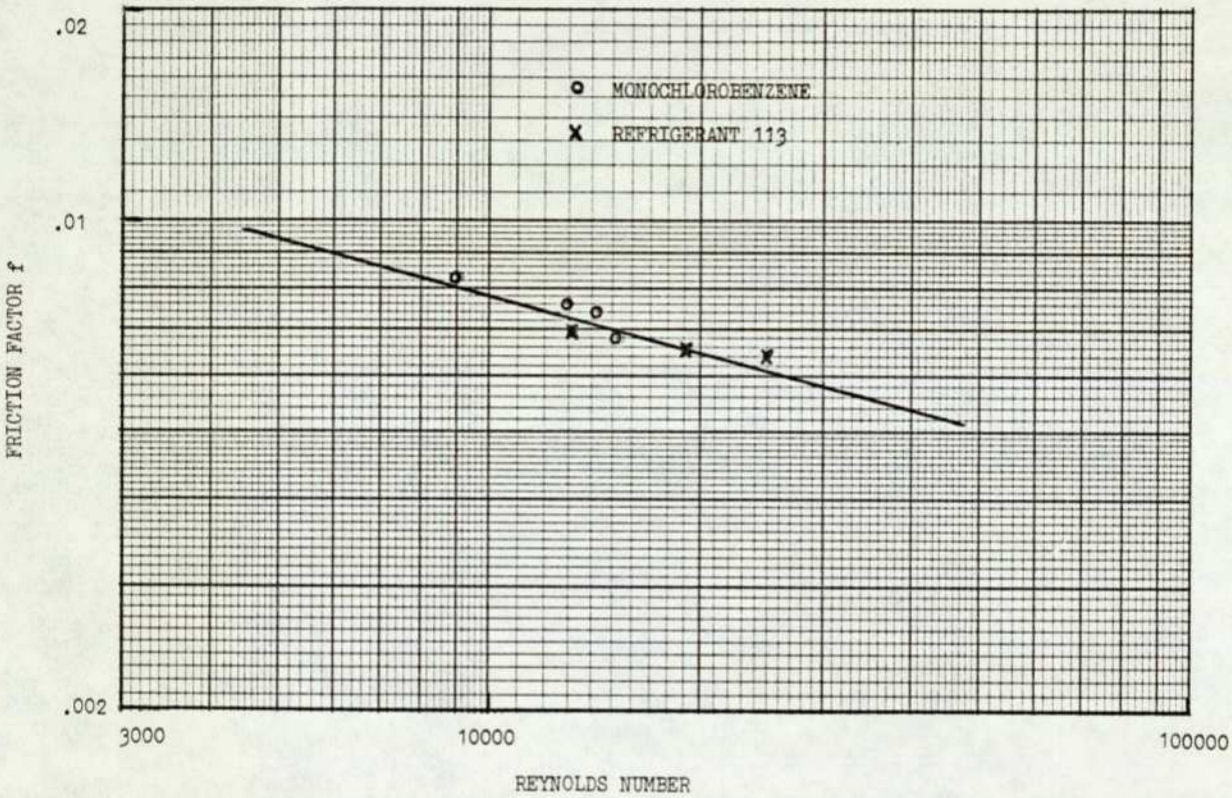


FIG. 29 Single-phase pressure drop results

4.8.7 Comparison between insulated and welded-on test section thermocouples. Initially it was considered that in the absence of pick-up emf's that the test section welded-on thermocouples would have a higher accuracy than the insulated ones. Accordingly 6 welded-on thermocouples were incorporated in the test section instrumentation for comparison purposes when there was no test section power. During the start-up phase of loop operation test section power was not applied until nearing the intended operating point. During these start-up periods when steady state temperature conditions had been established for each adjustment of pre-heater power and/or mass flow rate test section wall temperature readings were recorded from both the insulated and welded-on thermocouples. Due to pre-heater power limitations it was not possible to obtain a test section wall temperature higher than about 307°C which thus represents the upper limit at which the thermocouple comparison exercise was carried out. The results of the comparison study are shown in Fig.30 where the difference in temperature between the insulated and welded-on thermocouples is plotted against temperature. It can be concluded from these results that the initial assumption was incorrect and that errors due to fin effects would need to be quantified when welded-on thermocouples are employed for test section wall temperature measurements.

4.8.8 Heat loss from test section. The heat loss from the test section at various temperatures was determined by comparing the measured heat input into the test fluid under single phase flow conditions with that calculated from the electrical power input. The heat input into the test fluid was determined from the measured inlet and exit temperatures, calculated liquid specific heats and computed flow rate. The results of this comparison exercise for all the non-boiling runs carried out during the test programme is shown in Fig.31 . A correction factor, a function of the measured power input was calculated from a least squares

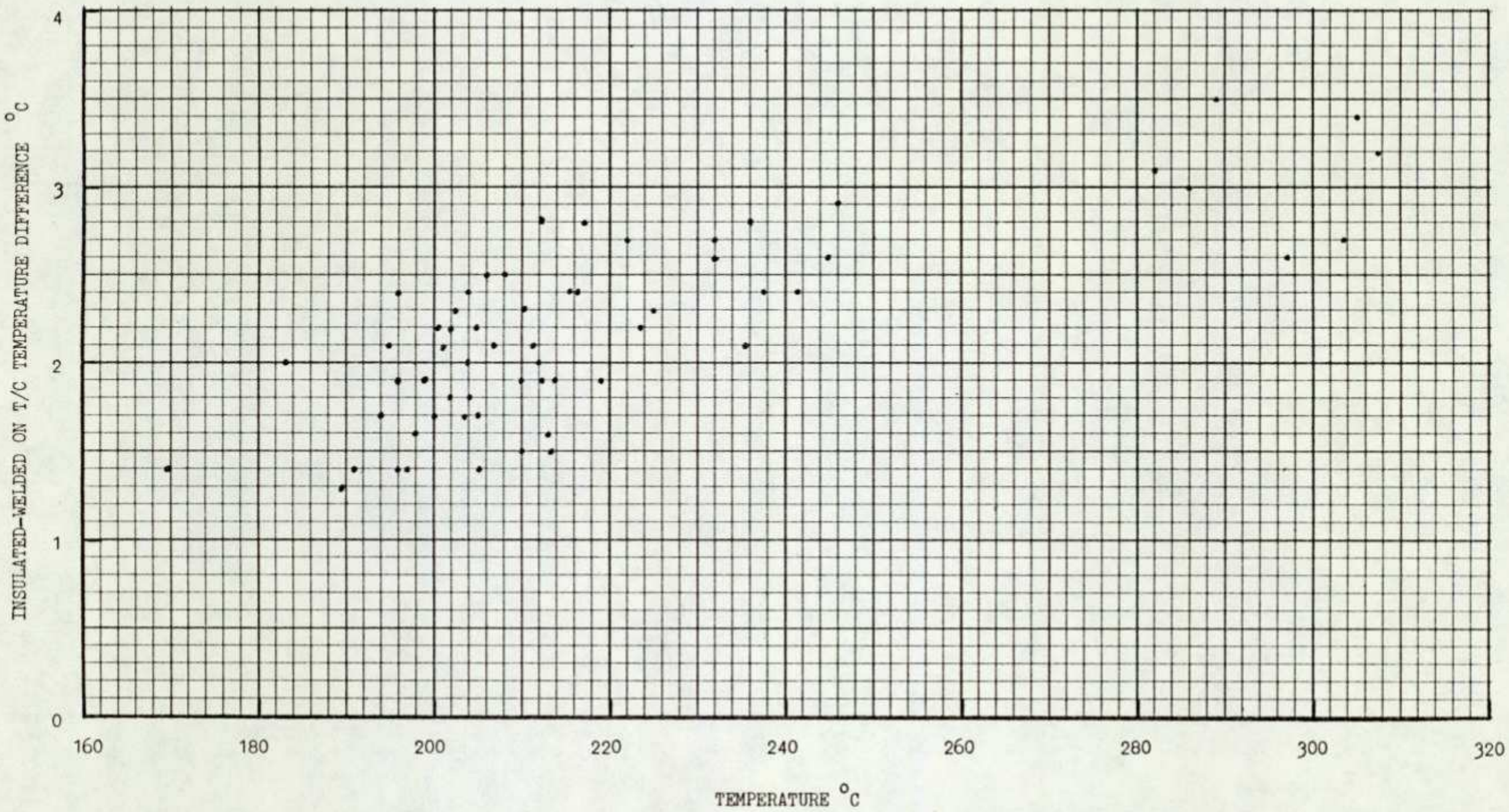


FIG.30 Comparison between insulated and welded-on test section thermocouples derived from tests undertaken using pre-heater power input only.

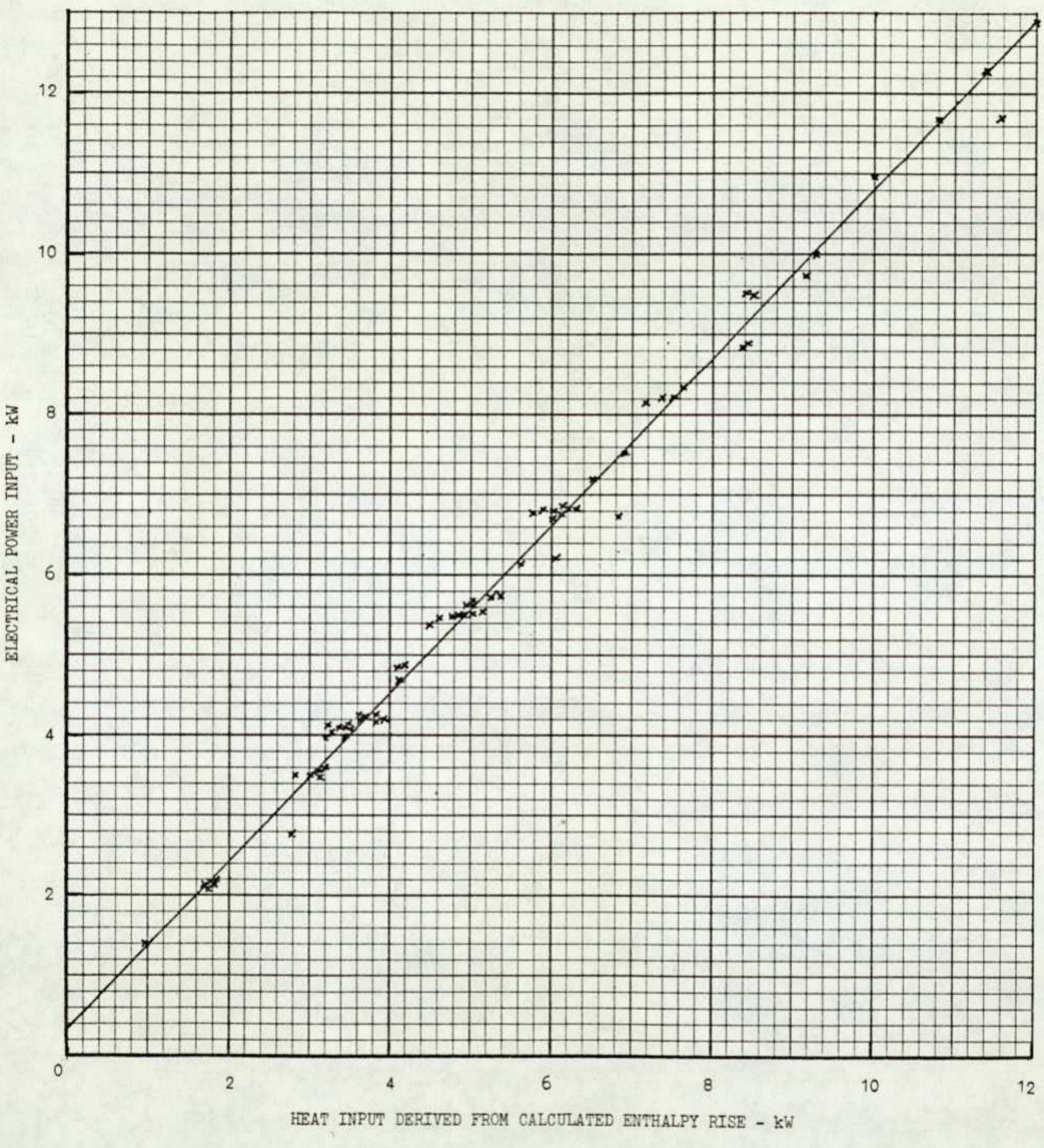


FIG. 31 Comparison between measured electrical power input to the test section and the power input as derived from the calculated enthalpy rise under single-phase flow conditions.

fit to the data points shown which was incorporated in the data reduction computer program.

5. EXPERIMENTAL PROCEDURE AND OBSERVATIONS

5.1 The test programme was commenced upon completion of the system calibration and check out exercises. In all a total of 254 experimental runs were undertaken with monochlorobenzene and 38 with biphenyl-biphenyl oxide as the test fluids. This Chapter will deal with the loop starting, operating and shut-down procedures, the data-taking operation and a discussion of some rig design deficiencies and limitations.

5.2 Starting procedure.

The starting procedure for each series of test runs was identical and it took between 3 and 4 hours to reach the desired operating point. The test fluid in the storage tank was degassed by heating it up to its boiling point and subsequently holding it under a sub-atmospheric pressure for half an hour. For monochlorobenzene the resulting dissolved gas content was 5 ml/100 ml (see Appendix 6, page 247). During this period the primary loop was evacuated down to a pressure of about 2 torr and then filled with degassed fluid from the storage tank using a transfer under vacuum process. A low-pressure nitrogen blanket gas was employed over the fluid in the storage tank to complete the filling operation, indicated by air-free fluid flowing at the sight glass vents when the vent and filling valves were closed. The pressuriser which was isolated during the filling operation was checked to be about one third full and heated up with the vent valve open to boil off any non-condensible gases. After closing the vent valve and building up a pressure of about 140 kN/m^2 in the pressuriser the isolating valve to the loop was opened to pressurise the loop. Before an excessive differential pressure was allowed to build up across the pressure transducers the reference pressure gas supply was opened up and continuously adjusted to balance out the loop fluid pressure. At this stage whilst there was no flow in the system the output of the differential pressure transducers was checked against the known gravitational pressure drop between the test section inlet and exit tappings.

When the desired pressure level was being approached the circulating pump was started, a flow rate set and the pre-heater power switched on to heat up the primary fluid. The temperature of the liquid in the shell of the reflux cooler/condenser was brought up to around 30°C below that of the primary fluid circulating within the heat exchanger coil before cooling water was turned on to the condenser coil. An immediate reduction in shell pressure occurred on supplying cooling water to the condenser coil which caused vigorous boiling of the shell fluid which could be observed through the port-hole type viewing window. Henceforward until the conclusion of the particular series of tests the refluxing conditions so established were maintained by control of the shell pressure through alterations in condensing coil cooling water flow rate and/or adjustment of the vacuum pulled on the shell vapour space by a rotary vacuum pump. Water was employed as the heat exchange fluid for tests with monochlorobenzene up to and including reduced system pressure tests of .22. At the water temperatures involved with the $p_r = .22$ tests the shell pressure was approaching its design maximum of 1.8 MN/m^2 which necessitated a change to a high temperature, low pressure fluid for subsequent tests. Sub-atmospheric pressures were present in the reflux cooler shell with the thermal fluid so employed (ICI Thermex).

When the reflux cooler/condenser had been made operational the test section power was applied and adjustments made to the pre-heater power and/or flow rate to produce as far as possible the desired test section inlet condition for the first test of the series. It was found that one could best obtain the desired inlet test condition by keeping the pressure slightly above the saturation pressure for the fluid temperature, but below the final desired operating pressure during heating of the system. During pressurised operation i.e. no net vapour generation in the test section, at start up and during breaks in the data recording phase of operation, the loop pressure could be controlled very closely by the Ether controller which automatically switched the pressuriser heater(s) on and off. With two-phase conditions in the test section the pressure at the test section exit was controlled by manually switching on or off the pressuriser heaters.

5.3 Data recording phase of loop operation.

The data recording phase commenced when steady state operating conditions had been achieved with the desired pressure level, test section power input, test section inlet temperature and flow rate. Steady state loop operating conditions prevailed when the heat input to the loop system (test section, pre-heater and circulating pump) equalled the heat output (reflux cooler, sub-cooler, heat losses), and in practice these conditions were quickly established when changing the operating point because of the low primary loop inventory (2-3 litres, excluding the pressuriser and "dead leg" piping).

In addition to the inputs to the data logger listed in 4.6.6 the following were also recorded during data taking for a particular test of the series:-

(i) System pressure.

(ii) Test section exit - reference gas pressure difference as given by the differential pressure indicator.

(iii) Flow meter output frequency.

(iv) Test section volts as recorded by a Solatron LM3124 digital volt meter which was used for setting the test section volts for a particular test.

(v) Test section and pre-heater volts and current as displayed by a panel digital volt meter using the selector switch.

(vi) Reflux cooler - condenser cooling water flow rate.

(vii) Reflux cooler/condenser cooling water inlet and exit temperatures.

(viii) Sub-cooler flow rate.

During the recording phase the pressure difference between the reference gas and loop fluid as displayed by the Barton differential pressure indicator was closely controlled by manual control of the pressuriser heater(s). With experience it was possible to control to within one or two divisions (1 division = 0.48 kN/m^2) of a datum point when only single phase flow conditions were present. With evaporation taking place such a fine degree of control was unobtainable although it was possible to limit pressure fluctuations to $\pm$ 5 divisions whilst data recording was taking place. A second parameter closely controlled during the data-taking phase was the reflux cooler shell pressure to ensure that steady-state heat removal conditions prevailed.

Tests were carried out for ascending values of heat flux only and were terminated when the test section uppermost thermocouple indicated that dry-out conditions had occurred or were about to occur. The thermocouple nearest the test section upper power clamp was continuously displayed whilst the test section power level was raised. This latter operation was greatly facilitated by having 'raise' and 'lower' switches mounted on a 'wandering lead' which operated the motorised voltage controller. A second 'wandering lead' incorporated a push button switch for switching off the test section power in an emergency.

5.4 Loop shut down.

At the conclusion of the series of tests for the day both the test section and pre-heater power were removed and the loop gradually depressurised by operating the spray line to the pressuriser. During the spraying down process, which was capable of creating a rapid reduction in the system pressure, the reference gas pressure was continuously adjusted to avoid excessive differential pressures occurring across the transducers. It was found that the loop could be depressurised and returned to room temperature conditions in about two hours.

5.5 Rig operational observations and limitations

It is appropriate at this point to enumerate for the record some of the problems encountered during the experimental programme which arose either from deficiencies in the design of the loop system or were associated with the properties of the test fluids used.

The loop system as constructed provided remarkably trouble free operation on the mechanical side during the course of the investigation. Despite the low surface tension and excellent wetting characteristics of the two fluids tested there was a complete absence of primary fluid leaks. There was only one mechanical failure during the test programme, that of a thermocouple gland nut. There were no over-pressure incidents causing bursting disc rupture and no occasions when it was necessary to carry out an emergency depressurisation by dumping the loop contents to the dump/drain tank by using the solenoid operated valve.

On the thermal side there were limitations on the test section inlet temperature or inlet sub-cooling caused by inadequate pre-heater power and/or the temperature limitation of the circulating pump. Not enough pre-heater power was available for the higher flow rates and system pressures employed to raise the loop fluid temperature to the desired level after the fluid had been cooled down in the sub-cooler to an acceptable temperature at the pump inlet. There were also problems on the heat rejection side caused by variations of the pressure in the shell of the reflux cooler/condenser. This latter component operated under quasi-steady state conditions and it required almost constant attention during the data taking phase to make adjustments :(i) to the cooling water flow rate when operating above atmospheric pressure and (ii) the amount of bypass leakage to the vacuum system when operating at sub-atmospheric pressure so as to maintain a constant shell pressure. Shell pressure variations, unless closely controlled, would affect the system pressure by increasing or decreasing the heat rejection rate to the heat exchange fluid which was at the saturation temperature corresponding to the shell pressure. Some form of automatic pressure control of this component would have been highly desirable.

On the hydraulic side no serious loop instabilities of the type associated with two-phase systems[22] were encountered. Ideally a circulating pump having a higher head would have been desirable to maintain the desired flow rate on occasions when the increase in pressure drop created on evaporation caused the flow rate to reduce to match the increased circuit resistance. A second problem with flow rate adjustment was due to the insensitivity of the 12.7 mm flow control valve which was effective for only about its last full turn.

The high wall temperatures present under dry-out conditions caused fluid breakdown with carbon forming over the dry wall region at the test section exit. This carbon spalled off the wall and was carried around the circuit to be deposited in the filter upstream of the turbine flow meter. This filter had only a very small filtering element which very quickly clogged up when dry-out occurred. Usually there was just sufficient time to record data before the flow rate started to fall significantly, which necessitated the power being removed from the test section to ensure that the dry-out front at test section exit did not progressively march upstream. A filter having a much greater particulate trapping capacity or a system of changeover filters would have allowed the post dry-out regime to have been investigated in more detail than was undertaken in this investigation.

The major problem with the instrumentation was created by reference gas and loop fluid pressure fluctuations which affected the output of the differential pressure transducers. Gas reference pressure fluctuations occurred due to the 'floating' of the spring loaded adjusting valve despite the provision of a damping reservoir teed into the reference pressure line. Loop fluid pressure fluctuations could have been caused by the circulating pump, the mode of pressurisation or the evaporation process in the test section. A Solartron JM1776 computing digital volt meter was used for occasions, such as the frictional pressure drop measurements, when it was necessary to accurately know the mean level of the d.c. signal outputs of the differential pressure transducers. During the data-taking phase several readings of the differential pressure transducers outputs were taken and the mean of these was used to calculate the absolute pressure at the test section inlet and exit.

6. RESULTS

6.1 Reduction of Data and Calculation of Results.

In the interests of accuracy and to allow for the widest possible exploitation of the data it was decided to handle all data reduction and subsequent calculations by computer. The program developed for this purpose was written in Fortran and was initially run on the University ICL 1905E computer. The program was subsequently modified for use with a Univac 1108 system. The computer program calculated the experimental local heat transfer coefficients at points along the test section where an insulated thermocouple was positioned for measuring the wall temperature ie. at 25.4 mm intervals up the tube. Also calculated by the program were the predicted heat transfer coefficients as given by the correlations discussed in Chapter 3. The program was general for the case of vertical up-flow of fluid in an electrically heated tube and only required amendments to the thermo-physical properties calculation routine to be used with either of the two test fluids employed in the investigation. A listing and description of the data reduction computer program is given in Appendix 2 and the derivation of the associated thermophysical properties of the test fluids in Appendix 3. The input data required for the program is given in Tables 21 and 22 of Appendix 8 which lists the experimental data taken in the investigation.

6.2 Summary of Results.

Data were obtained from 254 and 38 test runs with monochlorobenzene and biphenyl-biphenyl oxide respectively. These were made over the range of variables shown in Table 5 overleaf.

A listing of the derived experimental conditions for each of the tests is given in Tables 23 and 24 of Appendix 8 for monochlorobenzene and biphenyl-biphenyl oxide respectively.

Variable	Range Investigated with monochlorobenzene	Range Investigated with biphenyl-biphenyl oxide
System pressure, MN/m^2	.51 - 3.093	.225 - .521
Mass velocity, kg/m^2 sec.	296 - 886	195 - 743
Heat flux, kW/m^2	13 - 200	40 - 190
Inlet sub-cooling, kJ/kg	12 - 201	25 - 191
Exit quality	.01 - .99	.02 - .99
Bulk fluid temp., ^oC	146 - 326	232 - 344
Inside wall temp., ^oC	176 - 575	252 - 503
Reynolds No.	28,000 - 86,900	15,500 - 47,600
Prandtl No.	2.9 - 3.7	4.0 - 5.8

Table 5: Range of test variables for investigation.

6.3 Comparison of Single Phase Heat Transfer Correlations with Experimental Results.

Single-phase heat transfer data was obtained from 39 runs with monochlorobenzene as the test fluid. Typical test data taken at the extreme ranges of reduced pressure employed during the experiments with monochlorobenzene are given in Figs. 32 and 33 along with calculated and predicted heat transfer coefficients. Comparisons between the experimental and predicted heat transfer coefficients for the single phase experiments are given in Fig. 34 for the Dittus-Boelter(24) correlation and Fig. 35 for the Sieder-Tate(25). The experimental points shown in Figs. 34 and 35 are based on the heat transfer coefficient for a particular run averaged between thermocouples Nos. 14-60 inclusive (thermocouple location numbers are as shown in Fig. 24). For some of the single phase tests the inner wall temperature exceeded the local saturation temperature for part of the heated length so that enhancement effects due to sub-cooled boiling could have been present. In these cases the averaging of the heat transfer coefficients was restricted to those lying between thermocouple

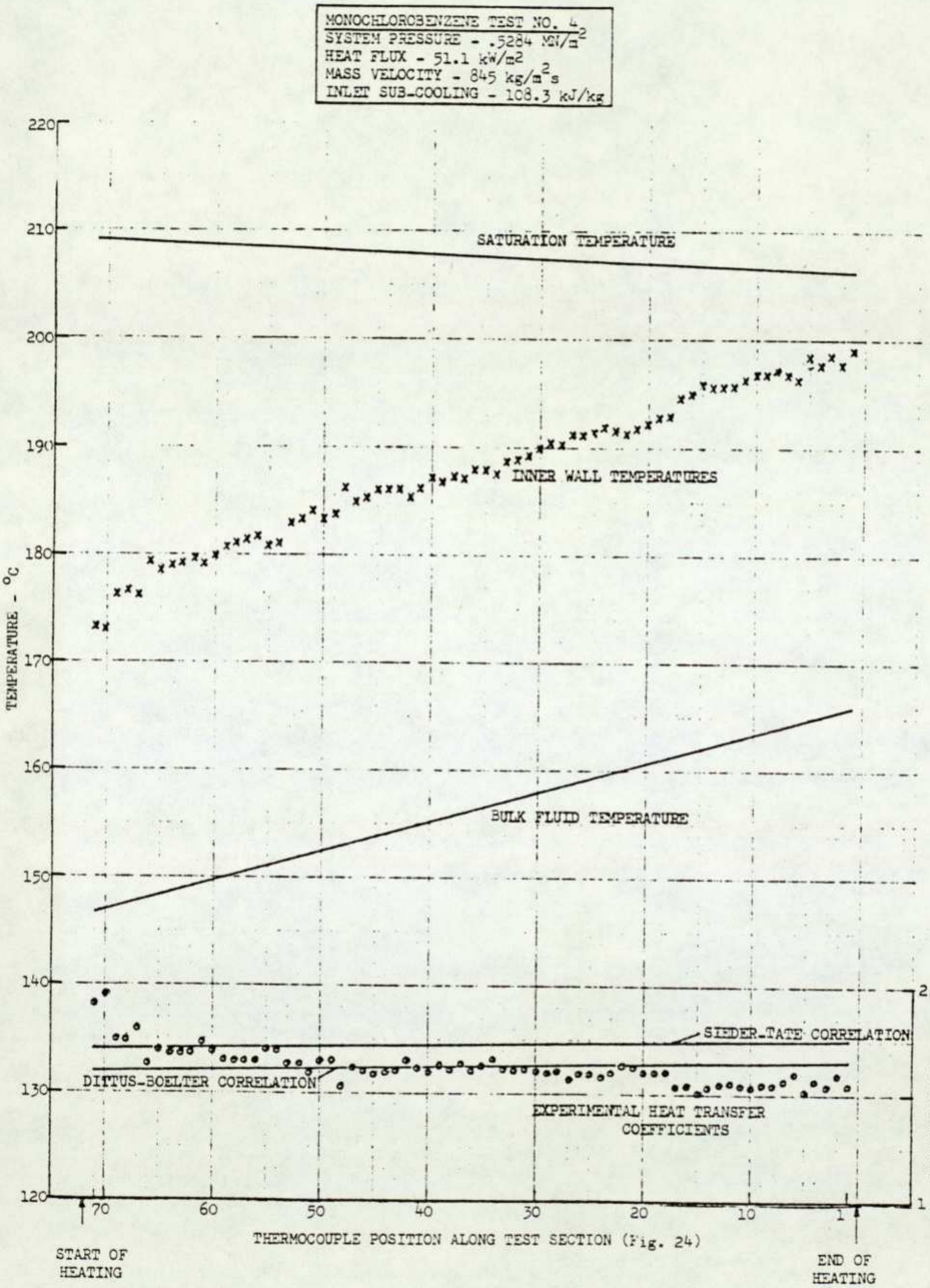


Fig. 32 Fluid and wall temperature profiles and local heat transfer coefficient variation for a single phase, low system pressure test with Monochlorobenzene.

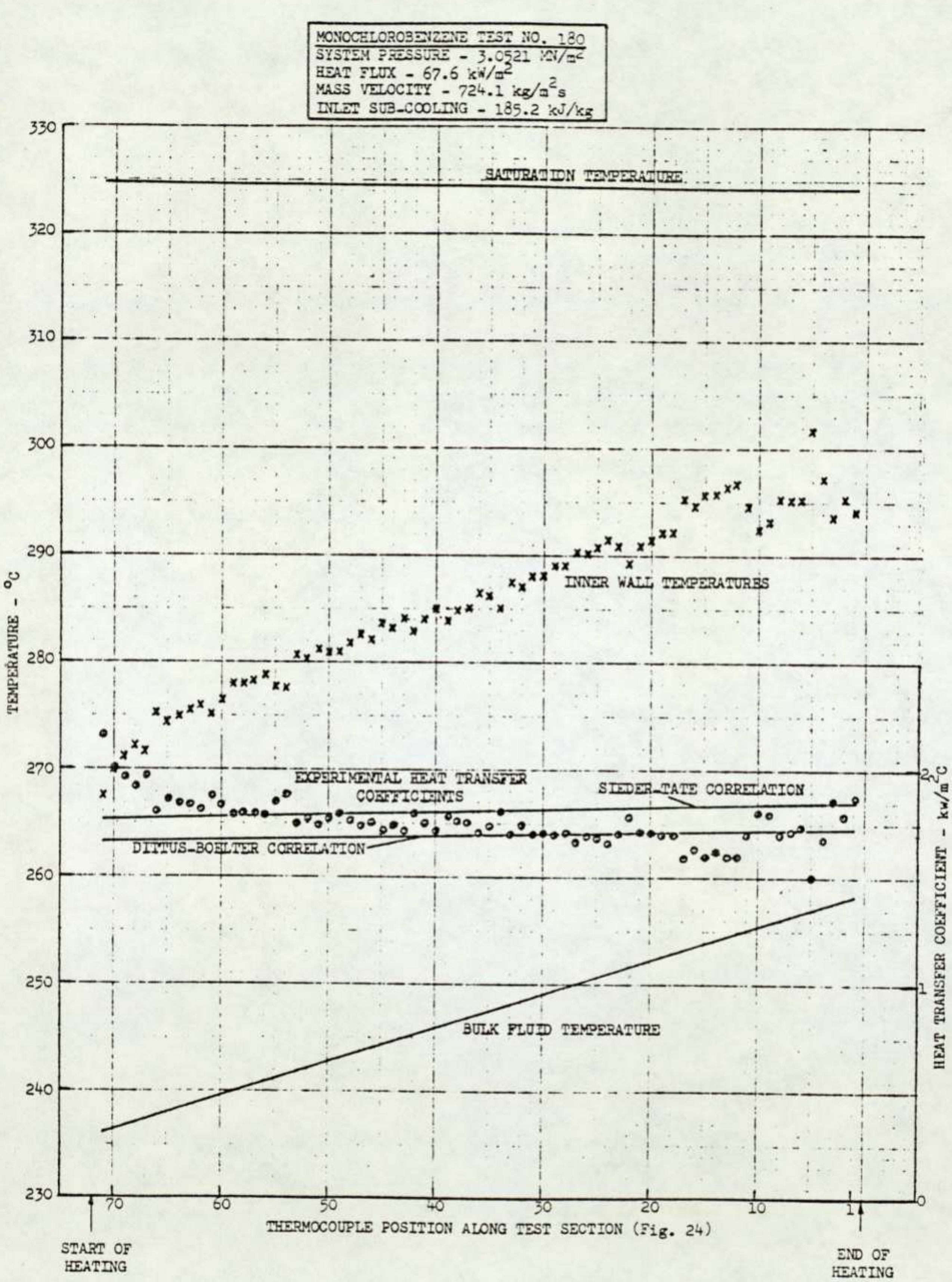


Fig. 33 Fluid and wall temperature profiles and local heat transfer coefficient variation for a single phase, high system pressure test with Monochlorobenzene.

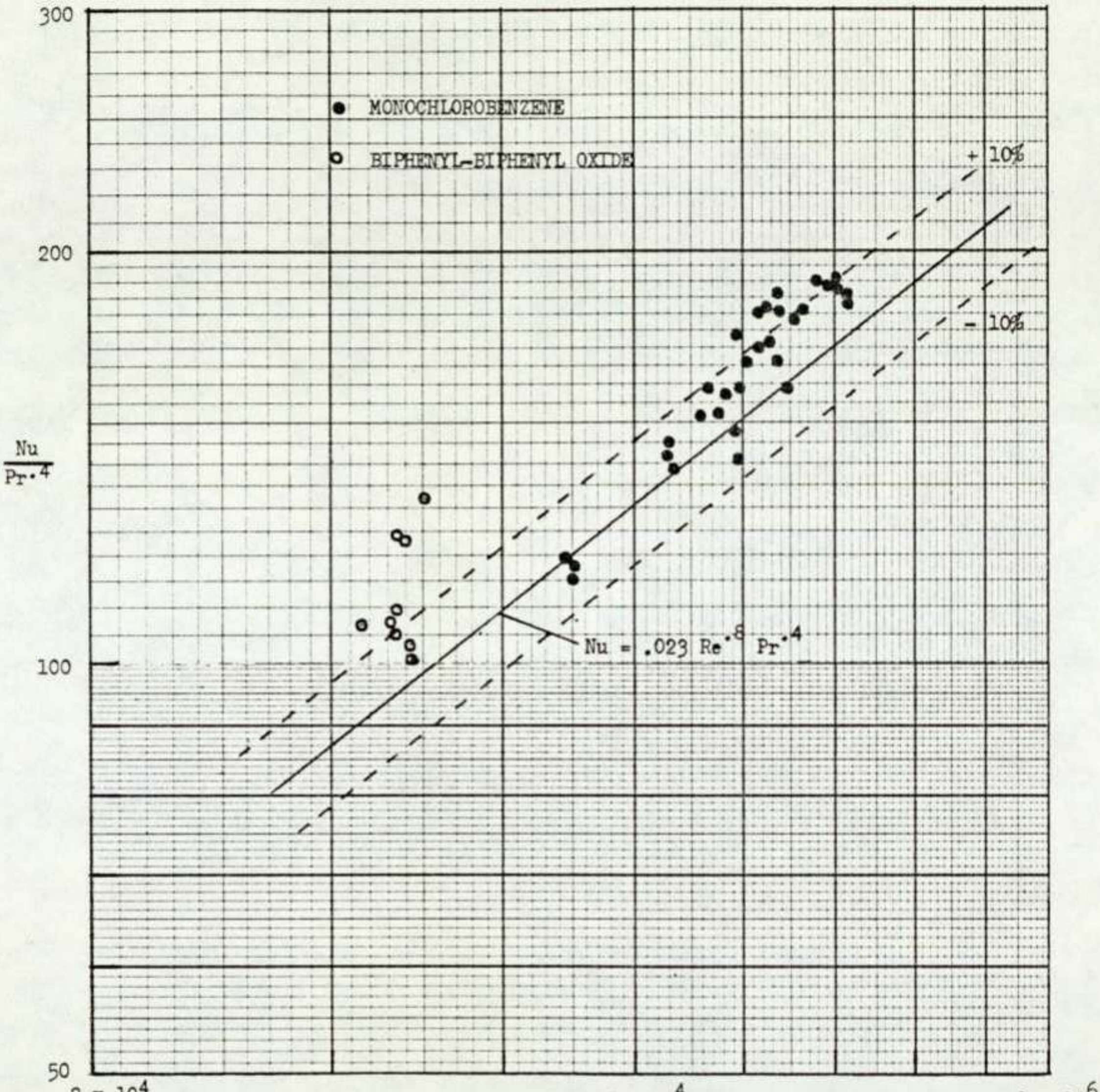


Fig. 34 Comparison of single phase heat transfer results for monochlorohenzene and biphenyl-biphenyl oxide with the Dittus-Boelter correlation.

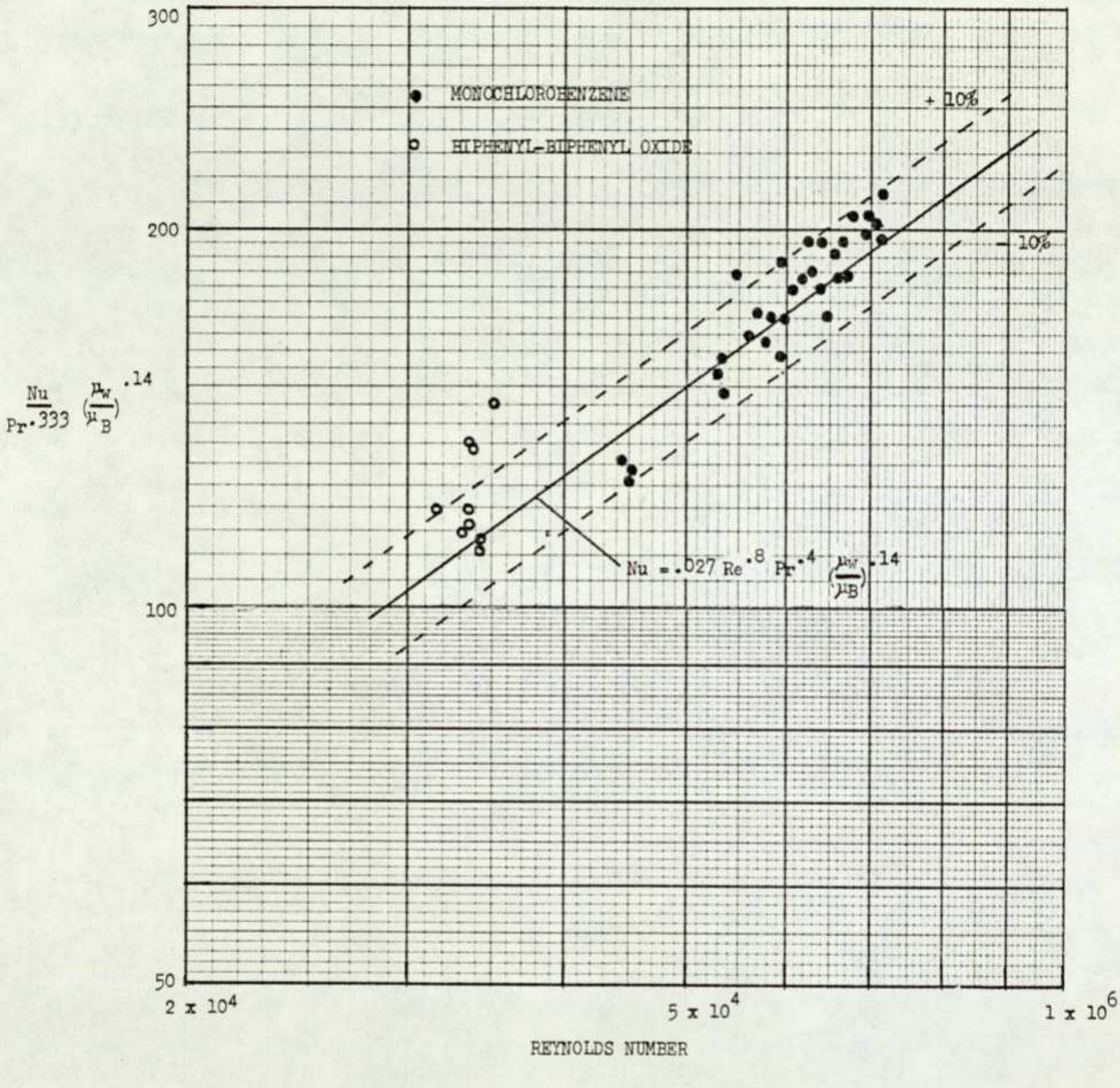


Fig. 35 Comparison of single phase heat transfer results for monochlorobenzene and biphenyl-biphenyl oxide with the Sieder-Tate correlation.

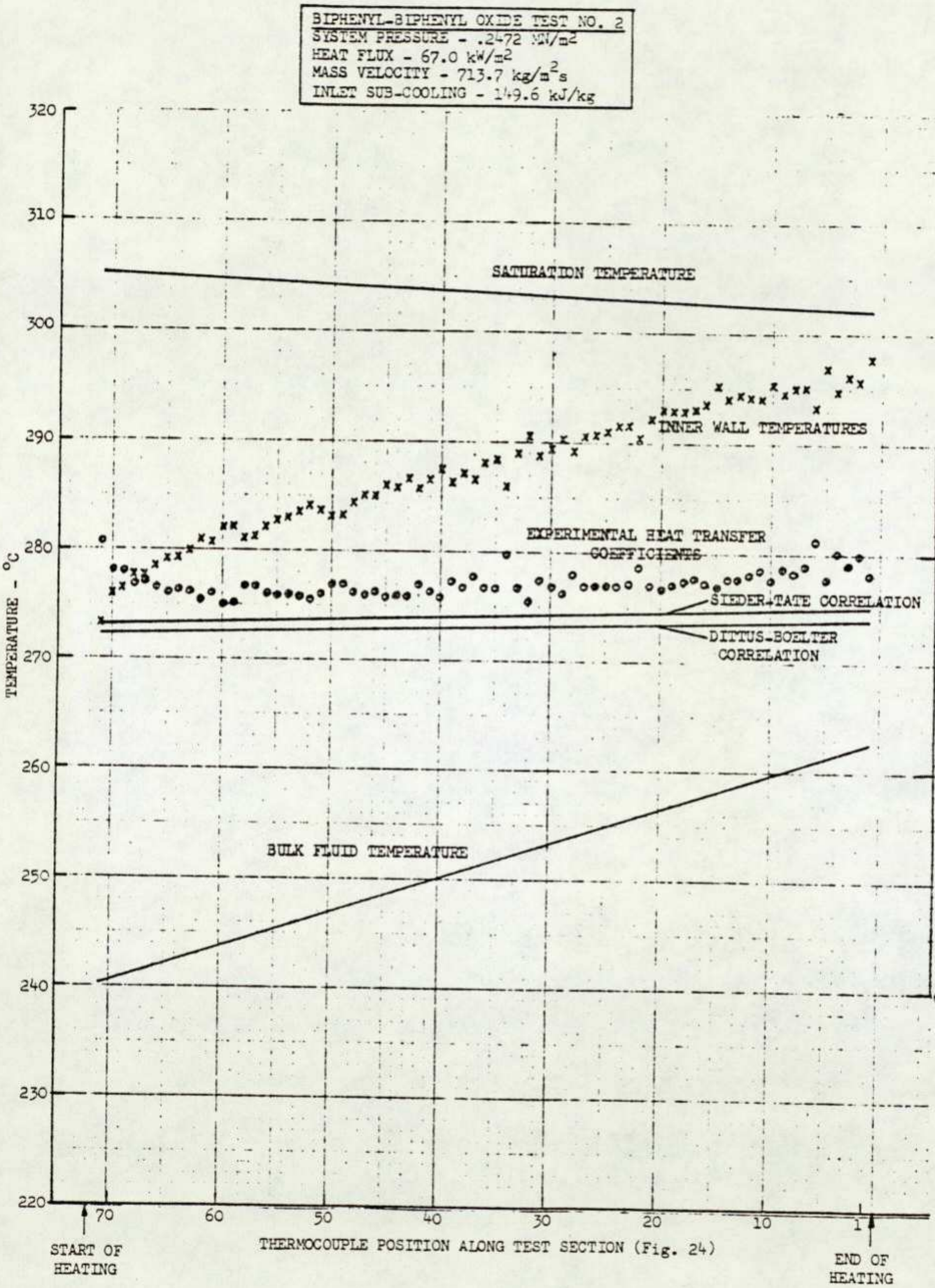


Fig. 36 Fluid and wall temperature profiles and local heat transfer coefficient variation for a single phase test with Biphenyl-Biphenyl oxide.

position No.60 at the lower end of the test section and the position at which the saturation minus inner wall temperature difference became negative. The number of data points considered in arriving at a mean heat transfer coefficient for a particular run was thus 47 in the majority of tests to between 20 and 45 in cases where the inner wall temperature exceeded the saturation temperature for varying portions of the test section length downstream from thermocouple 60. As can be observed from Figs. 34 and 35 the majority of the experimental points are within ± 10% of the values predicted by either the Sieder-Tate or Dittus-Boelter correlations. The heat transfer coefficients as calculated by the ESDU correlation were identical with the Dittus-Boelter values over the range of conditions investigated and have thus not been presented here.

Similar single phase heat transfer results obtained from 9 test runs with biphenyl-biphenyl oxide are also shown in Figs. 34 and 35 . An example of an inner wall temperature profile with this fluid is given in Fig. 36 together with the derived and predicted values of the local heat transfer coefficients as given by the Dittus-Boelter and Sieder-Tate correlations.

6.4 Comparison of Sub-Cooled Boiling Heat Transfer Correlations with Experimental Results.

Typical inner wall and fluid temperature profiles occurring under sub-cooled boiling conditions are shown in Figs. 37 and 38 for monochlorobenzene at reduced system pressures of .12 and .67 respectively. Also shown in Figs. 37 and 38 are the experimental heat transfer coefficients together with those predicted by the Moles and Shaw[27] and Papell[28] correlations. A total of 150 experimental results with monochlorobenzene were used in deriving the comparisons shown in Figs. 39 and 40 between the heat transfer coefficients predicted by the two correlations considered and the experimental values. As in the single phase

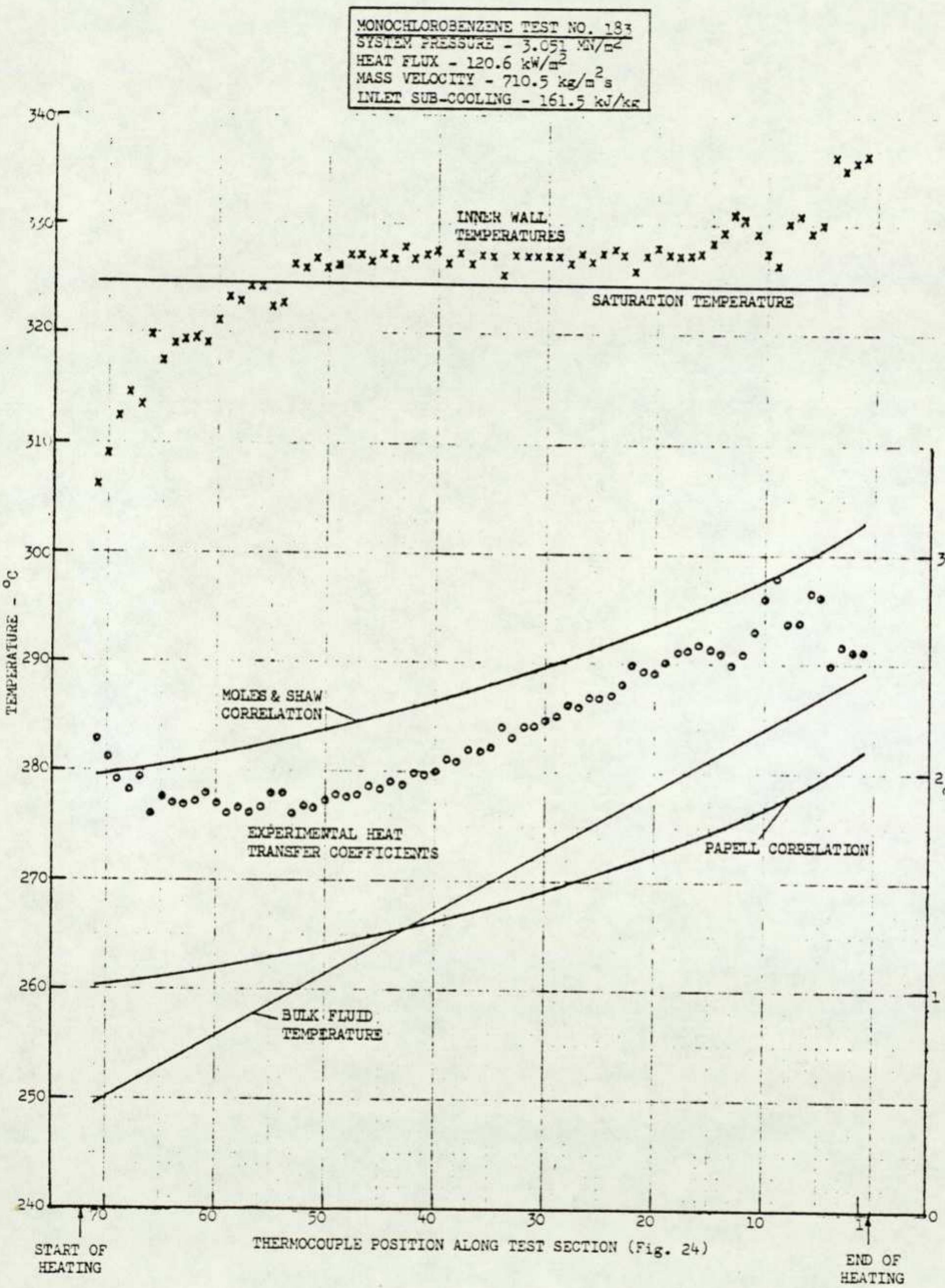


Fig. 38 Fluid and wall temperature profiles and local heat transfer coefficient variations for a sub-cooled boiling, high system pressure test with Monochlorobenzene.

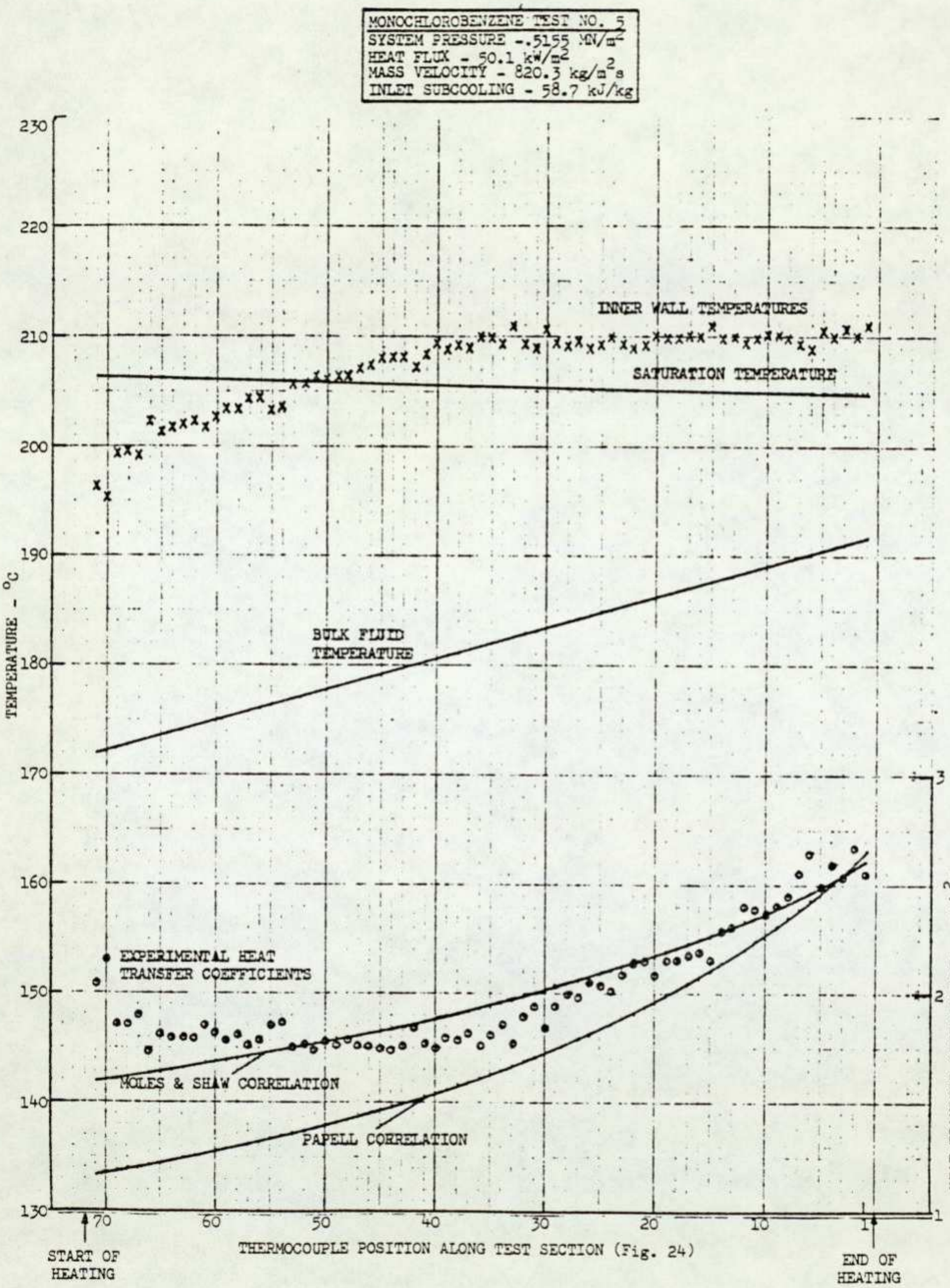


Fig. 37 Fluid and wall temperature profiles and local heat transfer coefficient variations for a sub-cooled boiling, low system pressure test with Monochlorobenzene.

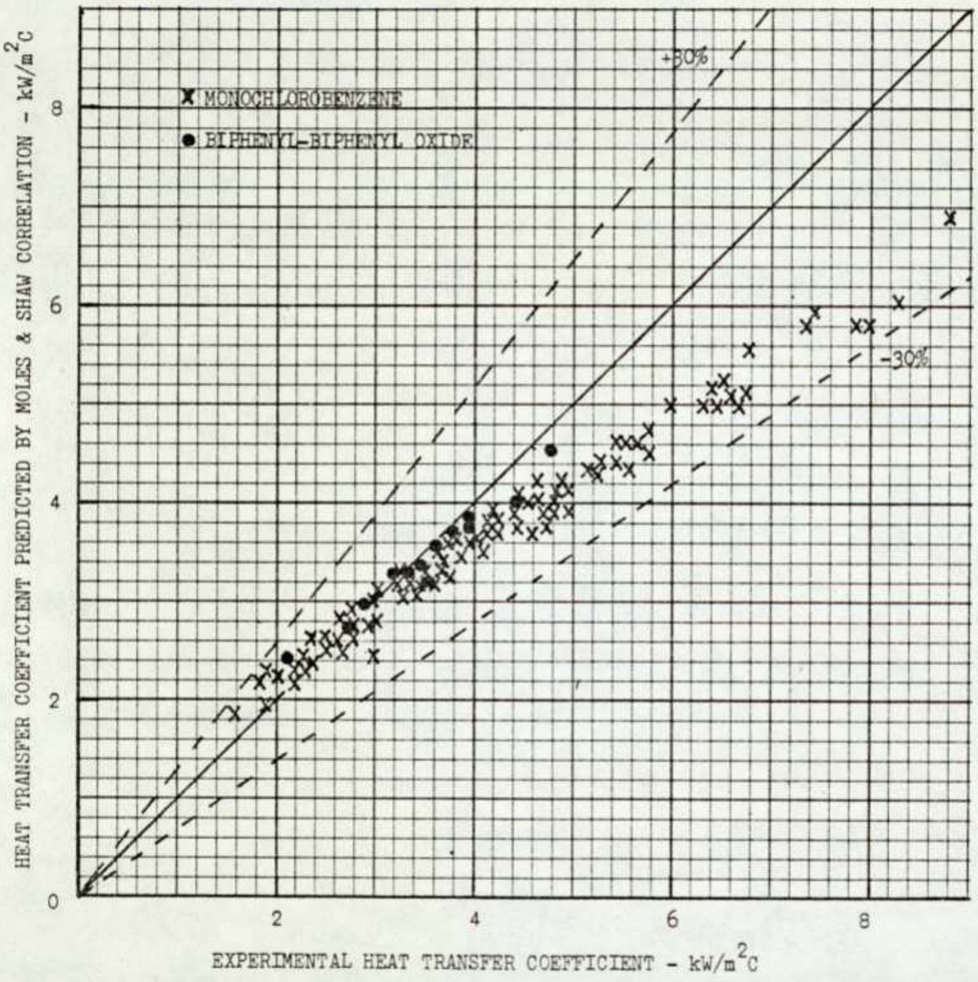


Fig. 39 Comparison between calculated and experimental values of heat transfer coefficients for Moles and Shaw correlation.

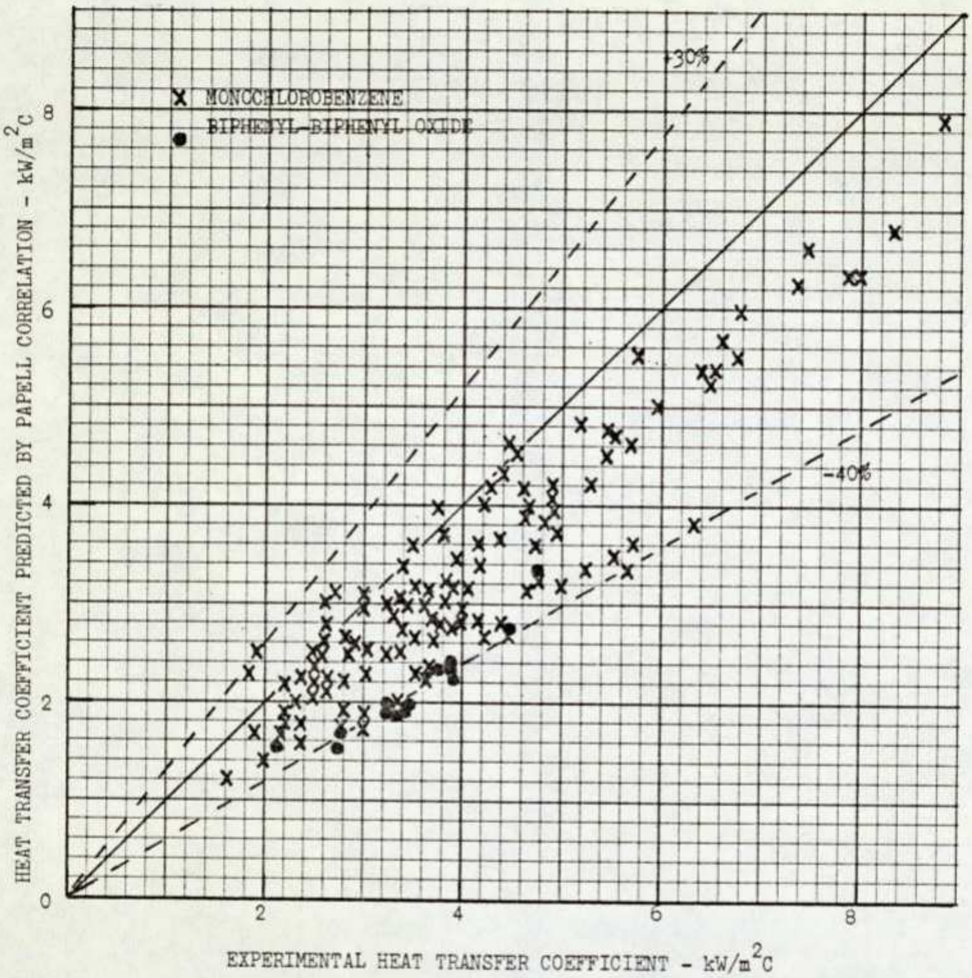


Fig. 40 Comparison between calculated and experimental values of heat transfer coefficients for Papell correlation.

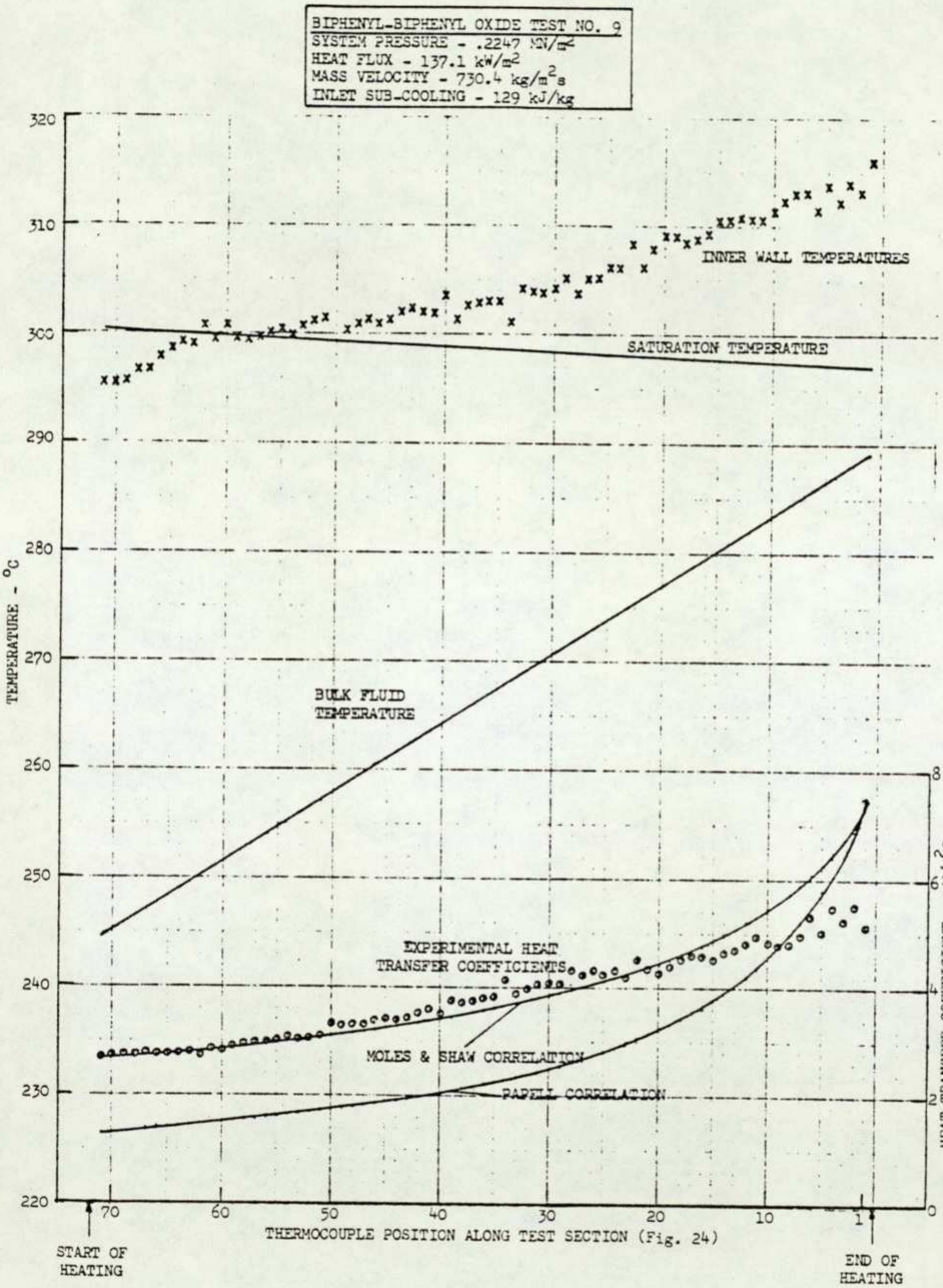


Fig. 41 Fluid and wall temperature profiles and local heat transfer coefficient variation for a sub-cooled boiling test with Biphenyl-Biphenyl oxide.

correlation comparisons the average heat transfer coefficient for a particular run was similarly restricted to those measured between thermocouple position numbers 14-60 excluding points upstream of thermocouple No. 14 in tests where the value of ΔT_{sub} was less than 10 C, the limit of the Moles & Shaw and Papell correlations applicability. Fig. 39 indicates that the Moles & Shaw correlation fits the experimental data to within about $\pm$ 25%. With the Papell correlation the difference between predicted and experimental values of heat transfer coefficient is + 30 and - 40%.

Sub-cooled boiling data from 15 tests with biphenyl-biphenyl oxide are included with the monochlorobenzene comparative results in Figs. 39 and 40 . A sub-cooled boiling wall temperature profile for one of these runs is presented in Fig. 41 .

6.5 Comparison of Net Boiling Heat Transfer Correlations with Experimental Results.

The data used for the comparison of the experimental values of the boiling heat transfer coefficients with the correlation predictions were obtained from 105 test runs in which net boiling occurred over a significant portion of the test section. The results from two of these tests, representing the extremes of system pressure used in the monochlorobenzene investigations are shown in Figs. 42 and 43 . The derived values of the heat transfer coefficients and the correlation predictions are plotted versus the test section boiling length and equilibrium quality in Figs. 42 and 43 . The boiling length was defined as that portion of the heated length from the thermocouple position where the equilibrium quality exceeded zero to the end or to the dry-out point in runs where this latter condition occurred. The average values of the experimental and predicted heat transfer coefficients for the boiling length up to and including thermocouple no. 14 were determined for each of the two-phase tests and are compared in Figs. 44 - 48 for the five literature correlations discussed.

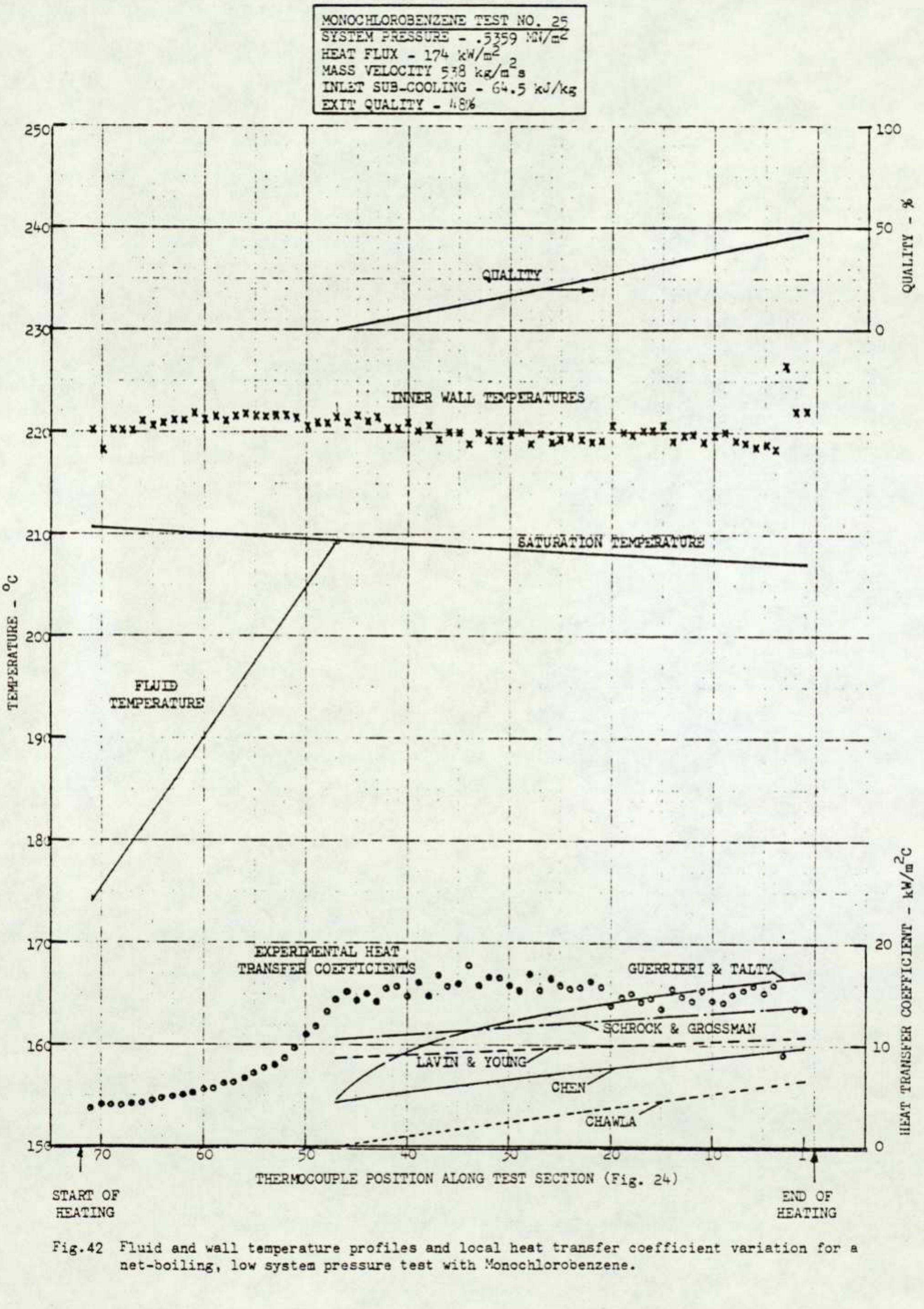


Fig.42 Fluid and wall temperature profiles and local heat transfer coefficient variation for a net-boiling, low system pressure test with Monochlorobenzene.

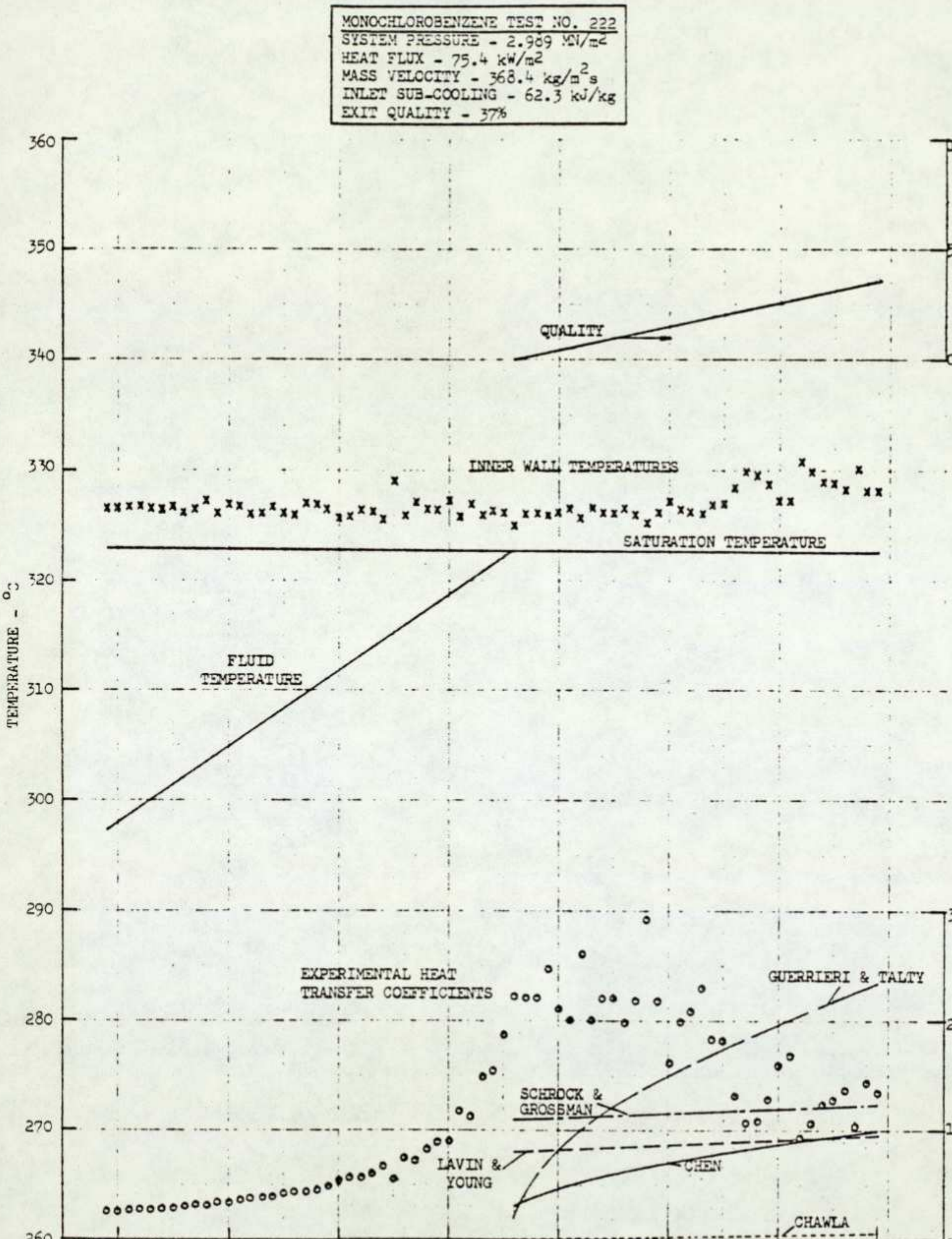


Fig. 43 Fluid and wall temperature profiles and local heat transfer coefficient variation for a net-boiling, high system pressure test with Monochlorobenzene.

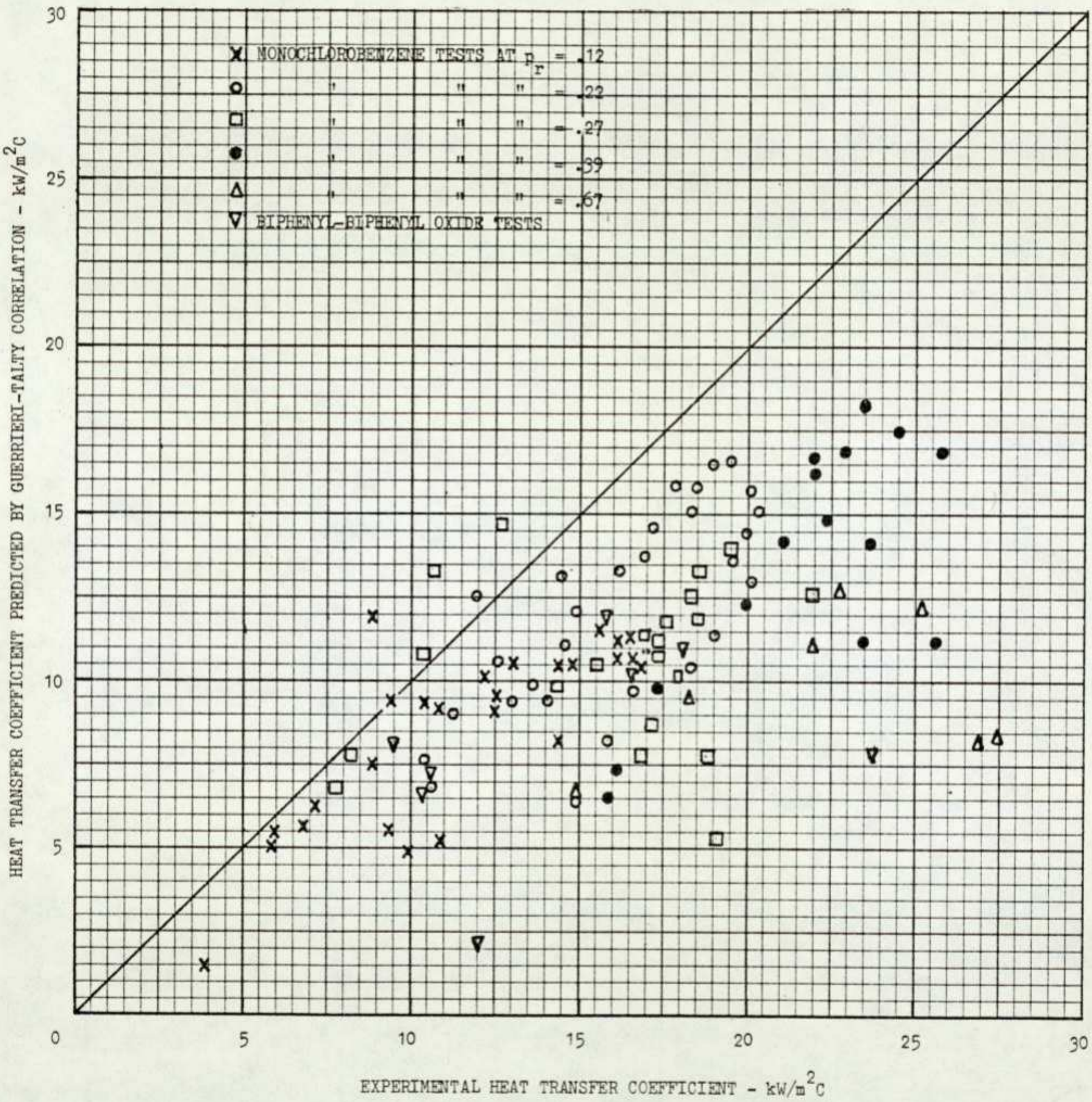


FIG. 44 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENTS WITH THOSE PREDICTED BY THE GUERRIERI-TALTY CORRELATION.

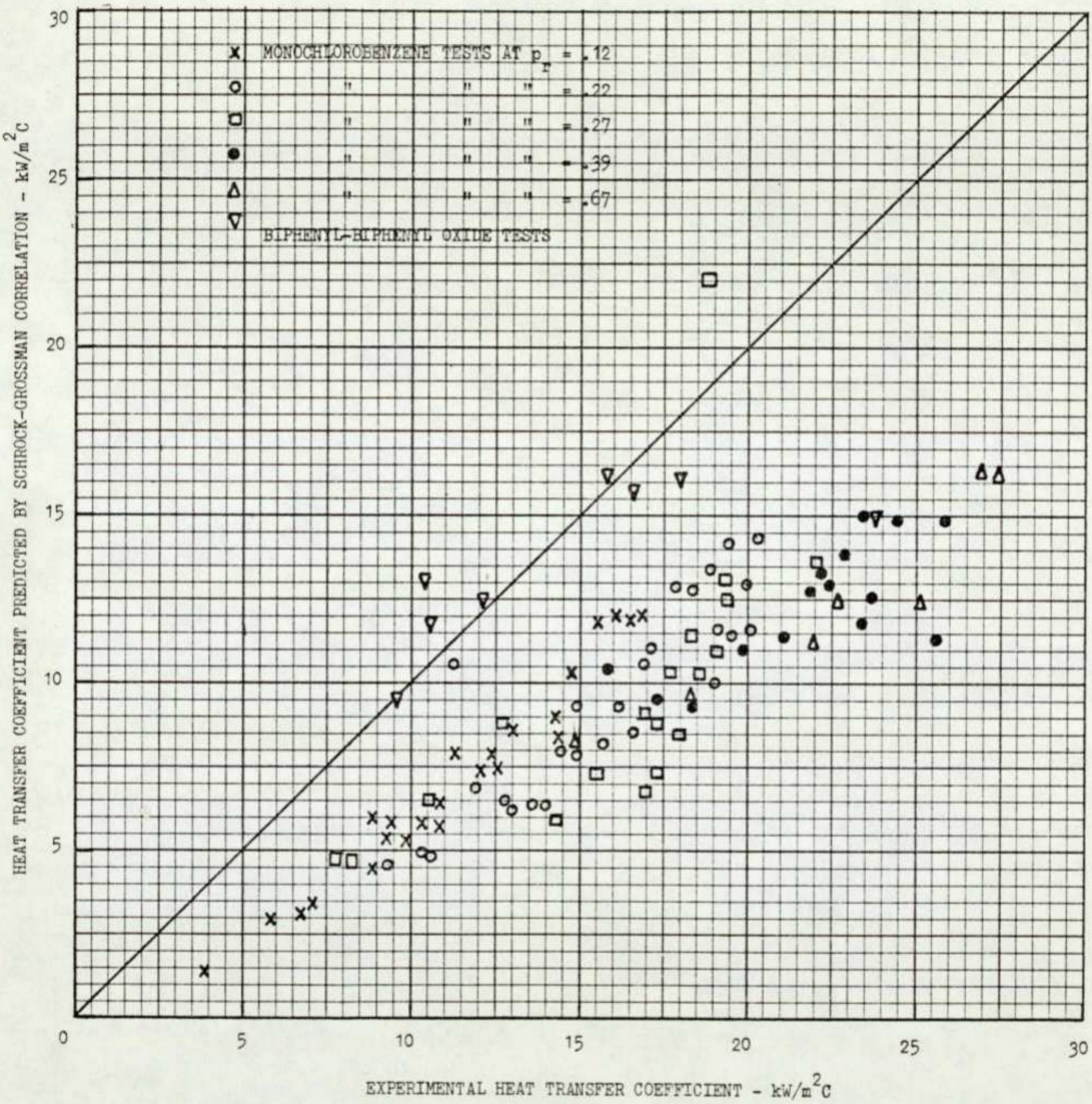


FIG. 45 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENTS WITH THOSE PREDICTED BY THE SCHROCK-GROSSMAN CORRELATION.

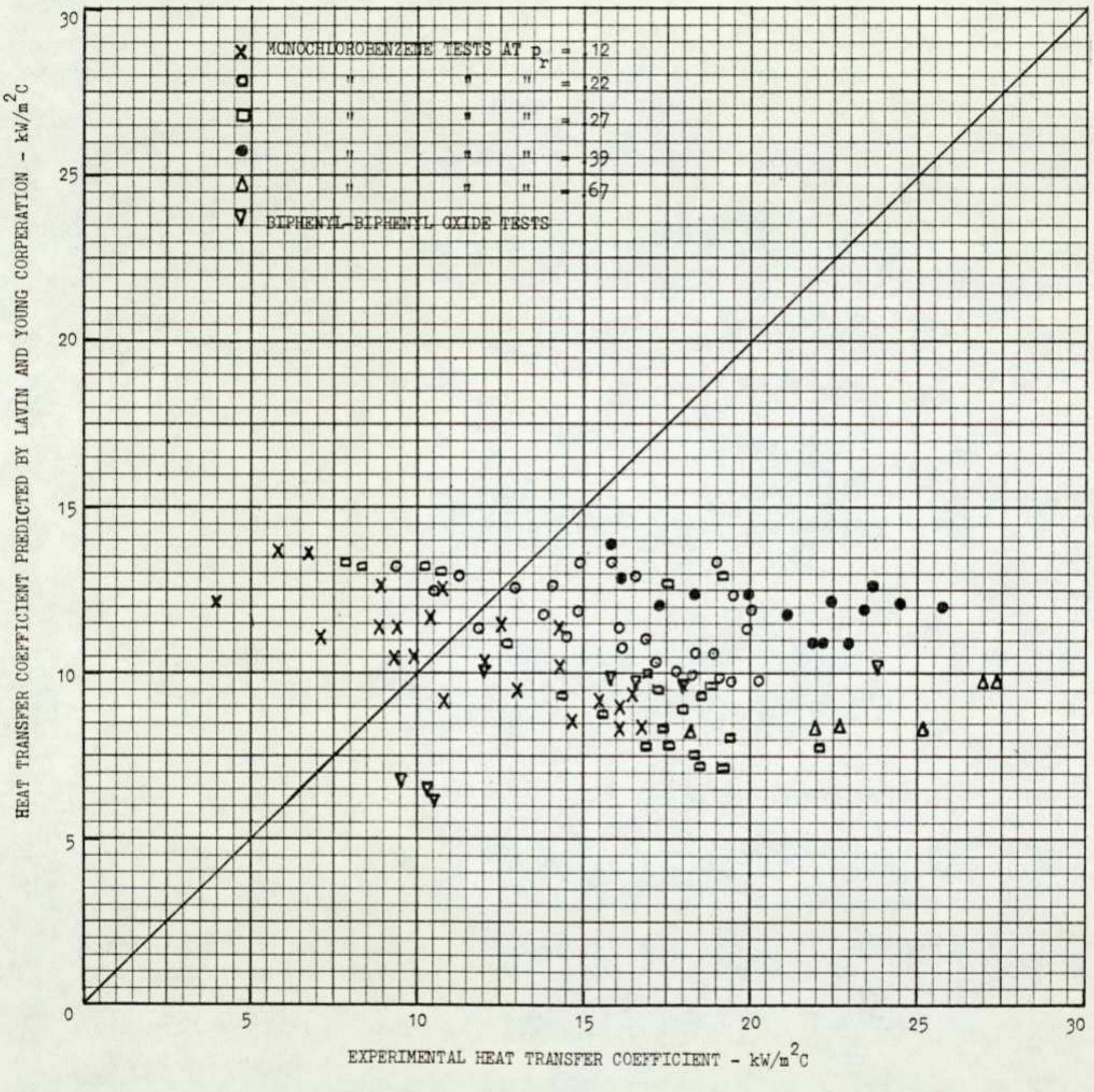


FIG.46 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENTS WITH THOSE PREDICTED BY THE LAVIN AND YOUNG CORRELATION

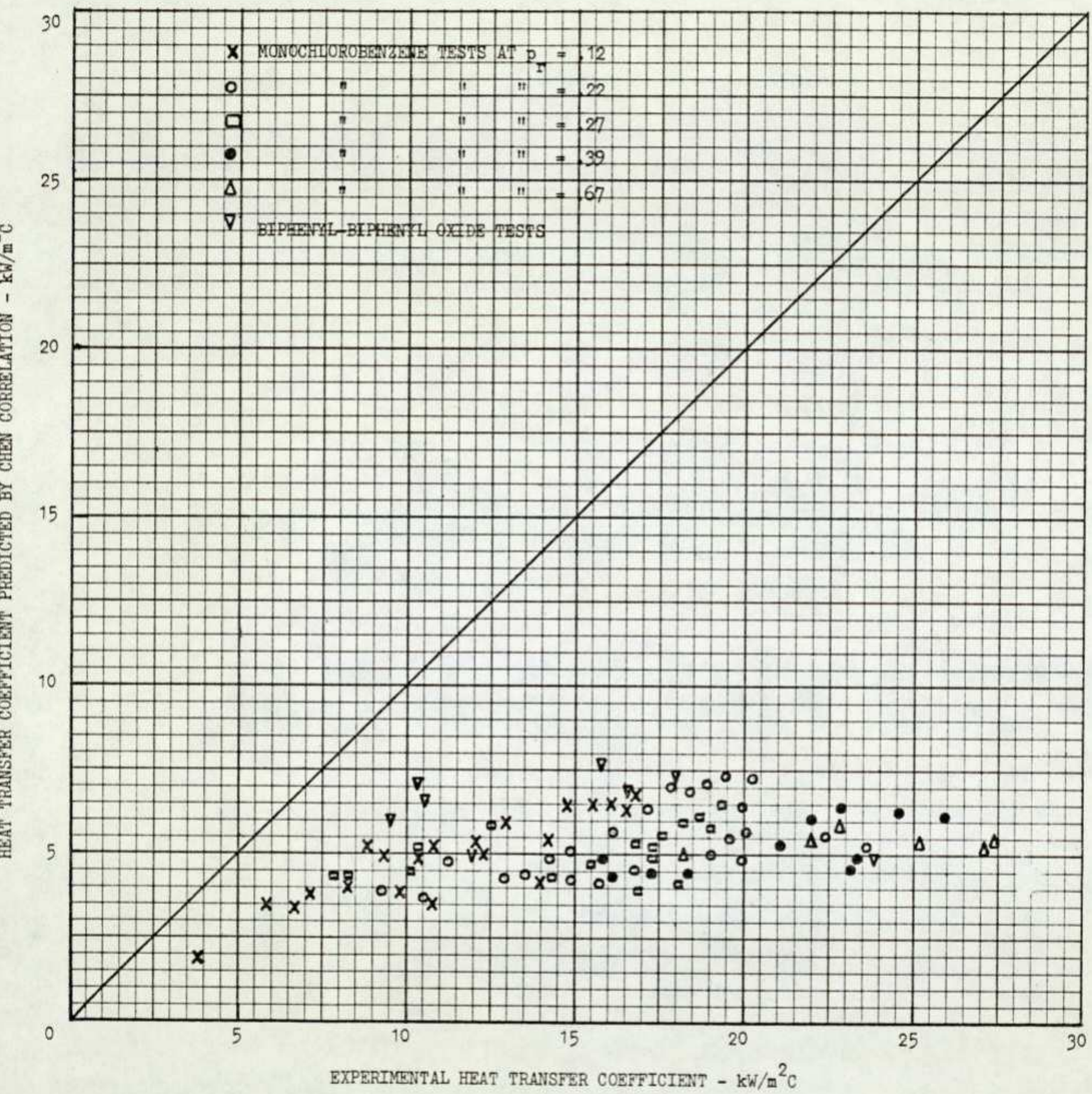


FIG. 47 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENTS WITH THOSE PREDICTED BY THE CHEN CORRELATION.

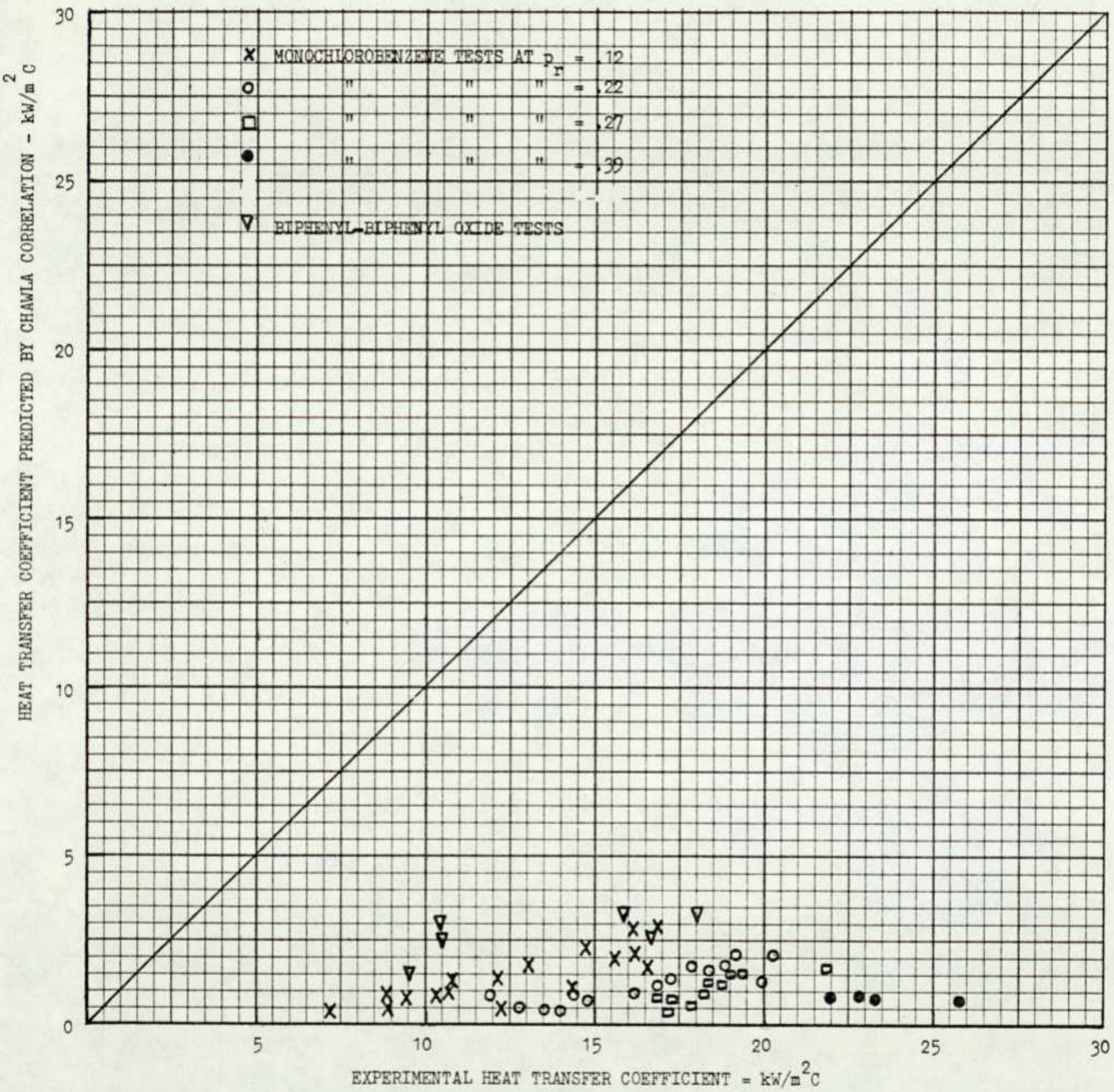


FIG. 48 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENTS WITH THOSE PREDICTED BY THE CHAWLA CORRELATION.

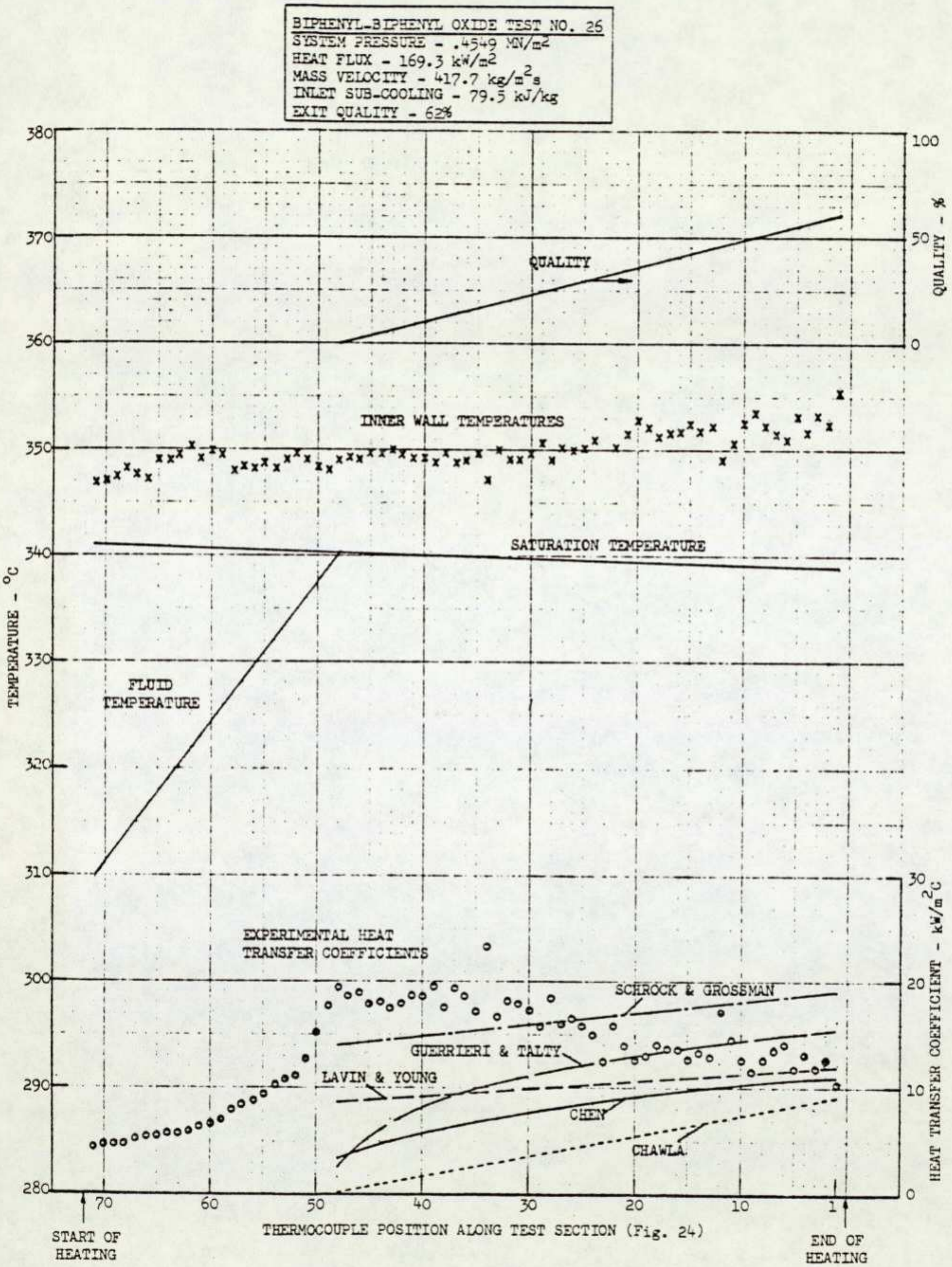


Fig. 49 Fluid and wall temperature profiles and local heat transfer coefficient variation for a net-boiling test with Biphenyl-Biphenyl oxide.

Of the 38 biphenyl-biphenyl oxide tests there were only 8 in which bulk boiling occurred over a significant portion of the test section. Inner wall, fluid and saturation temperature profiles and the quality variation for one of these tests are shown in Fig. 49 together with a comparison between the values of the local experimental and predicted heat transfer coefficients. The average values of the experimental and calculated heat transfer coefficients for the boiling length are included with the monochlorobenzene comparisons in Figs. 44 to 48 .

6.6 Correlation of net boiling experimental results employing linear multiple regression analysis.

As indicated in Figs. 44 to 48 there is poor agreement between the experimental and predicted values of the heat transfer coefficients for the range of variables covered in the investigation. One of the objectives of the research programme was to produce a design correlation if existing ones proved to be inadequate. Accordingly the experimental data were analysed using multiple linear regression analysis to develop a suitable correlation.

The experiments undertaken during the investigation involved several independent variables i.e. heat flux, mass velocity, system pressure etc. which could have influenced the heat transfer process as described by the heat transfer coefficient, the dependent variable. It thus becomes necessary to isolate the effect of one independent variable from the effects of the others to determine the contribution of each variable to the total effect. This was carried out using linear multiple regression analysis which is a standard statistical technique for establishing a linear functional relationship between one dependent and two or more independent variables[55].

Initially the correlation of the experimental data was carried out using a dimensionless group, non-linear equation employing four parameters commonly used in forced convection boiling heat transfer work to describe the dependent variable. These dimensionless groups were the Reynolds, Prandtl and Boiling numbers and the Martinelli parameter with the dependent variable being expressed in the first instance as the ratio of the heat transfer coefficient with boiling to the single phase heat transfer coefficient (h/h_L), i.e.

$$h/h_L = A(Re)^{b1} (Pr)^{b2} (X_{tt})^{b3} (Bo)^{b4} \qquad \text{(Eq. 6.1)}$$

by a logarithmic transformation Eq. 6.1 becomes:-

$$\log(h/h_L) = \log A + b1\log Re + b2\log Pr + b3\log X_{tt} + b4\log Bo \qquad \text{(Eq. 6.2)}$$

or in the general form of the linear function with multiple variables:-

$$y = a + b1x1 + b2x2 + b3x3 + b4x4 \qquad \text{(Eq. 6.3)}$$

where: y = dependent variable which varies partially due to variation in x1, x2, x3 or x4.

x1, x2, x3, x4 = independent variables.

a, b1, b2, b3, b4 = multiple regression parameters.

Eq. 6.3 is termed the linear multiple regression equation of y on x1, x2, x3 and x4.

The sum of squares E of the deviation of the data points from the most probable correlating line is:-

$$E = \sum_{i=1}^{N} (y - a - b1x1_i - b2x2_i - b3x3_i - b4x4_i)^2 \qquad \text{(Eq. 6.4)}$$

where: N is the number of sets of data points.

The optimum values of the parameters a, b1, b2, b3, b4 are those which minimise the sum of squares E. These are obtained by partially differentiating Eq. 6.4 with respect to a, b1, b2, b3 and b4, and setting the results equal to zero to produce after simplification a set of five simultaneous equations:-

$$Na + b1\Sigma x1 + b2\Sigma x2 + b3\Sigma x3 + b4\Sigma x4 = \Sigma y$$

$$a\Sigma x1 + b1\Sigma x1^2 + b2\Sigma x1x2 + b3\Sigma x1x3 + b4\Sigma x1x4 = \Sigma x1y$$

$$a\Sigma x2 + b1\Sigma x2x1 + b2\Sigma x2^2 + b3\Sigma x2x3 + b4\Sigma x2x4 = \Sigma x2y$$

$$a\Sigma x3 + b1\Sigma x3x1 + b2\Sigma x3x2 + b3\Sigma x3^2 + b4\Sigma x3x4 = \Sigma x3y$$

$$a\Sigma x4 + b1\Sigma x4x1 + b2\Sigma x4x2 + b3\Sigma x4x3 + b4\Sigma x4^2 = \Sigma x4y$$

where the summation is over N, the number of data sets.

By simultaneously solving the foregoing equations the regression coefficients b1, b2, b3, b4 and the intercept a can be determined. This latter exercise was carried out employing the proprietry computer program MULIRE(56).

The results of the regression analysis employing the four dimensionless groups as independent variables indicated that two of them, the Reynolds number and the Martinelli parameter could well be omitted since their contribution to the correlation was small. The most significant correlating group was the Boiling number and in the final two parameter dimensional equation chosen to fit the experimental data it was replaced by the applied heat flux along with the substitution of the liquid-vapour density ratio for the Prandtl number. For this final correlation the dependent variable employed was solely the boiling heat transfer coefficient. The regression coefficients calculated for a 95% confidence level by the computer program for the correlation were a = .5783, b = .7134, and c = -.3792 using the data in Table 25 (Appendix 8).

The final equation in the logarithmic form was:-

$$\log h = .5783 + .7134 \log_e \emptyset - .3792 \log_e (\rho_L/\rho_G)$$

and in the exponential form:-

$$h = 1.783\, \emptyset^{.713} (\rho_L/\rho_G)^{-.379} \qquad \text{(Eq. 6.5)}$$

where: h = average value of the heat transfer coefficient over the boiling length, kW/m^2 C.

$\emptyset$ = heat flux, kW/m^2

ρ_L/ρ_G = ratio of the liquid and vapour densities at the particular system pressure.

The foregoing two variable correlation accounted for 92.1% of the total squared deviation of the dependent variable, i.e. 92.1% of the total variation in the values of the heat transfer coefficients from the correlation line can be related to variations in heat flux and density

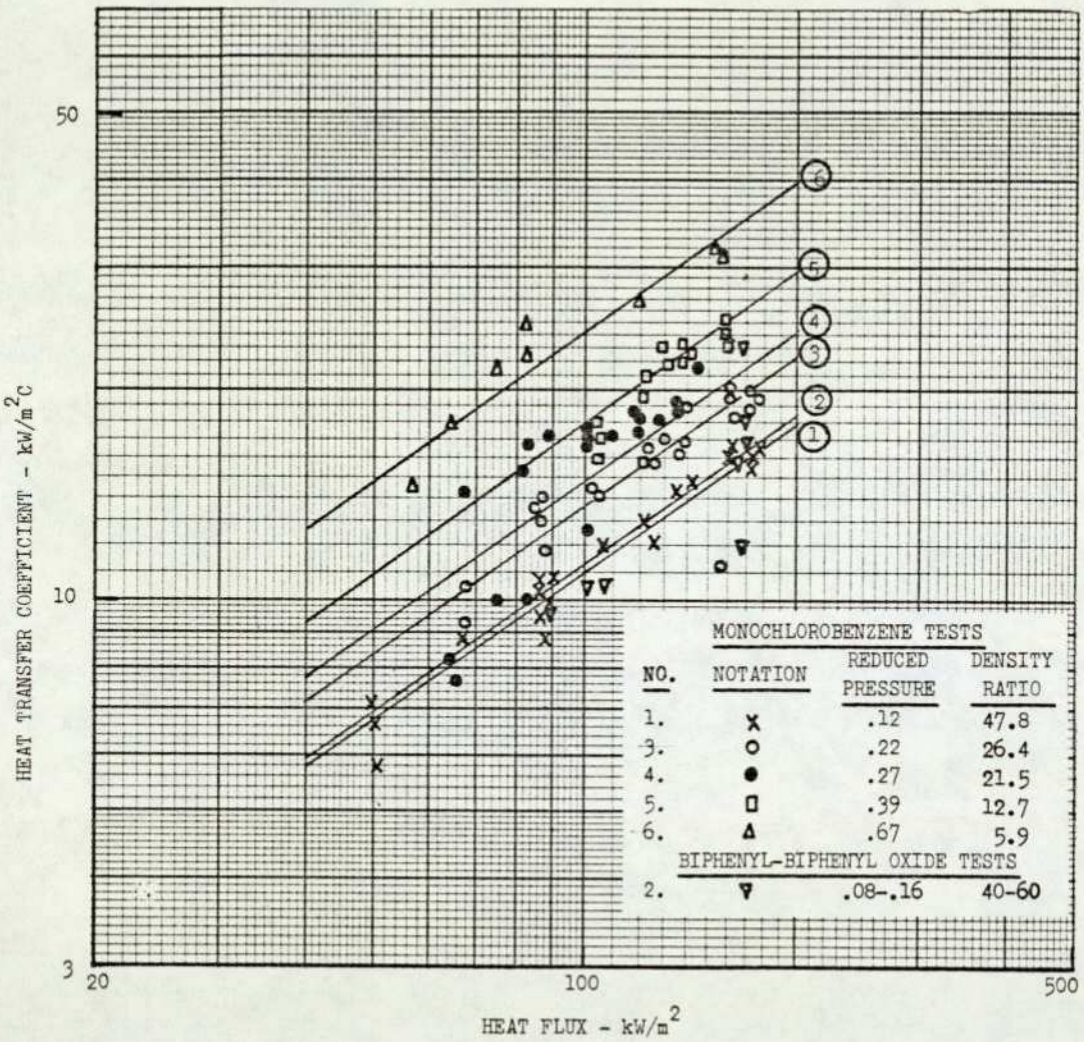


Fig. 50 Heat transfer coefficient as a function of heat flux for the monochlorobenzene and biphenyl-biphenyl oxide test series. Eq 6.5 is shown for the average value of the liquid-vapour density ratio present in each test series.

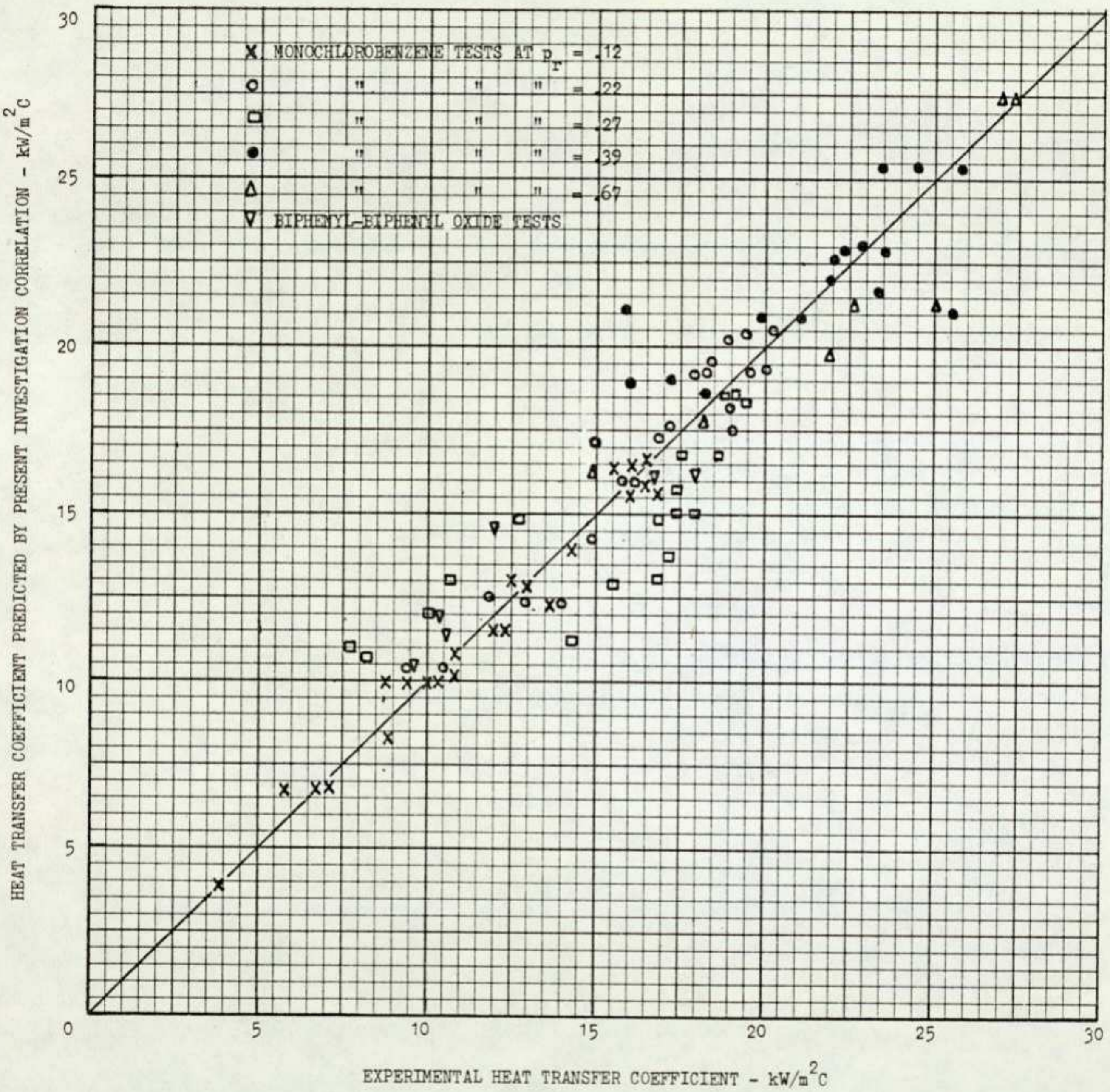


FIG. 51 COMPARISON OF NET BOILING EXPERIMENTAL HEAT TRANSFER COEFFICIENT WITH THOSE PREDICTED BY THE CORRELATION FROM THE PRESENT INVESTIGATION

ratio or system pressure. For the initial four independent variables correlation the percentage variation explained was 97.6%. Thus only about 5% in explained variation has been sacrificed in the simplification of the correlation to two independent variables.

With the inclusion of the 8 biphenyl-biphenyl oxide results in the regression exercise Eq. 6.5 becomes:-

$$h = 1.692\ \phi^{.725}\ (\rho_L/\rho_G)^{-.379} \qquad \text{(Eq. 6.6)}$$

in this case 91.3% of the data (121 cases) is correlated for a 95% confidence level.

A cumulative plot of the experimental heat transfer coefficients versus applied heat flux is shown in Fig. 50 together with correlation lines drawn for the average values of the density ratio employed in the test series. A further comparison between the heat transfer coefficients calculated using Eq. 6.5, and the measured values is presented in Fig. 51 and also in Table 25 of Appendix 8.

6.7 Correlation of dry-out heat flux data for monochlorobenzene.

Critical heat flux or dry-out conditions sometimes occurred at the conclusion of a day's loop operation. On every occasion when the test section power input was increased for the next test in a series when boiling conditions were present the uppermost wall temperature thermocouple was continuously displayed in order to detect the possible onset of dry-out as indicated by a step increase in temperature at the end of the heated section. As previously stated it was only possible to operate the loop for a short period (about 5 mins.) after the onset of dry-out due to filter blockage by carbon spalling off the dry wall region of the test section. During this period however it was possible to secure at least one set of data at nominally steady state conditions before the test section and pre-heater power were switched off and the loop shut down for filter cleaning.

Dry-out conditions were present in the monochlorobenzene tests listed in Table 6 which gives the value of the independent variables for each test along with the thermocouple no. which indicated the dry-out point by a significant rise in wall temperature. Also given in Table 6 is the equilibrium quality at the dry-out point (x_{DO}) as obtained from the heat balance equation:-

$$\phi_{DO} = (GD/4z)(\Delta h_i + \lambda x_{DO}) \qquad \text{(Eq. 6.7)}$$

As is the case with a uniformly heated tube it was found, from monitoring the wall thermocouples, that the dry-out condition occurred first at the exit end of the test section. This was also confirmed from a visual inspection of the test section after the completion of the experimental programme where there was clear evidence, from discolouration, of overheating just below the upper power clamp. Despite being carefully monitored however, the dry-out front had proceeded upstream to varying degrees as indicated in Table 6 at the instant of data recording, significantly so in the case of some of the test carried out at a reduced pressure of 0.27. Because the position of the dry-out front was invariably non-stationary during data recording it was considered that the usefulness of the data in Table 6 for developing a novel correlation was limited. A further factor considered in assessing the reliability of the data was the fact that the test section inlet temperature used to calculate the sub-cooling was not recorded (on channel no.77) until about 1 minute after the commencement of data recording when by then the dry-out position could have significantly altered, as could also have been the case with the mass velocity due to filter blockage.

The burn-out heat flux in uniformly heated tubes has been demonstrated to show a dependence upon the variables (D,G,p and x_{DO}) local to the burn-out point[63], the so called 'local conditions hypothesis' postulated by Barnett[120] which has subsequently become the basis for practical correlations for water data such as those developed by

Macbeth[63][121]. The latter concluded from an examination of the published world data on burn-out for water in uniformly heated tubes that the data could be subdivided for correlation purposes into low and high velocity regimes. The transition point between the regimes was found to vary with the system pressure and the test section length to diameter ratio. In the high velocity regime the burn-out heat flux is observed to be insensitive to mass velocity whilst almost direct proportionality is observed in the low velocity regime. Apart from the low velocity regime the effect of pressure on the burn-out heat flux is extremely complex[63]. Since the mass velocities present in the tests with dry out were relatively low and because of the limited number of tests undertaken at each pressure use was made of the following low velocity expression[121][21] as a first attempt to correlate the dry-out data. In this equation, which was evaluated using British units D and z were in inches, ϕ_{DO} in Btu/(ft^{2}hr), λ and Δh_i in Btu/lb and G in lb/(ft^{2}hr).

$$(\phi_{DO} \times 10^{-6}) = \frac{A_1 + C_1 D\,(G \times 10^{-6})\,(\Delta h_i)/4}{1 + C_1 z} \qquad \text{(Eq. 6.8)}$$

where: $A_1 = 0.00106\,\lambda\,D^{-0.63}\,(G \times 10^{-6})^{-0.17}$

$C_1 = 0.00344\,D^{-1.73}\,(G \times 10^{-6})^{-1.22}$

Table 7 lists the calculated dry-out heat flux values together with the % deviation from those determined experimentally.

6.8 Post dry-out heat transfer.

The tests chosen for post dry-out heat transfer analysis were those:-

(i) Where the wall temperature was reasonably constant for four or more thermocouples spacings from the end of the heated section upstream towards the commencement of dry-out and

(ii) Where the film temperature, $T_f = (T_w + T_{sat})/2$ was less than 350°C, this being the upper limit of the available fluid thermophysical property data for monochlorobenzene.

The results for 8 tests fulfilling the foregoing criteria are given in Table 8 where the experimental heat transfer coefficients are compared with those predicted by a Dittus-Boelter type expression (Eq. 3.1) employing both saturation and film temperatures for the calculation of the fluid properties. Additional data for these latter tests is given in Table 6 .

The inner wall temperature profiles for test numbers 245 and 246 are shown in Fig. 52 . This latter Figure shows the dry-out front propagating upstream as the power level was progressively increased. In both cases the heat transfer coefficient downstream of dry-out decreased to a value of around 1 kW/m^2C, a typical figure for all the dry-out runs in which the wall temperature profile was reasonably fully developed. The wall temperature profile for a case (test No. 244) where the onset of dry-out had moved upstream to about the mid-point of the test section is presented in Fig. 53 . This result shows a fairly rapid reduction in wall temperature after passing through a maximum value as the vapour quality increased along the channel.

6.9 Dry-out heat flux and post dry-out heat transfer data for biphenyl-biphenyl oxide.

Comparative dry-out conditions were experienced in only two of the tests with biphenyl-biphenyl oxide as listed in Table 9 . Temperature profiles etc. from one of these tests, (No. 27) are shown in Fig. 54 and comparative experimental and calculated heat transfer coefficient values in Table 10 . No values of the latter are given for the case of the film temperature properties figure since the film temperature exceeded the 350^oC limit of the thermophysical property data. A correlation of dry-out heat flux for biphenyl-biphenyl oxide was not attempted because there were too few data points.

TEST NO.	SYSTEM PRESSURE MN/m^2 p	HEAT FLUX AT DRYOUT kw/m^2 (ϕ_{DO})	MASS VELOCITY kg/m^2S (G)	ϕ/G RATIO kJ/kg	INLET SUBCOOLING kJ/kg (Δh_i)	T/C NO. AT ONSET OF DRYOUT (FIG. 24)	DISTANCE TO DRYOUT m. (z)	QUALITY AT DRYOUT (x_{DO})
26	.537	212.6	487.7	.44	64.5	13	1.50	.56
27	.536	211.5	506.8	.42	60.0	13	1.50	.54
42	.542	165.3	452.7	.37	29.1	2	1.78	.69
102	.986	174.3	500.2	.35	21.0	7	1.65	.67
103	.986	174.7	499.7	.35	20.8	8	1.63	.66
104	.986	175.1	493.3	.35	19.1	9	1.60	.67
105	.986	175.8	493.3	.36	17.9	9	1.60	.68
157	1.812	159.0	616.6	.26	57.6	6	1.68	.39
158	1.809	159.4	624.6	.26	57.3	6	1.68	.38
159	1.803	159.4	607.1	.26	54.2	6	1.68	.42
168	1.782	136.9	532.2	.26	38.5	6	1.68	.48
169	1.782	136.6	531.5	.26	39.6	4	1.73	.49
170	1.782	140.5	522.7	.27	37.3	9	1.60	.48
191	2.978	199.4	697.0	.29	149.8	6	1.68	.04
192	2.968	199.0	678.7	.29	144.6	6	1.68	.10
201	2.966	158.6	564.1	.28	126.1	4	1.73	.20
210	2.969	155.2	548.2	.28	127.4	6	1.68	.17
217	2.947	199.9	475.0	.42	109.7	2	1.78	.23
223	2.980	83.3	367.6	.23	61.6	3	1.75	.44
224	2.976	83.3	367.6	.23	60.6	3	1.75	.45
243	1.219	135.1	430.5	.31	17.4	31	1.04	.38
244	1.193	135.4	393.1	.34	11.6	36	0.92	.39
245	1.173	136.8	370.0	.37	11.9	7	1.65	.78
246	1.200	145.9	343.7	.42	18.3	13	1.50	.79
247	1.186	155.5	335.0	.46	20.8	15	1.45	.83
254	1.177	136.1	296.0	.46	18.1	9	1.60	.92

TABLE 6. SUMMARY OF DRY-OUT TESTS WITH MONOCHLOROBENZENE

TEST NO.	MASS VELOCITY lb/ft^2hr $x10^{-6}$	INLET SUBCOOLING Btu/lb	DISTANCE TO DRYOUT INCHES	LATENT HEAT Btu/lb	CALCULATED HEAT Btu/ft^2hr $x10^{-6}$	DRYOUT FLUX kw/m^2	EXP. D.O. HEAT FLUX kw/m^2	DIFF. % $\frac{\phi e-\phi c}{\phi e}$
26	.359	27.7	59	114.6	.0814	257	212.6	-20.8
27	.374	25.8	59	114.8	.0828	261	211.5	-23.4
42	.333	12.5	70	114.4	.061	192	165.3	-16.2
102	.369	9.0	65	105.6	.0627	198	174.3	-13.6
103	.368	9.0	64	105.6	.0633	200	174.7	-14.5
104	.364	8.2	63	105.6	.0636	201	175.1	-14.8
105	.364	7.7	63	105.6	.0633	200	175.8	-13.8
157	.455	24.8	66	90.5	.0712	225	159.0	-41.5
158	.460	24.6	66	90.5	.0713	225	159.4	-41.2
159	.448	23.3	66	90.7	.0698	220	159.4	-38.0
168	.392	16.6	66	91.1	.0600	189	136.9	-38.0
169	.392	17.0	68	91.1	.0594	187	136.6	-36.9
170	.238	16.0	63	91.1	.0430	136	140.5	3.2
191	.514	64.4	66	65.5	.0840	265	199.4	-32.9
192	.500	62.2	66	65.7	.0812	256	199.0	-28.6
201	.416	54.2	68	65.8	.0668	211	158.6	-33.0
210	.404	54.8	66	65.8	.0673	212	155.2	-36.6
217	.350	47.2	70	66.3	.0552	174	199.9	12.9
223	.271	26.5	69	65.5	.0375	118	83.3	-41.6
224	.271	26.1	69	65.6	.0375	118	83.3	-41.6
243	.317	7.5	41	62.1	.0747	236	135.1	-74.7
244	.290	5.0	36	101.5	.0750	237	135.4	-75.0
245	.273	5.1	65	101.8	.0469	148	136.8	- 8.2
246	.253	7.9	59	101.6	.0492	155	145.9	- 6.2
247	.247	8.9	57	101.9	.0498	157	155.5	- 1.0
254	.218	7.8	63	102.0	.0412	130	136.1	4.5

TABLE 7. COMPARATIVE DRY-OUT HEAT FLUX DATA AND PREDICTIONS FROM TESTS WITH MONOCHLOROBENZENE

TEST NO.	LENGTH OF DRY OUT ZONE m	AVERAGE QUALITY OVER DRY OUT ZONE	SAT. TEMP. C	RANGE OF $(T_w - T_{sat})$ OVER DRY OUT ZONE C	AVERAGE EXP. HTC OVER DRY OUT ZONE kw/m^2-C	CAL. HTC. OVER DRY-OUT ZONE USING SAT. TEMP. PROP kw/m^2C	CAL. HTC. OVER DRY-OUT ZONE USING FILM TEMP. PROP kw/m^2C
102	.127	.71	243	127-141	1.32	.97	1.01
103	.127	.72	243	137-147	1.23	.97	1.01
104	.152	.73	243	148-162	1.16	.98	1.02
105	.152	.74	243	149-163	1.15	.99	1.02
243	.533	.58	256	103-154	1.07	.75	.75
245	.102	.83	254	111-117	1.19	.87	.89
246	.203	.90	255	129-152	1.04	.89	.89
254	.127	.99	254	109-115	1.21	.85	.87

TABLE 8: Comparison of monochlorobenzene measured and calculated heat transfer coefficients following the onset of dry-out.

TEST NO.	SYSTEM PRESSURE MN/m^2	HEAT FLUX kw/m^2	MASS VELOCITY kg/m^2s	$\frac{\phi}{G}$ RATIO kJ/kg	INLET SUB-COOL kJ/kg.	T/C NO. AT ONSET OF DRY-OUT (FIG. 24)	QUALITY AT DRY-OUT
27	.460	169.5	416.1	.41	56.2	14	.55
34	.464	167.4	411.4	.41	51.7	15	.55

TABLE 9: Summary of dry-out tests with Biphenyl-biphenyl oxide.

TEST NO.	LENGTH OF DRY-OUT ZONE m	AVERAGE QUALITY OVER DRY OUT ZONE	SAT. TEMP. C	RANGE OF $(T_w - T_{sat})$ OVER DRY OUT ZONE. C	AVERAGE EXP.HTC. OVER DRY OUT ZONE kw/m^2C	CAL. HTC. OVER DRY OUT ZONE USING SAT. TEMP.PROP kw/m^2C	CAL. HTC. OVER DRY OUT ZONE USING SAT TEMP. PROP kw/m^2C
27	.152	.67	339.5	142-163	1.10	1.123	FLUID PROP. DATA NOT AVAIL.
34	.152	.68	340.2	142-162	1.10	1.126	

TABLE 10: Comparison of Biphenyl-biphenyl oxide measured and calculated heat transfer coefficients following the onset of dry-out.

MONOCHLOROBENZENE TEST NOS. 245 & 246		
TEST NO.	245	246
SYSTEM PRESSURE MN/m²	1.1726	1.200
HEAT FLUX kW/m^2	136.8	145.9
MASS VELOCITY - kg/m^{2}s	370	343.7
INLET SUB-COOLING - kJ/kg	11.9	18.3
EXIT QUALITY - %	85	96

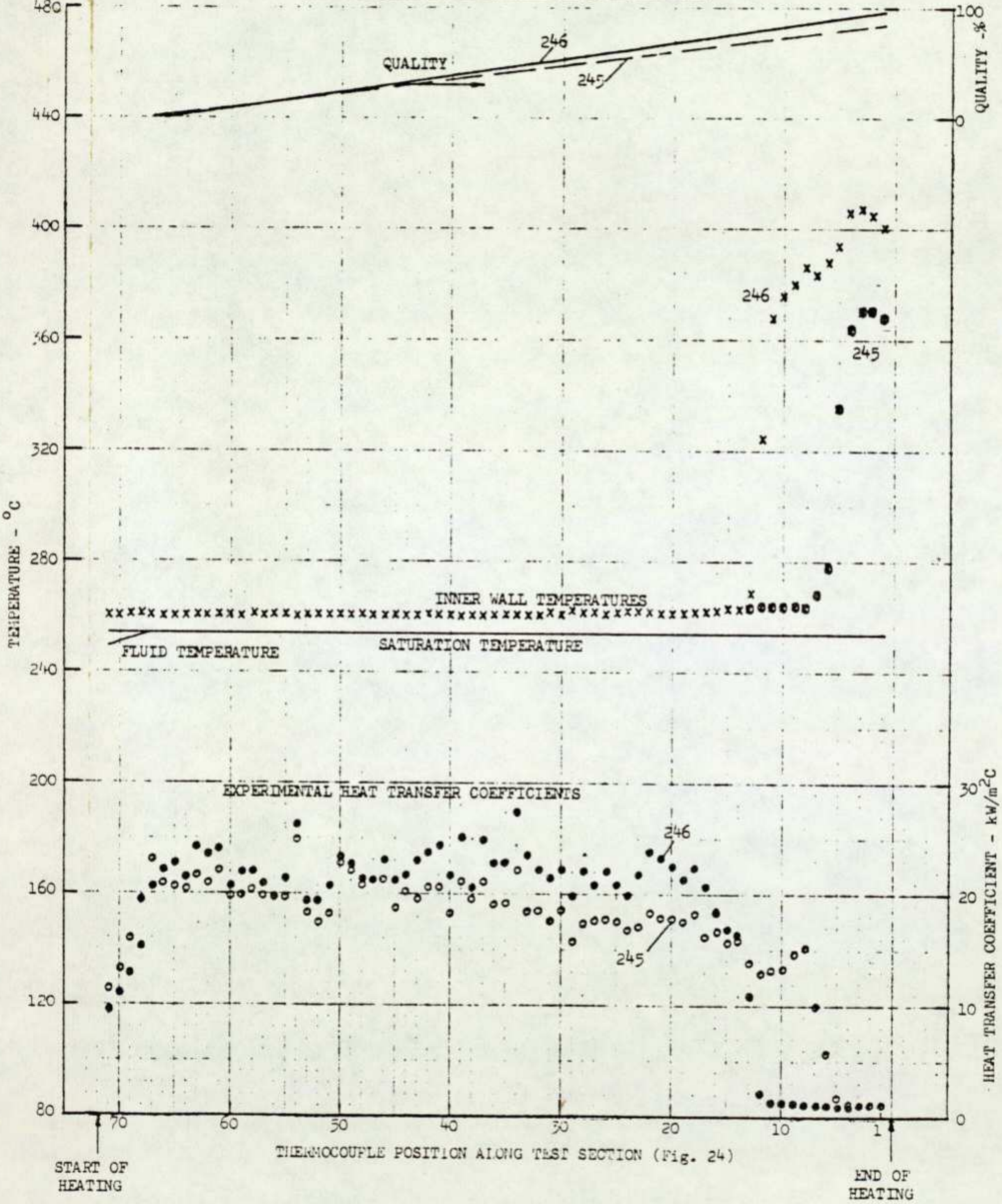


Fig. 52 Fluid and wall temperature profiles and local heat transfer coefficient variation for two consecutive wall dry-out tests with Monochlorobenzene showing the dry-out front moving upstream as the heat flux was increased.

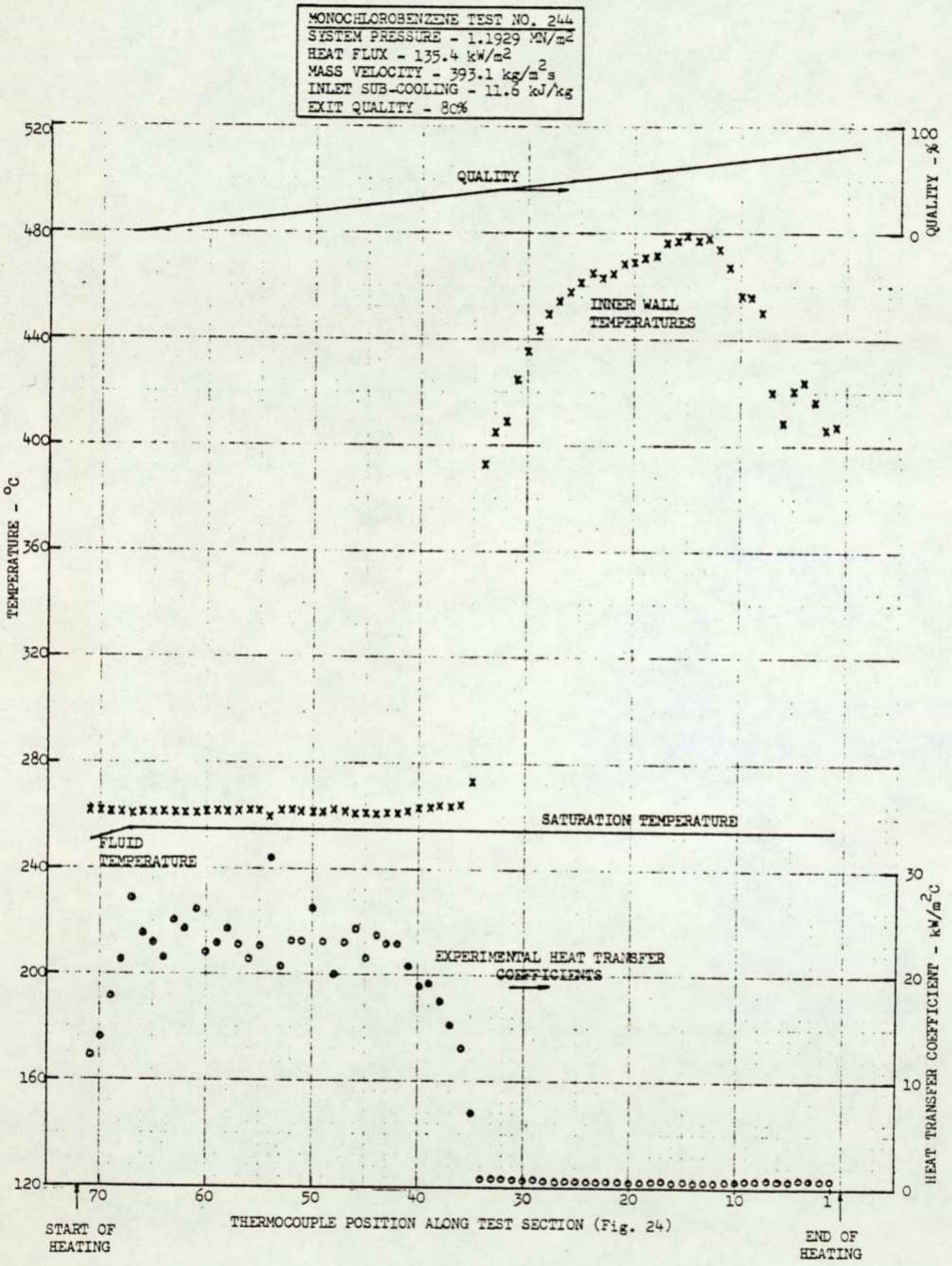


Fig.53 Fluid and wall temperature profiles and local heat transfer coefficient variation for a wall dry-out test with Monochlorobenzene.

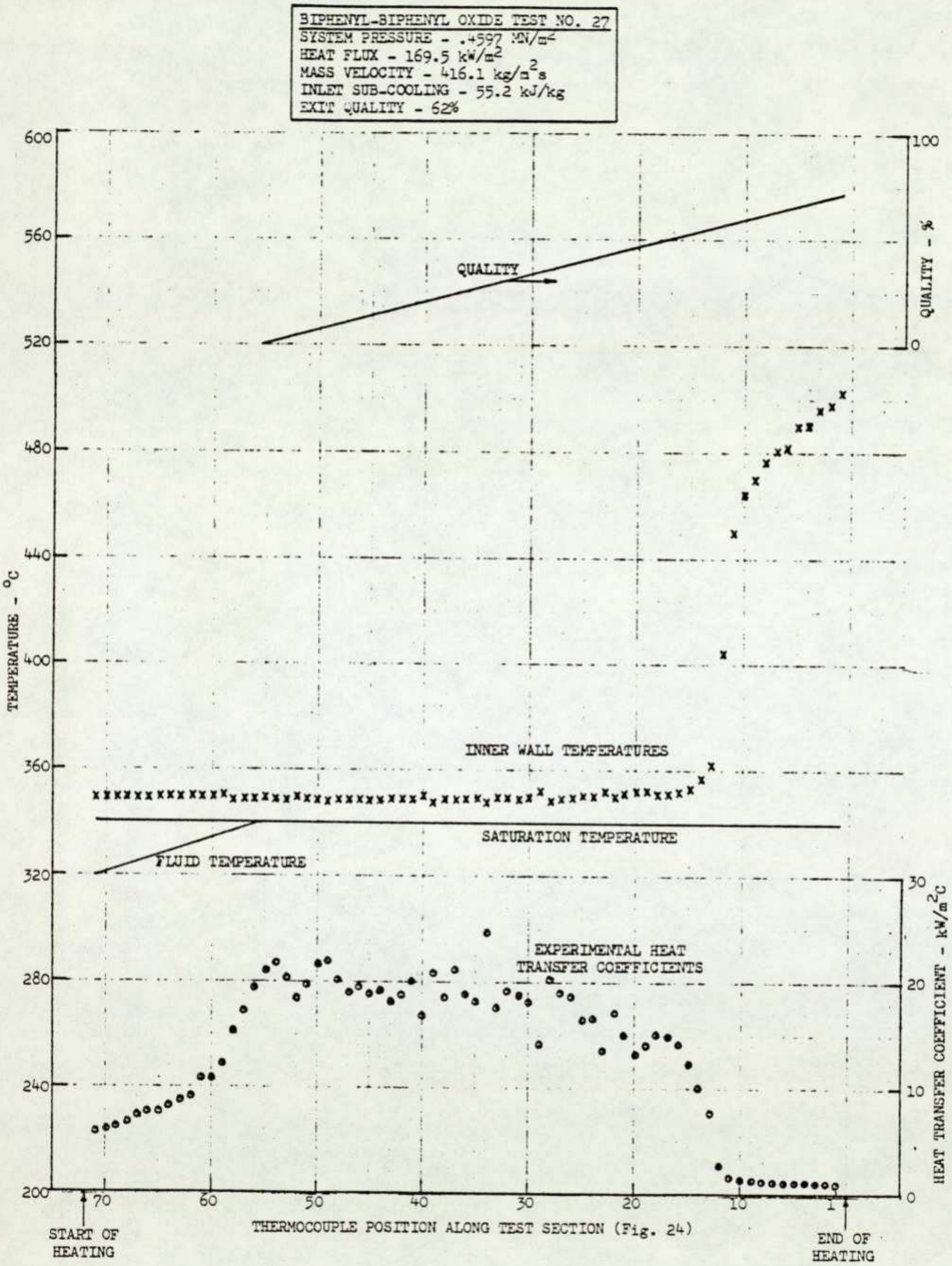


Fig. 54 Fluid and wall temperature profiles and local heat transfer coefficient variation for a wall dry-out test with Biphenyl-Biphenyl oxide.

7. DISCUSSION

7.1 Four modes of heat transfer were studied during the investigation, viz:-

(i) Single phase heat transfer with both the tube wall and bulk fluid below the local fluid saturation temperature.

(ii) Sub-cooled boiling heat transfer when the tube wall and bulk fluid temperatures were respectively above and below the local saturation temperature and there was no net generation of vapour.

(iii) Two-phase convective boiling heat transfer with net generation of vapour.

(iv) Post dry-out heat transfer.

7.2 The conventional dimensionless parameters for fully developed turbulent flow in tubes were utilised to correlate the single phase heat transfer data as summarised in Figs. 34 and 35. The data points shown represented the average heat transfer coefficients for particular tests evaluated at distances greater than 24 diameters from the commencement of heating where conditions should have been fully developed. The results for specific tests given in Figs. 32, 33 & 36 indicate that the film temperature drop was essentially constant and thus the wall temperature followed the bulk fluid temperature which was linear with distance up the tube for the case of uniform heating. It is evident from Figs. 34 and 35 that the established Dittus-Boelter and Sieder-Tate single phase heat transfer correlations adequately predict the monochlorobenzene experimental results within + 15, -10%. The viscosity correction term $(\mu_b/\mu_w)^{.14}$ in the Sieder-Tate equation reduced the spread of the data with heat flux and was the superior correlation of those used for comparison purposes in the data reduction exercise. However the difference between the predictions of all three correlations (the ESDU gave the same values as the Dittus-Boelter) was less than 5%. The results for the biphenyl-biphenyl oxide tests indicate that some points lie outside the $\pm$ 10% limits bounding the correlation lines. The most probable explanation for the outliers is that the sub-cooling was insufficient in some of these tests to prevent dissolved gases from coming out of solution and creating increased heat transfer through the additional fluid agitation present at the tube wall. Since it was not expected that the single phase heat transfer experimental results would show any marked departure from those given by the established correlations the measurements obtained in the non-boiling runs served as a simple overall check on the reliability of the experimental apparatus, and of the methods used in the reduction of the data. Since most of the single phase results lay within 10% of the accepted correlations the test facility was considered to be reliable and adequate for the boiling heat transfer measurements which was where the main interest of the experimental investigation lay.

7.3 As the bulk fluid gradually increased in temperature a point was reached where the wall temperature exceeded the local saturation temperature by a small amount and bubbles began to form at nucleation sites on the wall. Depending on the degree of sub-cooling and also on the properties of the fluid the bubbles could either move away from the wall into the cooler bulk stream and be condensed or continue to grow as they were carried downstream. The latter was most likely to have occurred in the present experiments on account of the low thermal conductivity and low heat of vaporisation of the fluids used. Such a combination would result in a slow cooling rate for the superheated liquid boundary layer associated with the detached bubble[57] as it moved relative to the surrounding sub-cooled liquid. This slow cooling would allow time for the bubble to grow by further evaporation from the bubble-superheated liquid interface, which would have been aided by the low heat of vaporisation of the bulk fluid. In the case of water, the liquid thermal conductivity and latent heat values are greater than those for either monochlorobenzene or biphenyl-biphenyl oxide by factors of about 5 and 8 respectively. In contrast therefore bubbles would generally tend to collapse immediately upon leaving the heating surface until the sub-cooling decreases sufficiently to allow the bubbles to grow in the bulk fluid when a rapid increase in void faction would occur.

7.4 The formation of bubbles and the mechanism of growth in the sub-cooled boiling regime creates increased fluid agitation which results in significantly higher heat transfer coefficients than those present under non-boiling conditions. This can be observed from the monochlorobenzene results shown in Figs. 37 and 38 for the extreme system pressures considered. The wall temperature does not increase with increasing bulk temperature as with single phase heat transfer and eventually it levels off and remains a few degrees above the fluid saturation temperature. The data for monochlorobenzene shows that the wall superheat ($T_w - T_{sat}$) in fully developed sub-cooled boiling decreases as the pressure increases in a similar way as in the case of sub-cooled flow boiling of water[58]. The biphenyl-biphenyl oxide data shown in Fig. 41 indicates a somewhat different trend to the monochlorobenzene results in that the inner wall temperature increases with distance in the sub-cooled boiling region. There was however some doubt on this unusual observation since the wall temperature measurements from thermocouple No. 13 to the end were considered to be unreliable due to the possible presence of carbon on the heating surface. A similar effect with sub-cooled boiling was however noted by Stone[58] in experiments employing water in vertical upflow where thermal entrance effects were suggested as a possible explanation for this observation.

7.5 Of the two sub-cooled boiling correlations examined for comparison purposes Fig. 40 shows that the one due to Papell[28] only provided a modest correlation of the experimental data. The correlation was however derived using data solely for water although agreement with sub-cooled boiling data for liquid ammonia was claimed. A better correlation of the experimental data was given by the Moles & Shaw[27] equation as indicated in Fig. 39. The latter correlation was derived employing a much greater range of experimental data including that for several organic fluids. Both the Papell and the Moles & Shaw correlations were very sensitive at low values of the sub-cooling and in fact predict infinite heat transfer coefficients at zero sub-cooling. Thus their use with sub-coolings below 10°C is not recommended as indicated by the asymptotic trend of the biphenyl-biphenyl oxide calculations shown in Fig. 41 .

7.6 The commencement and ending of the net boiling and sub-cooled boiling regions respectively were assumed to be at the intersection between the bulk temperature and the saturation temperature profiles. As illustrated in Fig. 7 the flow pattern in the net boiling region is shown to change from a nondescript bubbly-churn flow to one of annular flow where the liquid phase is concentrated in a film adjacent to the heated surface. On the basis of the findings of other investigators it was assumed that this transition to annular flow would occur at about 2% quality and therefore the predominant heat transfer mechanism up to dry-out was expected to be forced convection boiling. Thus the correlations employed for comparison purposes in the data reduction exercise were based primarily on annular flow models. Generally these correlations gave predictions lower than the experimental values of the heat transfer coefficients. As indicated in Figs. 44 - 48 a rather widespread variation exists in the heat transfer coefficients calculated using the referenced correlations. All of the predictions however show the same trend, that of increasing heat transfer coefficient with increasing quality. In contrast, the experimental values of heat transfer coefficient were essentially constant along the boiling length. The

Guerrieri-Talty, Schrock-Grossman and Chen correlations all incorporate the Lockhart-Martinelli parameter X_{tt} which is a strong function of the weight fraction of vapour or quality. The modification of the liquid phase convective term for the Guerrieri-Talty correlation by the inclusion of the point mass velocity of the unvaporised part of the stream in the expression for the Reynolds number further makes this correlation a strong function of the flowing quality.

7.7 As discussed in Chapter 3 the Guerrieri-Talty, Schrock-Grossman and Chen correlations all take account of nucleate boiling effects to varying extents. In the Guerrieri-Talty correlation a multiplication factor (F_{NB} in 3.4.2) was applied to the convective heat transfer coefficient for this purpose which in the present experiments ranged from 2.44 - 6.46 and 1.9 - 2.7 for the monochlorobenzene and biphenyl-biphenyl oxide data respectively. In the Schrock-Grossman correlation the nucleate and convective boiling components of heat transfer were additive, the relative proportions being a function of the Boiling number and the Lockhart-Martinelli parameter. For the range of experimental conditions covered in the investigation, the Schrock-Grossman correlation predicted that nucleate boiling effects accounted on average for approximately 95% of the local heat transfer coefficient. Fig. 45 indicates that of the five correlations considered the one due to Schrock-Grossman showed the most consistent trend in comparison with the experimental data for monochlorobenzene, however the calculated values of the heat transfer coefficient were only about half of the measured values. This underestimation has been noted previously from the data of other investigators for both water and organic fluids(35) and thus the constant of 7390 appearing in Eq. 3.12 cannot be considered to have any generality. The Chen correlation combined the effects of nucleate boiling and convective boiling in an additive manner as in the Schrock and Grossman correlation. It was more complex however than the latter but unlike the previous two which assume the total suppression of nucleation at some stage the Chen correlation admits to some nucleate boiling contribution throughout the finite Reynolds number range. In the present experiments the Chen correlation indicated that the nucleate and convective contributions to the total heat transfer coefficient were about equal for most tests. An exception was in the case of the highest system pressure tests with monochlorobenzene when nucleation effects were calculated to be 3-4 times greater than convective effects. Lavin & Young provided several correlations as a function of the local flow regime. The one (Eq. 3.13) used to derive the values for comparison purposes shown in Fig. 46 was for annular flow which did not include any contribution for nucleation effects. As in the case of the previous correlations the expression was a strong function of vapour quality through the inclusion of the dimensionless quantity $(1 + x)/(1 - x)$. The final correlation considered for comparison purposes in the data reduction exercise was the one due to Chawla[37] which solely considered convective boiling. The values of heat transfer coefficients predicted by this correlation bore the least resemblance to the experimental values of the five correlations discussed. The correlation was similarly a strong function of the vapour quality and also of the density ratio of the liquid and vapour phases. This dependence on the density ratio is evident from a comparison of Figs. 42 and 43 in which the density ratios are different by a factor of about eight in going from low (large ρ_L/ρ_G) to high system pressures. Better agreement to the experimental values can be observed to be present in high density ratio tests. An explanation for the wide difference encountered in the present work between the experimental and predicted values of the heat transfer coefficients probably lies in the value used for ε , the two phase flow parameter. In the publication[59] where the correlation for this latter quantity was presented it was noted that significant errors could be present at density ratios, ρ_L/ρ_G , of less than 200. For the range of conditions investigated in the present work the maximum value of the density ratio was 60 in the case of the lowest net boiling system pressure tests with biphenyl-biphenyl oxide (50 in the case with monochlorobenzene).

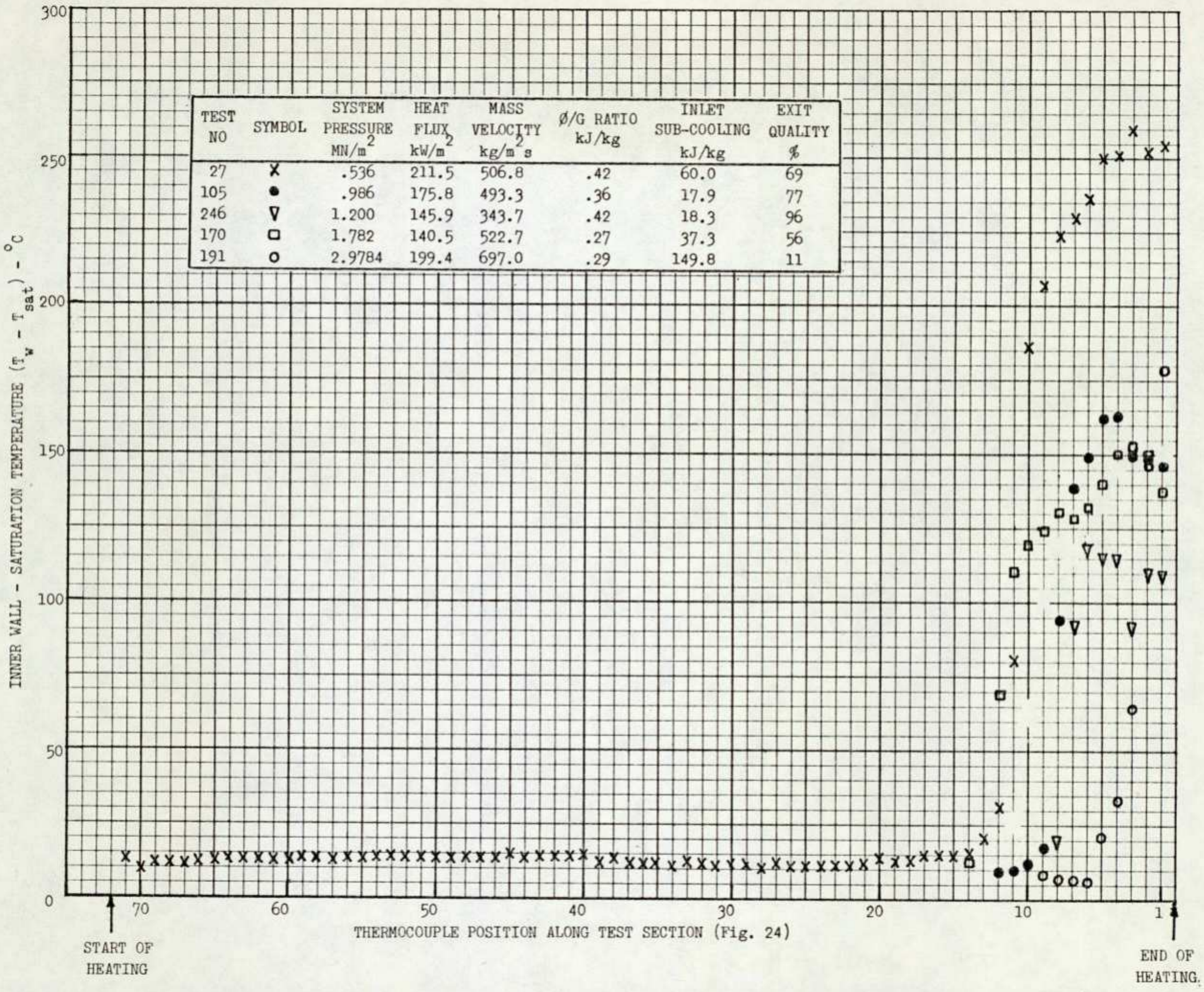
7.8 Only the data obtained from the middle portion (1.168 m) of the 1.83 m test section was used in calculating the mean heat transfer coefficients presented in Figs. 44 - 48 . The data from the omitted section at the test section inlet was considered to be unreliable due to possible thermal entrance effects. The data from the end portion was similarly considered to be unreliable due to the probable presence of carbon on the heated surface formed during tests when dry wall conditions were present in this region. Evidence of carbon formation can be observed from the scatter in the wall temperature measurements of Figs. 33, 38, 43 and 53 (test numbers 180, 183, 222, and 244) which were obtained towards the end of testing with monochlorobenzene. As noted earlier there was a lack of agreement between the correlation predictions and the boiling heat transfer data taken in the investigation and thus an empirical approach, using multiple linear regression analysis was adopted to derive a heat transfer correlation suitable for design purposes. This statistical analysis of the experimental data showed a strong heat flux or nucleation effect and a weak vapour quality and flow rate or forced convection effect in the range of variables considered, similar to that noted by other investigators for water[58] and refrigerant fluids[60]-[62]. The data clearly indicated a pressure dependance of increasing wall superheat with decreasing pressure and the final equation derived only incorporated heat flux and pressure as correlating parameters. Pressure was expressed in terms of the liquid-vapour density ratio, a parameter common to all fluids, unlike pressure which has significance only when the fluid experiencing it has been named.

7.9 Since by definition dry-outmust occur in a once-through evaporator it becomes essential for design purposes to be able to predict the dry-out point, the magnitude of the surface temperature rise and of the heat transfer coefficients in the post-dry-out region. The position of dry-out determines the length of the dry wall region of the evaporator tube which can be an important economic factor if special steels are required for the high tube wall temperature conditions. The temperature profiles shown in Figs. 52-54 all show the characteristic uncontrolled rise in wall temperature at the onset of dry-out present with electrically or radiantly heated tubes. Under these heat flux controlled conditions there is theoretically no upper limit to the wall temperature which will adjust itself upwards to whatever temperature level is required to force the heat through the tube. In comparison with experiments with water however the heat fluxes employed in the investigation were modest and thus the maximum temperatures experienced (around 600°C) were fortunately below those which may have caused physical burn-out of the test section. It was likely however that the dry-wall region temperature profiles were still developing to a greater or lesser extent at the time of data recording. Thus the derived values of the heat transfer coefficients for the dry-wall region should be regarded as providing an order of magnitude indication only unlike those obtained from the other regions of the test section where nominally steady state conditions prevailed.

7.10 As discussed in Chapter 6 there were operational and rig deficiencies which effectively prevented precise burn-out data from being obtained. In investigations specifically designed to obtain burn-out data for a fixed length to diameter ratio pressure and mass velocity are usually held constant for a test series and the burn-out heat flux is determined for a range of inlet subcoolings[122][123]. Here, due to preheater power limitations and the insensitive flow control valve it was not possible to set a specific flow or test section inlet temperature for a particular test. Additionally it was considered that conditions over the test section could have changed significantly during the data recording period either through dry-out front propogation or filter blockage. Despite these limitations a correlation of the dry-out data was attempted using the 'low velocity' expression given by Macbeth[121][21], the comparison being shown in Table 7. The use of a 'low' rather than a 'high' velocity correlation was considered to be justified since the mass velocities used were comparable to those present in some of the tests with R12 (a high MW fluid) carried out by Stevens et al[123] which were shown to correspond to the low velocity regime. Considering that the correlation constants of Eq. 6.8 were derived from water burn-out tests there is fair agreement, particularly at the higher qualities, with the present data. The only modification for its use here involved the latent heat term (in A_1) which suggests, as previously noted by Macbeth[63], that latent heat is the dominant fluid property controlling burn-out or dry-out in the low velocity regime. The effect of increasing wall heat flux on the position of dry-out when the other parameters remain essentially unchanged is shown for two successive test runs in Fig. 52 (test nos. 245-6). The location of the dry-out point moved upstream and the maximum wall temperature increased as the heat flux was increased.

7.11 Whilst the temperature rise at dry-out is abrupt it is some distance from this point before the maximum temperature is reached. This is indicative that the inception of dry-out does not start simultaneously all around the perimeter of the heat tube, but is extremely localised as observed by Hewitt et. al[64]. These latter researchers were the first to observe the liquid film on the outside of a heated rod, as seen through a glass annulus, become very thin at the dry-out point and break up into rivulets. It is presumed that these thin and narrowing rivulets of liquid on the heated wall continue downstream of the dry-out point until all wetting finally ceases and a maximum temperature, such as indicated in Fig. 53 is reached. The wall temperature reduces after reaching the maximum value due to increasing convective heat transfer effects through the vapour film which now completely blankets the surface. This improved heat transfer is caused by the higher flow velocities in the tube as more entrained liquid is evaporated. Finally a stage, not shown in Fig. 53 is assumed to be reached further downstream when only vapour is present and the wall temperature increases once more due to the decreasing heat transfer coefficients present as the vapour becomes superheated.

7.12 Evaporator tube gas side corrosion is a function amongst other factors of the tube wall operating temperature. It is thus desirable to have a knowledge of the magnitude of the surface temperature rise on the transition to dry-out and of the heat transfer coefficients in the post dry-out region so as to determine adequate operating margins. The temperature rise at dry-out, expressed as the difference between the inner wall and saturation temperature, is shown in Fig. 55 for tests at the five reduced pressures at which tests were undertaken with monochlorobenzene. For three of these tests at p_r = .12, .22 and .39 a pressure effect can be observed in which the temperature rise at dry-out decreases with increasing system pressure. This is in keeping with the observations of other investigators[65][66] from tests with water-steam systems which indicated a very strong pressure effect. For example, for a constant mass velocity and heat flux, reduction of pressure from 19 to 14 MN/m^2 increased the maximum temperature rise



TEST NO	SYMBOL	SYSTEM PRESSURE MN/m^2	HEAT FLUX kW/m^2	MASS VELOCITY $kg/m^2 s$	Ø/G RATIO kJ/kg	INLET SUB-COOLING kJ/kg	EXIT QUALITY %
27	X	.536	211.5	506.8	.42	60.0	69
105	●	.986	175.8	493.3	.36	17.9	77
246	∇	1.200	145.9	343.7	.42	18.3	96
170	□	1.782	140.5	522.7	.27	37.3	56
191	o	2.9784	199.4	697.0	.29	149.8	11

Fig. 55 Inner wall - Saturation temperature profiles for tests carried out over a range of system pressures with Monochlorobenzene

by a factor of 4.5. Data from the tests at reduced pressures of .27 and .67 do not however fit into the trend suggested by the other system pressure tests. These anomalies could be due to the lower mass velocities used in the p_r = .27 tests and with the large inlet sub-coolings for those at p_r = .67. With the p_r = .27 temperature profile shown in Fig. 53 which had the much longer post dry-out region, it is evident that a maximum wall temperature rise condition has been passed through unlike the other system pressure tests where the wall temperature profiles were probably still developing. The highest sub-coolings arose in the p_r = .67 tests because of pre-heater power input limitations. As a consequence the boiling length was quite short (also influenced by the reduced latent heat) with the dry-out zone being constrained to a few thermocouple spacings from the end of the heated length. It was found from water-steam experiments[65][66] with uniformly heated vertical tubes that the maximum temperature rise at dry-out could be correlated in terms of the ratio Ø/G (units kJ/kg.) by a simple relationship:-

$$T_{w.max} - T_{sat} = C.(\text{Ø}/G)^{2.5} \qquad \text{(Eq. 7.1)}$$

As previously noted it was found that the constant C was a strong function of pressure and it was concluded that at high pressures, say above p_r = .8 with water, the maximum temperature rise at dry-out can be small and undetectable above the 'wet wall' temperature provided the Ø/G ratio was sufficiently low, about .15 kJ/kg[65]. Whilst a similar pressure effect could be detected in the data obtained in this investigation a correlation on the lines of Eq. 7.1 for the maximum wall temperature rise on dry-out was not attempted due to the large variation in Ø/G present in the tests (see Table 6), and the probability that the wall temperature profiles were not fully developed, quite apart from the questionable accuracy of the wall temperature measurements towards the end of the heated section.

7.13 In the tests with dry-out the heat transfer coefficients over the dry wall portion of the test section considered, were, as indicated in Table 8, around 20-30% greater than those calculated by the Dittus-Boelter equation assuming all vapour flow and employing either the saturation or the film temperatures for the determination of the fluid properties. This would indicate, as previously concluded by Kearsey(67) that in the initial portion of the dry wall region the liquid plays an important part in the heat transfer process. The contribution from the liquid would diminish until a stage was reached further downstream of the film dry-out point when heat transfer would be solely to a vapour stream having droplets entrained in it when the heat transfer coefficient would be expected to correspond with the Dittus-Boelter all vapour value. In practice however it has been found from water-steam post dry-out investigations(68) that the heat transfer coefficients in the liquid deficient region are less than the Dittus-Boelter values for the equivalent steam flow alone assuming the steam to be at the saturation temperature. This would suggest that the steam was not in thermodynamic equilibrium with the water and was probably superheated inspite of the presence of a considerable amount of entrained liquid. Since no significant departure from the values calculated from the standard Dittus-Boelter correlation, assuming all vapour flow, was found for the data obtained in this investigation the analysis of heat transfer in the post dry-out regime was not taken any further. A further factor influencing the latter decision was also the doubts about the accuracy of the wall temperature data taken from the dry wall region of the tube which was in all probability affected to some extent by carbon formation.

7.14 The factors affecting the accuracy of the heat transfer coefficient values derived from the investigation have been commented upon in Appendix 4. Based upon the error analysis in this latter Appendix, the maximum errors estimated for the main independent variables of this study are:-

System pressure :- $\pm$ .17 kN/m^2

Mass velocity :- $\pm$ 2.5 to $\pm$ 6.0%

Heat flux :- $\pm$ 10%

Inlet temperature :- $\pm$ 1.1°C

The determination of the boiling heat transfer coefficient required an accurate measurement of the tube-fluid temperature difference. It was estimated on the basis of the available data that this difference would be of the order of 11 - 17°C. In fact however the heat transfer coefficients proved to be greater than expected and in many of the experimental runs the temperature difference was less than 5°C, presenting increasing difficulties in measurement. The possibility exists that in these cases where the temperature difference was small that there could be significant errors in the derived values of the heat transfer coefficients due to the uncertainties involved in temperature measurement. The absence of reliable experiemental data for the physical properties of the test fluids for the range of temperature and pressure considered creates further uncertainties when analysing the results of the investigation. In particular there exists some uncertainty regarding the liquid thermal conductivity of monochlorobenzene and the liquid viscosity of biphenyl-biphenyl oxide. When more reliable information becomes available on these properties the results of the heat transfer tests can be re-evaluated. Overall however the good agreement of the single phase heat transfer results, as compared to standard correlations gives credence to the view that the boiling heat transfer results obtained in the investigation are accurate to within $\pm$ 25%.

7.15 For data reduction purposes, in the absence of experimental information on the local pressure gradient variation, a linear pressure drop was assumed across the test section. Since the pressure drops measured in the investigation were small the latter assumption was considered to be justified for simplifying the data reduction process in the calculation of the local fluid saturation temperature without introducing significant errors. It was not possible to undertake a systematic analysis of the test section pressure drop due to the absence of void fraction data. The void fraction with two-phase flow directly affects the magnitude of the gravity and acceleration components of the total pressure drop and thus must be known over the channel pressure drop measurement increment for their relative contributions to be identified. As a part of the data reduction exercise the test section pressure drop was calculated employing the homogenous theory which assumed equal liquid and vapour phase velocities i.e. a slip ratio of unity. The results of these calculations are presented in Tables 26 and 27 of Appendix 8 which give the contributions of the three components of pressure drop present in vertical upflow viz. gravity, friction, and acceleration together with the experimentally measured overall pressure drop for monochlorobenzene and biphenyl-biphenyl oxide respectively. From Tables 26 and 27 it can be observed that for the range of mass velocities employed in the investigation the pressure drop was mainly due to the head of liquid in the tube i.e. the gravity component was dominant and the frictional and acceleration components were small compared with the overall pressure difference. In hindsight it would have been desirable for the gravity or hydrostatic head to have been a sufficiently small proportion of the total pressure drop so that the forces due to phase interaction could, with suitable instrumentation, have been measured accurately. This would have entailed employing larger mass flow rates or a smaller bore test section.

7.16 As recorded in Appendix 7 the void fraction was measured using the gamma attentuation technique at a position immediately above the upper power clamp. The void fraction values obtained however were considered to be in error for several reasons given in Appendix 7 and were thus not used in the analysis of the heat transfer or pressure drop data. Evaluation work undertaken with the void fraction measurement system prior to the commencement of the experimental programme showed that there could be large differences between the actual and measured void fractions particularly at low values of the latter. Despite this it was considered to be worthwhile to obtain measurements with the system during the data taking sessions for future development purposes. These latter measurements are included as Table 28 in the compilation of experimental and derived results of Appendix 8. Examination of Table 28 shows that voidage is only indicated as being present in the net boiling tests, whereas from the discussion in 2.5 a significant amount of voidage was expected to be present in test runs having a low sub-cooling at the test section exit.

7.17 As well as influencing fluid decomposition the presence of dissolved air in the loop fluid can have a significant effect on heat transfer, particularly in the case of sub-cooled boiling. It could be expected that with organic fluids that such effects are accentuated over the case with water due to their much larger dissolved gas contents (c.f. Table 20 page 246). As detailed in Appendix 6 an existing apparatus was utilised to determine the dissolved air content of monochlorobenzene to serve as a check on the reliability of the method when it was employed for air solubility measurements on candidate fluids for which literature data was not available. In the event however the method was not adopted for the other fluid tested, biphenyl-biphenyl oxide because of the requirement for the refurbishment of the apparatus and for the lack of time.

7.17 In conclusion, from the findings of the present investigation, for the fluids and range of conditions evaluated in the tests it is recommended that the inner wall temperatures for a monotube evaporator system should be calculated as follows:-

(a) Using either the Dittus-Boelter or Sieder-Tate equations for the single phase region.

(b) The Moles and Shaw correlation for the sub-cooled region, up to values of $\Delta T_{sub} = 10^{o}C$.

(c) Use of Eq. 6.5 from the upper limit in (b) to the dry-out boundary for the net boiling region.

(d) Dittus-Boelter equation employing all vapour properties for the post dry-out region.

Thus with the exception of the net boiling region, heat transfer in the present investigation could be adequately predicted by established correlations. From the lack of agreement between the net boiling data and the various literature correlations one might conclude that the latter should only be used over the tested range and not be construed to have any general validity.

The existence of the dry wall region in a once-through evaporator creates a potential hot spot problem, especially when high combustion gas temperatures are present such as in fossil fuel fired systems. Under such heat flux controlled conditions the wall temperatures in the dry-wall region could, as demonstrated, be significantly higher than when the tube wall was wetted because of poorer heat transfer coefficients. Of the factors influencing the rate of fluid thermal decomposition the most important one is the metal surface temperature. As an example of the effect of temperature; for the case of biphenyl-biphenyl oxide the degradation rate increases by a factor of 2.5 when the heating temperature is increased from 343°C (600°F) to 371°C (700°F) [(69)]. It must therefore be ensured that the design values of evaporator tube wall temperatures are within specified limits for acceptable fluid decomposition, making allowances for fault conditions which may arise from off-design performance or inadequate maintenance of the system. Several methods have been reported for the avoidance of hot spots with organic monotube systems:-

(i) An evaporator for refrigerants having a very low thermal stability threshold (200°C) incorporated a corrugated firetube which acted as a radiation shield preventing the tube bundle from being exposed to the flames of the heat source[70].

(ii) A double pipe system[71][72] where the inner tube containing the evaporating organic fluid was protected by a 'buffer' annulus of water. The pressure in the annulus was arranged to be such so as to permit heat transfer from the combustion gases to the organic fluid by a boiling and condensation process such as in a heat pipe.

(iii) The immersion of the evaporator in a heat treatment salt which acted as an intermediate heat transfer medium[73].

(iv) The employment of lower heat fluxes in the high quality region of the evaporator tube[74].

(v) The suggestion for the adoption of supercritical operating conditions[10], as in the pioneering UK demonstration system[75] and in the more recent total energy system development in the USA[76].

Of the foregoing , subject to metallurgical limitations, (v), has many attractions from a thermodynamic standpoint for extracting the maximum amount of heat from the combustion products. For organic fluids, in comparison with water, the required pressure conditions for supercritical operation are not prohibitively high for application to low power output systems. Studies of supercritical heat transfer to suitable organic fluids are suggested as an extension of the present investigation.

8. CONCLUSIONS.

This investigation was conducted to determine the heat transfer characteristics of two candidate organic Rankine cycle working fluids. A test facility was designed and constructed in which forced convection boiling and non-boiling of monochlorobenzene and biphenyl-biphenyl oxide were studied over a range of system pressures, flow rates etc. A computerised data reduction system was developed for processing the experimental data obtained from the vertically orientated electrically heated test section. Specific problems arising from the poor thermal stability of the organic fluids employed were also examined. Within the range of variables covered in this experimental investigation the following conclusions and recommendations can be made:-

(i) Heat transfer in the single phase region was adequately represented by standard correlations for turbulent flow in tubes i.e. the Dittus-Boelter or the Sieder-Tate equations.

(ii) The experimental sub-cooled boiling data could be satisfactorily correlated by the Moles & Shaw equation and to a lesser extent by the Papell equation.

(iii) An examination of the net boiling data showed that whilst most of the data was in the annular flow regime strong nucleation effects were present. Vapour quality and flow rate effects were of second order significance to heat flux effects over the range of conditions investigated. The net boiling correlations recommended in the literature for the determination of local heat transfer coefficients did not correlate the data for the same local flow and thermodynamic conditions.

(iv) An empirical equation incorporating the parameters which most affected the boiling heat transfer process was used to correlate the data obtained in the investigation. These latter parameters were the heat flux and system pressure the latter being expressed as the ratio of the liquid -vapour density ratio. A multiple linear regression analysis technique was used to determine the constant and exponents for the correlation equation.

(v) The burn-out or dry-out conditions experienced in a number of tests produced tolerable wall temperatures in all cases. There were operational problems and rig design deficiencies which effectively prevented precise dry-out data from being obtained during these latter tests. A Macbeth low mass velocity expression was used to correlate the dry-out data, the tests with high dry-out quality showing reasonable agreement between measured and calculated values of the dry-out heat flux.

(vi) The post dry-out heat transfer coefficients measured during the short period that was available for data taking following the onset of dry-out could be correlated with a Dittus-Boelter type equation employing vapour phase properties.

(vii) Operational problems caused by carbon formation during the investigation highlighted the prime importance of thermal stability considerations in organic Rankine cycle fluid selection. Results obtained from gas chromatographic analysis of monochlorobenzene, sampled before and after heating, showed an increase in the concentration of benzene and ortho- or para-dichlorobenzene.

9. RECOMMENDATIONS FOR FURTHER WORK.

9.1 The problem of wall dry-out causing high wall temperatures with a heat flux controlled monotube boiler design is considered to be a critical factor when employing organic fluids which have relatively poor thermal stability in comparison with water. A possible way of avoiding high tube wall temperatures and consequent fluid decomposition is by the use of supercritical operating conditions. An investigation of supercritical heat transfer is thus suggested as an area of research as an extension of the present investigation.

9.2 The absence of reliable thermophysical property data for the test fluids introduced additional uncertainties in the present work in the interpretation of the experimental results. Experimentally derived data, particularly in respect of liquid thermal conductivity and viscosity for the test fluids under consideration would be highly desirable so as to avoid the use of sometimes questionable fluid property prediction methods.

9.3 Since fluid thermal stability aspects are the critical factor in fluid selection, dual use should be made of a loop facility such as was used in the present investigation for obtaining both liquid and gas phase samples for chemical analysis. Almost all the information on fluid thermal decomposition has been obtained from experiments conducted using laboratory glassware type apparatus which bears little resemblance to a practical situation.

APPENDIX 1 - PHOTOGRAPHIC ILLUSTRATIONS OF THE HEAT TRANSFER LOOP

Plate 9. View of circulating pump looking downstream to turbine flow meter. Connection on discharge side of pump was to spray/dump line. Filling line isolating valve is shown in the bottom left hand corner.

Plate 10. Test section lower support structure showing Belleville washer tensioning arrangement with flow control valve beneath. The test section lower flange pressure tapping is shown above the washer stack.

Plate 11. View inside test section and pre-heater enclosure looking upwards towards the test section exit.

Plate 12. View of test section and pre-heater enclosure at upper level with part of the panelling removed. The test section support structure is shown fixed to a concrete ceiling beam.

Plate 13. Thermocouple gland cooler removed to show sealing gland for 1.59 mm dia. sheathed thermocouples.

Plate 14. View of upper level showing DART system data logger and reflux cooler. In the background is the portable rotary vacuum pump used for reflux cooler shell pressure control. In the foreground is a centrifugal pump which was employed for boosting the domestic water supply pressure to the reflux cooler condensing coil.

Plate 15. View of reflux cooler showing condenser coil cooling water flow meter. The vacuum gauge was employed for shell pressure monitoring when Thermex was used as the intermediate heat exchange fluid in the reflux cooler shell. The porthole type window in the reflux cooler shell was used for observing the refluxing process.

Plate 16. View of sub-cooler, pressuriser and circulating pump suction line. The pressuriser is shown with part of its enclosure removed when operating at a pressure of about 1.655 MN/m^2 (240 psi). The line to

the upper portion of the pressuriser is the spray line which was connected to the discharge side of the circulating pump (see Plate 9). The solenoid valve shown level with the pressure gauge take off tee was employed for discharging the loop contents to the dump/drain tank. The pressurising line to the loop is shown just below the top of the sub-cooler support structure.

Plate 17. View of lower loop area showing circulating pump in background, pressuriser enclosure, dump/drain and storage tanks and air-operated reciprocating pump. The access staircase to the upper working level is shown to the right.

Plate 18. Test section and pre-heater power supplies. The one in the foreground was for the pre-heater (Simpson) which was manually controlled by the regulator set in the upper portion of its casing. The test section power supply was in two units, a Berco motorised voltage regulator to the left with the main Ferranti transformer-rectifier located behind the pre-heater unit.

Plate 19. View of central display panel at upper working level. Below the clock is the frequency meter for the turbine flow meter with the Heise gauge and Barton differential pressure indicator to its left and right respectively. Below the frequency meter is the panel digital volt meter and above the panel is the Ether indicator/controller. To the right of the panel is the Hopkinsons gauge and just below it the reference-pressure regulating valve. The four meters shown above the clock were for indicating the test section and pre-heater volts and amps. The view shows the system at a pressure of around 1.93 MN/m^2 (280 psia). The Barton gauge indicates a reading of 95% of its range i.e. the reference pressure was above the loop pressure at the test section exit by 45.5 kN/m^2.

Plate 20. View of 3 stage high pressure air compressor and reference gas storage bottles located outside the loop enclosure. The smaller cylinder on the left hand side was used as the reference pressure

damping cylinder, teed in to the downstream side of the precision pressure regulating valve.

Plate 21. View of test section assembly prior to installation in the loop. The door to the enclosed rig area is shown to the left.

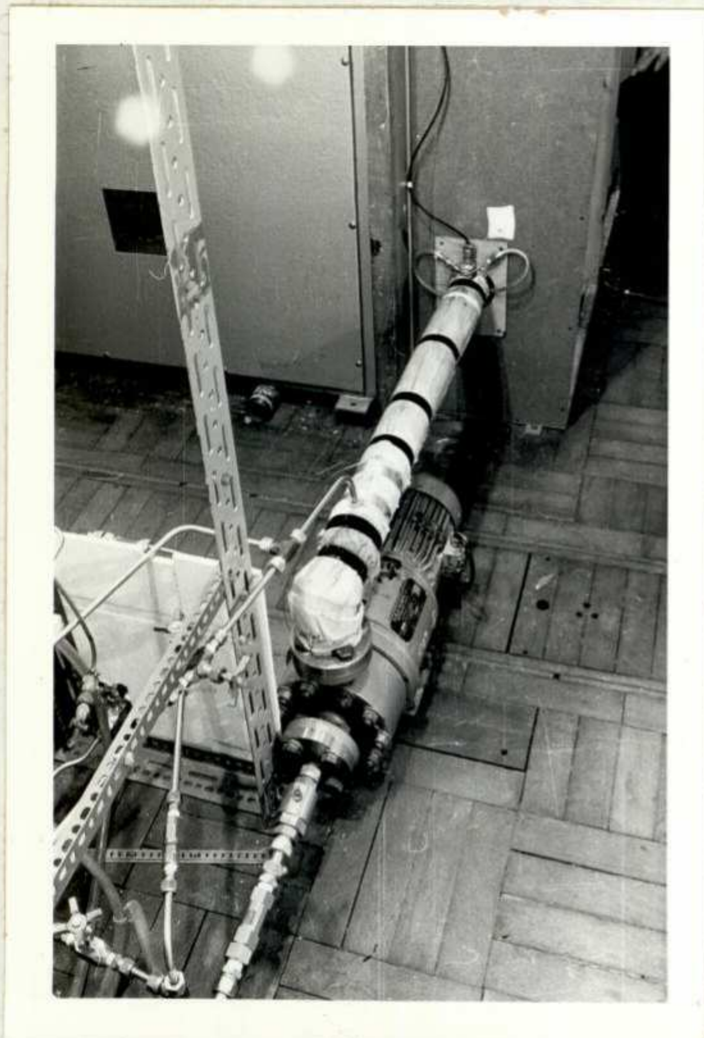


Plate 9. View of glandless type circulating pump looking downstream to the turbine flow meter.

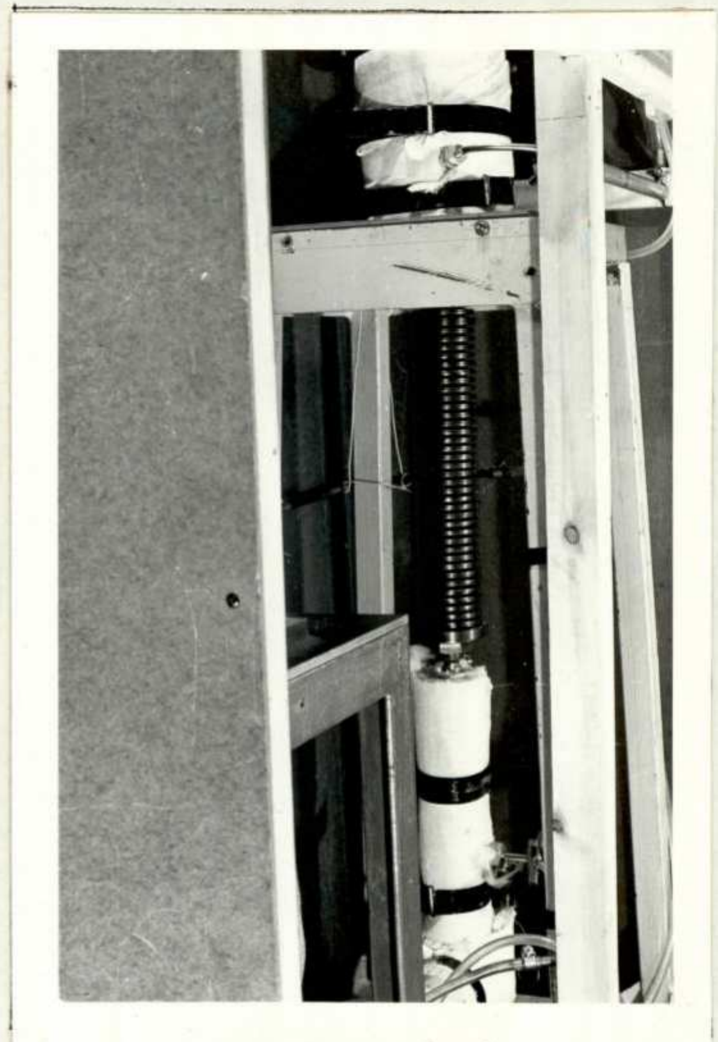


Plate 10. Test section lower support structure showing the Belleville spring washer tensioning arrangement and flow control valve.

Plate 11. View inside test section and pre-heater enclosure upwards towards the test section exit.

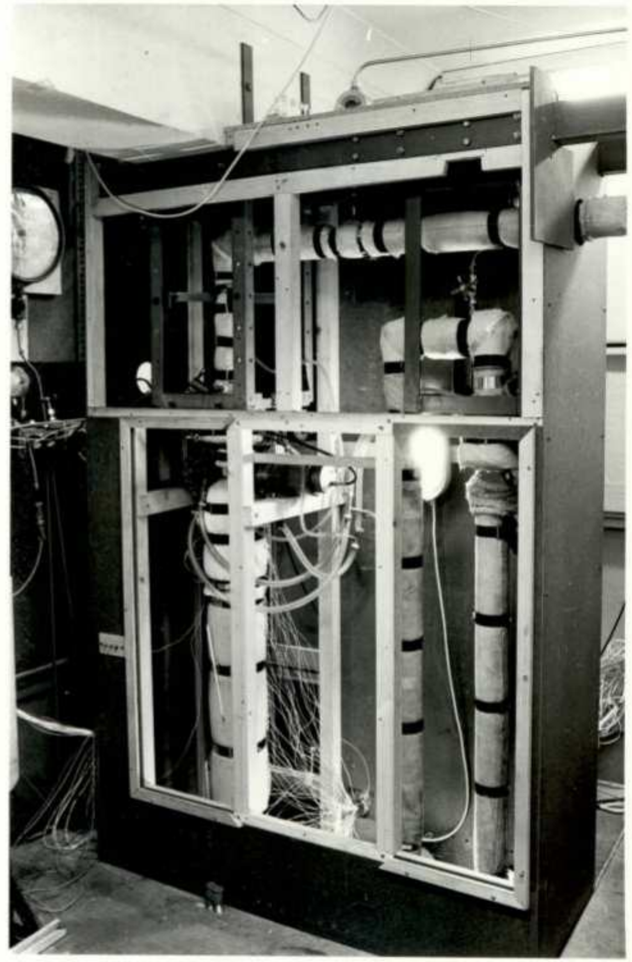


Plate 12. View of the test section and pre-heater enclosure at the upper working level.

Plate 13. View of thermocouple gland cooler removed to show sealing gland for sheathed thermocouples.

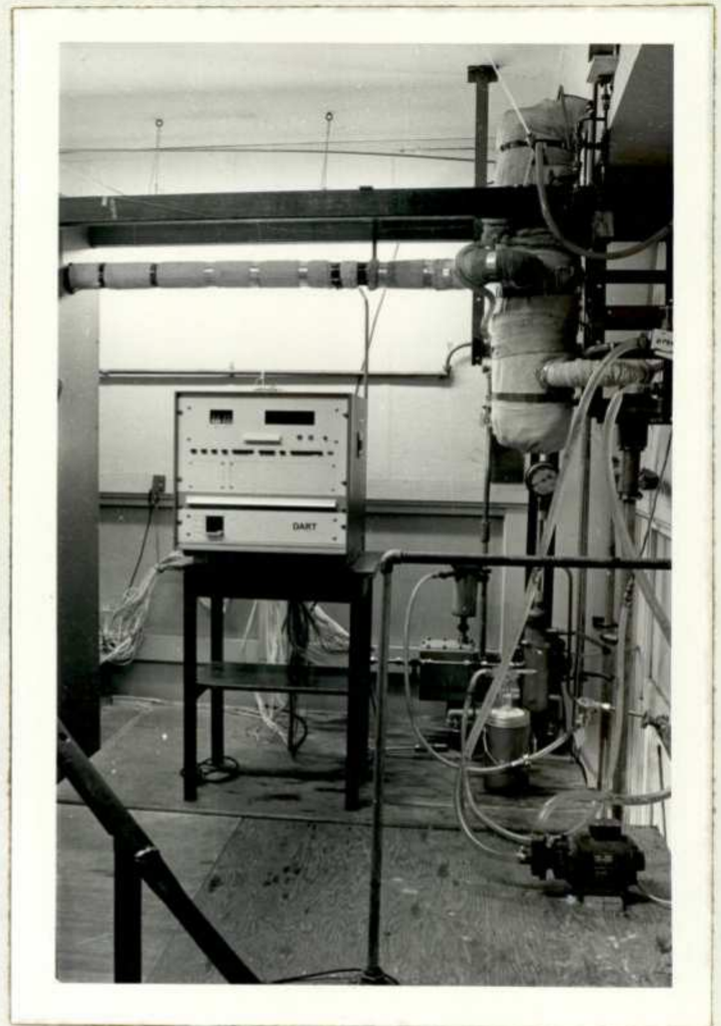


Plate 14. DART system data logger and reflux cooler/condenser at upper working level.

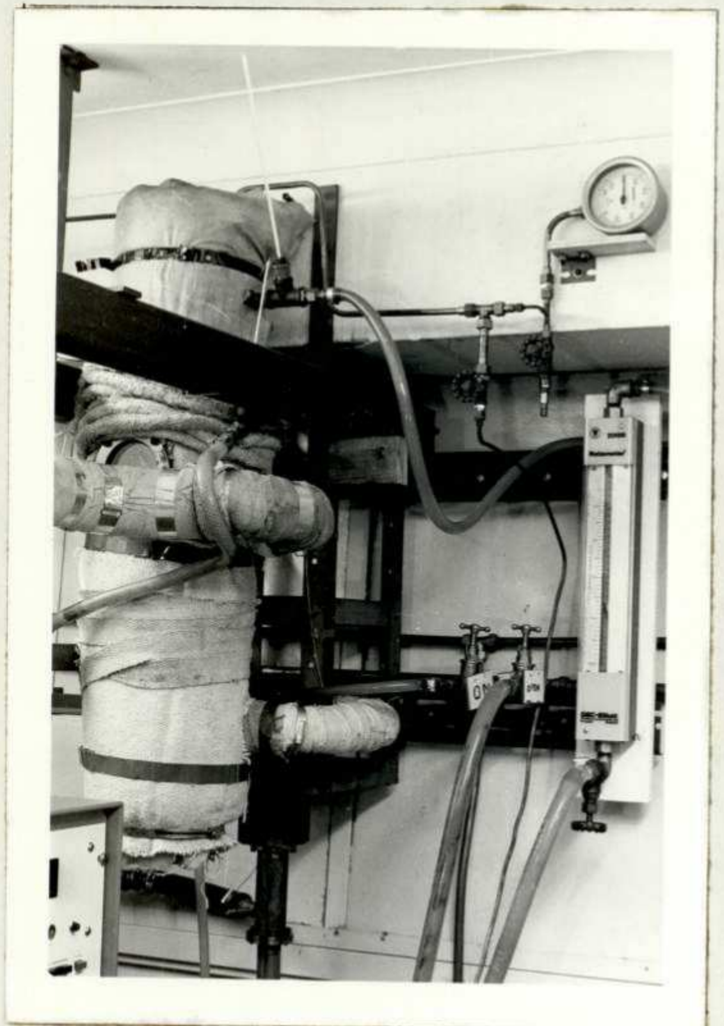


Plate 15. View of reflux cooler/ condenser.

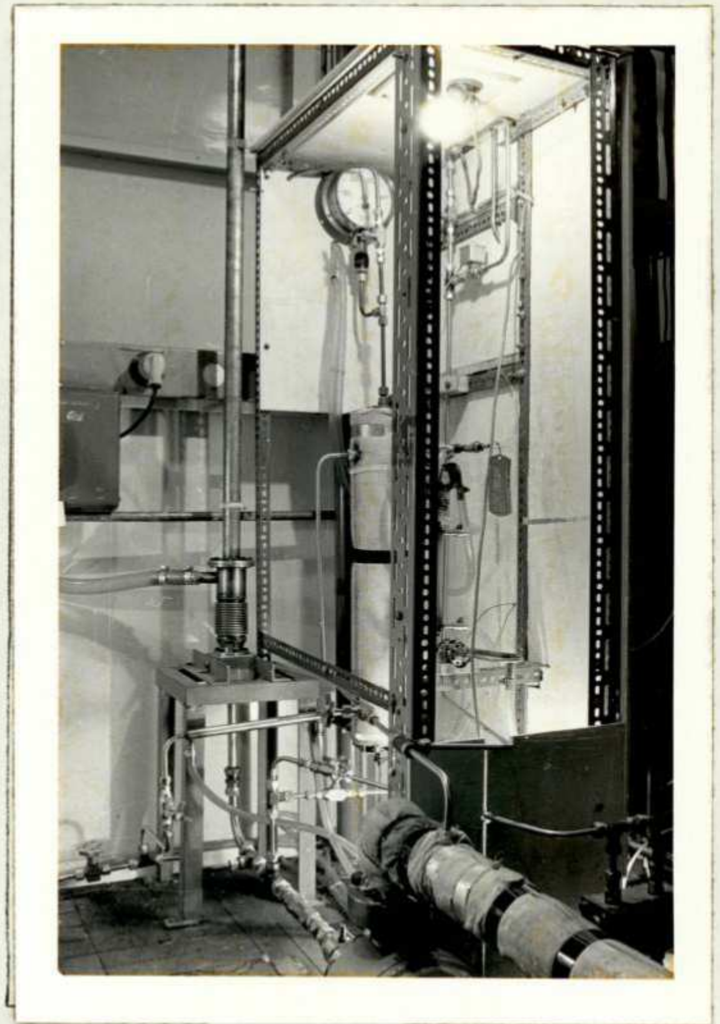


Plate 16. View of loop at the lower working level showing the sub-cooler and pressuriser.

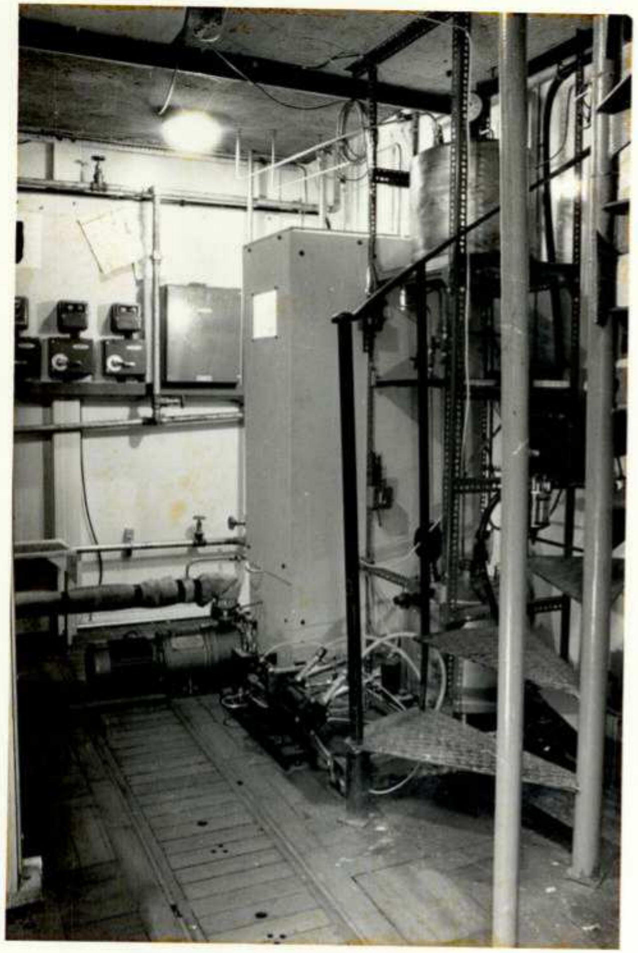


Plate 17. View of lower loop working area showing the circulating and reciprocating pumps, storage tanks and access stairway to upper level.

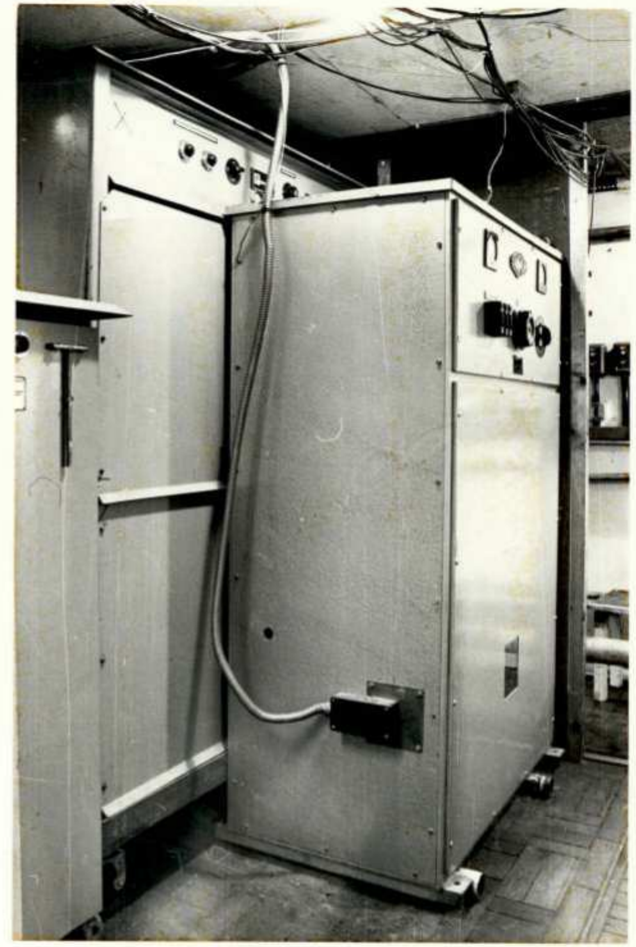


Plate 18. View of test section and pre-heater d.c. power supply units.

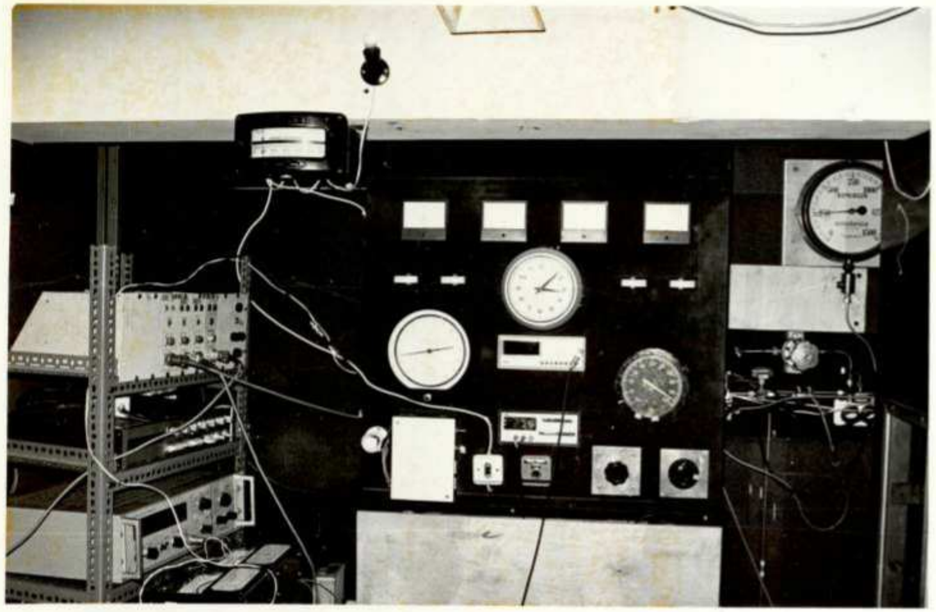


Plate 19. View of central display panel at upper working level.

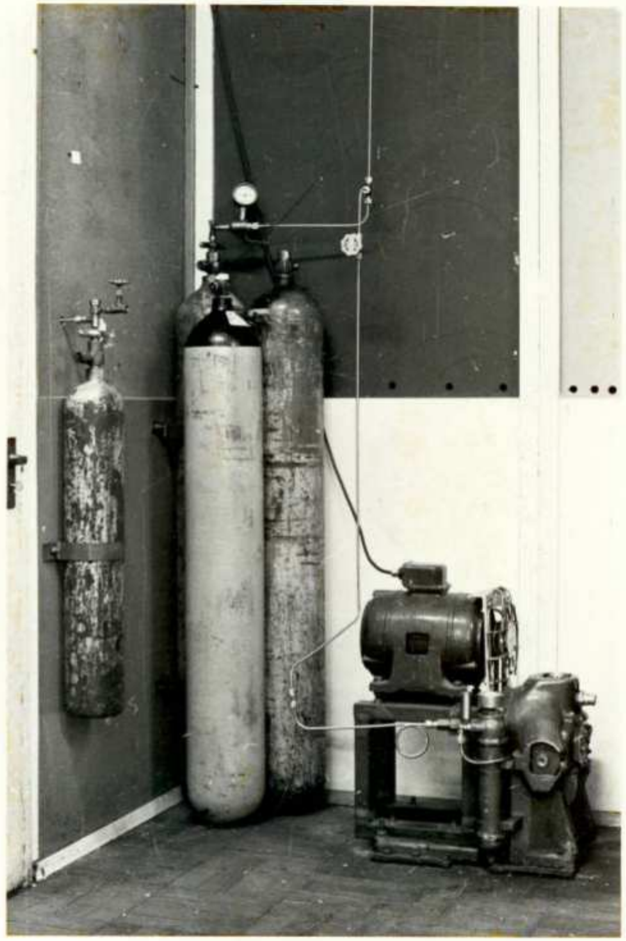


Plate 20. View of high pressure air compressor situated outside the loop enclosure.

PLATE 21. VIEW OF TEST SECTION ASSEMBLY PRIOR TO INSTALLATION IN THE LOOP.

APPENDIX 2 - DATA REDUCTION PROCEDURE

A2.1 Introduction

Since there were a large number of wall temperature and other measurements taken during the investigation it was considered to be essential to employ a computer program in the data reduction exercise. A suitable computer program for this purpose was developed as part of the investigation which was used for analysing the results from the test runs. The logic flow chart for the program is given in Fig. 56 and the program listing in pages 188 - 198 . The first five pages of this latter listing contain a brief program description, literature references for the correlations and an index of the program nomenclature. As there were a number of candidate organic working fluids shortlisted for testing it was a requirement that the program should be as general as possible. With the exception of the coefficients used for calculating the thermo-physical properties of the particular fluid and the test section dimensions the program as developed is generally applicable for analysing the results of heat transfer tests in the case of vertical upflow of one component fluids. The program was written in Fortran initially for use on an ICL1905E machine and was later adapted for use on a Univac 1108.

A2.2

After reading in the data for a specific test, the mass velocity and applied heat flux were calculated from the dimensions of the test section. A power loss correction factor was included in the heat flux calculation to allow for the heat loss from the test section to the surroundings. This latter factor had been derived from single phase tests when the electrical power input was compared with the measured enthalpy increase of the test fluid (Fig. 31). Two polynomials covering adjacent ranges in the overall range 0-600°C were employed to convert the wall thermocouple emf's into centigrade units, namely:-

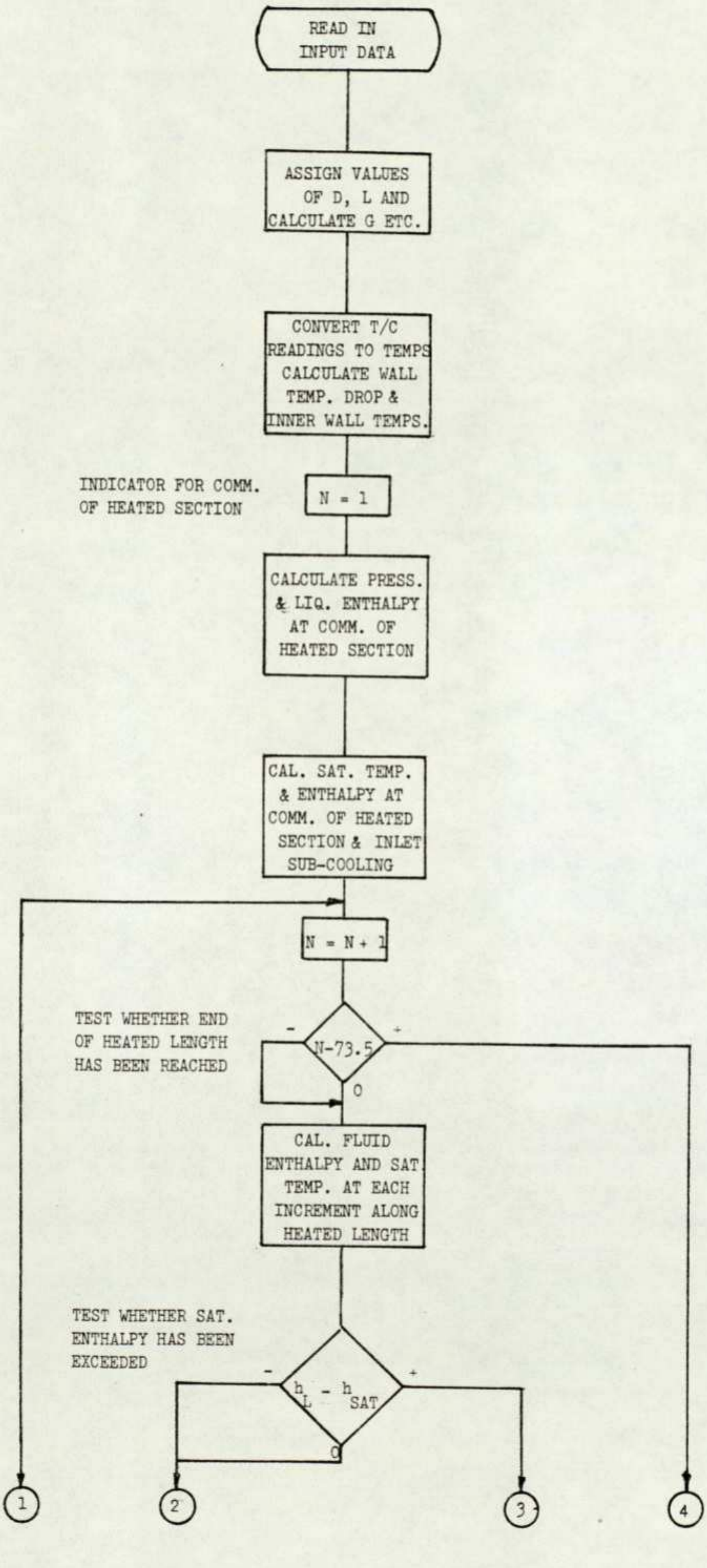
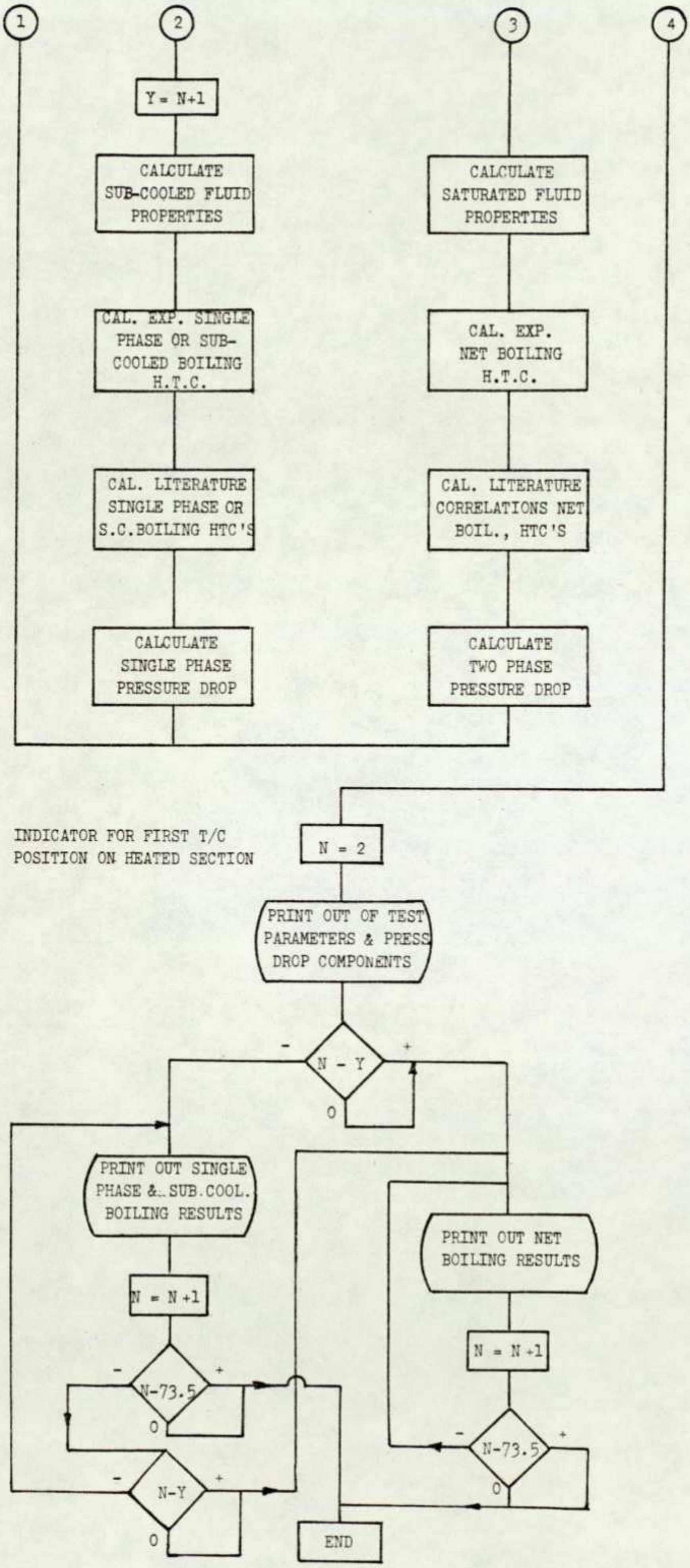


Fig. 56 Data Reduction Computer Program Logic Diagram


1
2
3
4
Y = N+1
CALCULATE SUB-COOLED FLUID PROPERTIES
CALCULATE SATURATED FLUID PROPERTIES
CAL. EXP. SINGLE PHASE OR SUB-COOLED BOILING H.T.C.
CAL. EXP. NET BOILING H.T.C.
CAL. LITERATURE SINGLE PHASE OR S.C.BOILING HTC'S
CAL. LITERATURE CORRELATIONS NET BOIL., HTC'S
CALCULATE SINGLE PHASE PRESSURE DROP
CALCULATE TWO PHASE PRESSURE DROP
INDICATOR FOR FIRST T/C POSITION ON HEATED SECTION
N = 2
PRINT OUT OF TEST PARAMETERS & PRESS DROP COMPONENTS
N - Y
PRINT OUT SINGLE PHASE & SUB.COOL. BOILING RESULTS
PRINT OUT NET BOILING RESULTS
N = N +1
N-73.5
N-Y
END

0-400°C:

$$T = 25.886297 \times E - .61954869 \times E^2 + .022181644\ E^3 - .00355009 \times E^4$$

400-600°C:

$$T = 11.782 + 10.8989 \times E + .210921 \times E^2 - .00295912 \times E^3$$

The expression for the 0-400°C range was taken from Benedict[77] and the third order polynomial for the 400-600°C range was derived from a least squares fit to the data obtained in the investigation as part of the wall thermocouple calibration exercise (Table 4).

A2.3

The inner wall temperature at a particular thermocouple position was determined by subtracting the calculated temperature drop through the wall from the measured outer wall value. The temperature difference across the tube wall was calculated from the heat conduction equation for a cylinder with uniform internal heat generation given by:-

$$T_{wo} - T_w = \frac{\emptyset\, r}{k_m\ (r_o^2 - r^2)} \left(r_o^2 \log_e\left(\frac{r_o}{r}\right) - \frac{(r_o^2 - r^2)}{2} \right) \quad \text{(Eq. A2.1)}$$

The above was derived assuming uniform generation of electrical heat, constant thermal conductivity and constant electrical resistivity both radially and axially along the length of the tube. The more elaborate equation s e.g. Kreith & Summerfield[78] allow for the variation with temperature of the thermal and electrical conductivities. However with the small temperature differences employed in the present experiments the simpler formula suffices. For the dimensions of the test section used Eq. A2.1 reduces to:-

$$T_{wo} - T_w = \emptyset / k_m \times .775 \times 10^{-3} \quad \text{(Eq. A2.2)}$$

The thermal conductivity k_m of the test section material was taken to be a linear function of temperature as shown by the data of Powell and Tye[39] in Fig. 57. Strictly, the value of k_m employed in Eq. A2.2 should have been the mean of the inside and outside values which would have required an iterative technique to be used to determine the wall temperature difference.

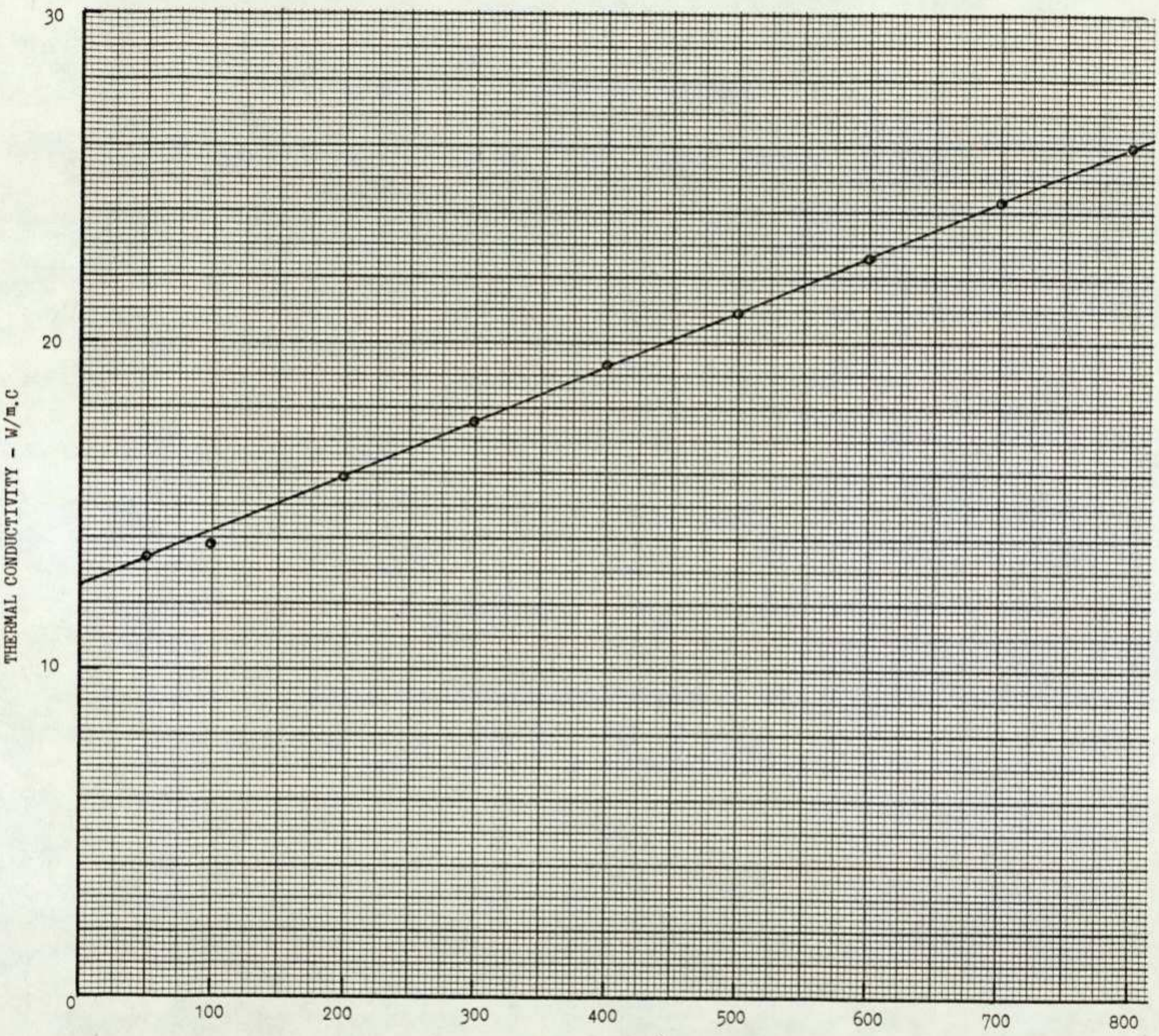


FIG. 57 Thermal conductivity variation with temperature of Nimonic 75 (39)

However, since the applied heat flux was relatively low the associated wall temperature difference was also low and thus the error involved in the calculation of this latter quantity by using the simplified assumption that the thermal conductivity was constant across the wall thickness at $T = T_{wo}$ was very small.

A2.4

The next stage in the program calculation was the determination of the thermodynamic condition of the test fluid at the commencement of the heated section. For this purpose and for the subsequent program calculations the thermophysical properties of the test fluids were expressed as 3rd order polynomials in reduced temperature. An exception to the foregoing was the fluid saturation temperature which was expressed as a 6th order polynomial in reduced pressure. After the sub-cooling at the start of heating had been calculated a marching process up the test section was commenced, the incremental steps being the distance between successive thermocouples. Since a uniformly heated test section was employed in the tests the fluid enthalpy could be calculated at successive steps along the tube.

At each segment the bulk fluid enthalpy was tested against the enthalpy of the saturated liquid at the calculated local test section pressure. If the bulk enthalpy of the liquid in the segment was less than that of the saturated liquid the routine proceeded to treat the fluid in that segment as sub-cooled liquid and calculate all single phase quantities and dimensionless groups using $T_b = T_L$. If the bulk enthalpy equalled or exceeded that of the saturated liquid, the computer routine switched to a two-phase mode with the fluid properties now being calculated using $T_b = T_{sat}$. Both the single-phase and sub-cooled boiling regimes were considered to be a single region with all five of the referenced correlations being evaluated at each segment. An inspection of the computer print-out had thus to be made to decide on which of the correlation predictions were valid i.e. depending on whether the wall temperature was above or below the local saturation temperature and upon the value of the sub-cooling at a particular point. For the bulk boiling region the literature correlations were similarly evaluated at each point and in their case none of them are valid downstream of the onset of wall dry-out, quite apart from any deficiency in the model upon which any of them were based.

A2.5

Whilst there was no systematic experimental study of the test section pressure drop in the investigation, the computer data reduction routine calculated the pressure drop according to the homogeneous theory for both the single and two-phase regions. For both regimes the pressure drop in the case of vertical up-flow consists of three components viz: $\Delta p_{gravity}$, $\Delta p_{friction}$ and $\Delta p_{acceleration}$. The latter term in the case of single-phase flow is essentially zero for a constant cross section channel and incompressible liquid and is normally neglected. For the net boiling regime the homogeneous model considers the two phases to flow as a single-phase possessing mean fluid properties. In the case of a uniformly heated tube where liquid is evaporated from a saturated liquid condition to a vapour-liquid mixture of quality x at a constant rate the expression for the pressure drop in vertical upflow reduces to[21] :-

$$\Delta p = \frac{2f_{TP}\, L\, G^2\, v_L}{D}\left(1 + \frac{x}{2}\left(\frac{v_{LG}}{v_L}\right)\right) + G^2 v_{LG} x + \frac{gL}{v_{LG} x}\log_e\left(1 + \frac{v_{LG}}{v_L}x\right)$$

(total) (frictional) (accel) (gravity)

The above expression also assumes that the compressibility of the gaseous phase is negligible and that the term (v_{LG}/v_L) and the two-phase friction factor f_{TP} remain constant over the length considered. The Fanning expression $f = .046Re^{-.2}$ was employed for the calculation of the friction factor with the mean viscosity in the Reynolds number term being defined as:

$$\frac{1}{\mu} = \frac{x}{\mu_G} + \frac{(1-x)}{\mu_L}$$

A2.6

After the end of the heated section has been reached the results are printed out as shown in the specimen output on pages 202 - 5 . The two main groups of results are prefaced by a summary of the experimental conditions for the test and the calculated pressure drop components. The first group gives information on the fluid thermodynamic conditions at each thermocouple location up the test section along with the experimental and predicted values of the heat transfer coefficients. This group can include both the single and two-phase regime results as for the example shown or only a sub-cooled fluid headed listing if net boiling conditions were not achieved. The second group of results which again can be sub-divided into single and two-phase regions give essentially the fluid property valuesat each thermocouple position up the test section.

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C                         ***********************************
C                         *                                 *
C                         * COMPUTER PROGRAM FOR REDUCTION  *
C                         * OF EXPERIMENTAL DATA ON THE     *
C                         * FORCED CONVECTION EVAPORATION   *
C                         * OF ORGANIC FLUIDS IN VERTICAL   *
C                         * UPFLOW THROUGH AN ELECTRICALLY  *
C                         * HEATED TUBE.                    *
C                         *                                 *
C                         ***********************************
C
C
C
C                                 ******************
C                          ******    DESCRIPTION    ******
C                                 ******************
C
C      THE PROGRAM ACCEPTS EMF READINGS FROM 71 EQUALLY SPACED
C      THERMOCOUPLES ALONG A UNIFORM BORE VERTICALLY ORIENTED TEST
C      SECTION WHICH IS RESISTANCE HEATED BY LOW VOLTAGE, HIGH
C      CURRENT ELECTRICAL POWER.OTHER INPUT DATA ARE THE MEASURED
C      FLUID PRESSURE AND TEMPERATURE AT THE TEST SECTION INLET AND
C      EXIT,FLOWRATE AND POWER INPUT.
C      FROM THE MEASURED INLET CONDITIONS THE FLUID ENTHALPY IS
C      CALCULATED AT EACH THERMOCOUPLE INCREMENT UP THE TUBE WHICH IS
C      COMPARED WITH THE SATURATED FLUID ENTHALPY TO DETERMINE
C      WHETHER SATURATION OR BULK BOILING CONDITIONS HAVE BEEN
C      REACHED.
C      THE EXPERIMENTAL HEAT TRANSFER COEFFICIENTS CALCULATED BY THE
C      PROGRAM ARE COMPARED WITH THOSE GIVEN BY CORRELATIONS CONTAINED
C      IN THE UNDERMENTIONED REFERENCES.
C
C
C
C                              ******************
C                       ******    REFERENCES    ******
C                              ******************
C
C      MOLES F.D. AND SHAW J.F.G.  BOILING HEAT TRANSFER TO SUBCOOLED
C      LIQUIDS UNDER CONDITIONS OF FORCED CONVECTION
C      TRANS.INST.CHEM.ENGRS. V50,PP76-84 (1972)
C
C      ENGINEERING SCIENCES DATA UNIT NO.67016.  FORCED CONVECTION HEAT
C      TRANSFER IN CIRCULAR TUBES- PART 1:CORRELATIONS FOR FULLY
C      DEVELOPED TURBULENT FLOW,THEIR SCOPE AND LIMITATIONS. APRIL 1967
C
C      DITTUS F.W. AND BOELTER L.M.K.  HEAT TRANSFER IN AUTOMOBILE RADIATORS
C      OF THE TUBULAR TYPE.
C      UNIV.OF CALIFORNIA PUBLICATIONS IN ENGINEERING V2,P443 (OCT 1930)
C
C      SIEDER E.N. AND TATE G.E. HEAT TRANSFER AND PRESSURE DROP OF
C      LIQUIDS IN TUBES.
C      IND.ENG.CHEM. V28,PP1429-1435,(1936)
C
C      CHEN J.C.  CORRELATION FOR BOILING HEAT TRANSFER TO SATURATED
C      FLUIDS IN CONVECTIVE FLOW.
C      IND.ENG.CHEM.,PROCESS DESIGN & DEVELOPMENT V5,3,PP322-329(1966)
C      ALSO ASME PAPER NO. 63-HT-34 (1963)
C
C      CHAWLA J.M.  CORRELATION OF CONVECTIVE HEAT TRANSFER COEFFICIENT
C      FOR TWO PHASE LIQUID VAPOUR FLOW.
C      1970 HEAT TRANSFER CONF. PARIS PAPER NO. B 5.7
C
C      LAVIN J.G. AND YOUNG E.H. HEAT TRANSFER TO EVAPORATING
C      REFRIGERANTS IN TWO PHASE FLOW.
C      A.I.CH.E. JNL. V11,6,PP1124-1132 (1965)
C
C      SCHROCK V.E. AND GROSSMAN L.M.  FORCED CONVECTION BOILING
C      IN TUBES.
C      NUCLEAR SCIENCE AND ENGINEERING V12,PP474-481 (1962)
C
C      GUERRIERI S.A. AND TALTY R.D.  A STUDY OF HEAT TRANSFER TO
C      ORGANIC LIQUIDS IN SINGLE TUBE NATURAL CONVECTION VERTICAL TUBE
C      BOILERS.
C      CHEM.ENG.PROG.SYM.SERIES NO.18,V 52 PP69-77(1956)
C
C      PAPELL S.S.  SUBCOOLED BOILING HEAT TRANSFER UNDER FORCED
C      CONVECTION IN A HEATED TUBE.
C      NASA TN D1533 (1962)
C
C
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C                              ********************
C                           ******   NOMENCLATURE   ******
C                              ********************
C        A,B,C,D     COEFFICIENTS IN FLUID THERMOPHYSICAL PROPERTY
C                    POLYNOMIALS
C        ACTPOW      CORRECTED POWER INPUT ,I.E. CALCULATED POWER LESS
C                    HEAT LOSS
C        ALPHA       EQUILIBRIUM VOID FRACTION CALCULATED USING EQUAL LIQUID
C                    AND VAPOUR PHASE VELOCITIES
C        AMPS        TEST SECTION CURRENT
C        ASG,BSG     CONSTANTS AND EXPONENT IN SCHROCK AND GROSSMAN
C        & CSG       CORRELATION
C        AVREN       AVERAGE REYNOLDS NO. IN SINGLE OR TWO-PHASE REGIONS
C        BC          NUSSELT NO. CALCULATED USING CHAWLA CORRELATION
C        BO          BOILING NO.
C        CE          CHAWLA TWO-PHASE FLOW PARAMETER
C        CF          FACTOR FOR EVALUATING CHAWLA TWO-PHASE FLOW PARAMETER
C        CLY         CONSTANT IN LAVIN AND YOUNG CORRELATION
C        CN,SN       CONSTANT AND EXPONENT IN EQUATION FOR FIT OF CHENS
C                    BUBBLE GROWTH SUPPRESSION FACTOR S
C        CPLIQ       CONSTANT PRESSURE SPECIFIC HEAT OF LIQUID AT SATURATION
C                    TEMPERATURE
C        CPLIQF      CONSTANT PRESSURE SPECIFIC HEAT OF LIQUID AT FILM
C                    TEMPERATURE
C        CPLFQ       CONSTANT PRESSURE SPECIFIC HEAT OF LIQUID AT SUB-COOLED
C                    TEMPERATURE
C        CPVAP       CONSTANT PRESSURE SPECIFIC HEAT OF VAPOUR AT SATURATION
C                    TEMPERATURE
C        CSA         FLOW CROSS SECTIONAL AREA
C        DATE        DATE OF TEST
C        DC          EQUIVALENT LIQUID FILM HYDRAULIC DIAMETER IN CHAWLA
C                    CORRELATION
C        DEL         LAMINAR FILM THICKNESS
C        DELPSA      SINGLE PHASE ACCELERATION PRESSURE DROP COMPONENT
C        DELPSF      SINGLE PHASE FRICTIONAL PRESSURE DROP COMPONENT
C        DELPSG      SINGLE PHASE GRAVITATIONAL PRESSURE DROP COMPONENT
C        DPTOTS      SUM OF SINGLE PHASE ACCELERATION,FRICTIONAL AND
C                    GRAVITATIONAL COMPONENTS
C        DELPTA      TWO PHASE ACCELERATION PRESSURE DROP COMPONENT
C        DELPTF      TWO PHASE FRICTIONAL PRESSURE DROP COMPONENT
C        DELPTG      TWO PHASE GRAVITATIONAL PRESSURE DROP COMPONENT
C        DELTAL      AXIAL DISTANCE BETWEEN WALL TEMPERATURE THERMOCOUPLES
C        DELTAP      PRESSURE DROP BETWEEN INLET AND EXIT TEST SECTION
C                    FLANGES
C        DI          TEST SECTION BORE
C        DPBAR       CALCUATED PRESSURE DROP IN BAR.
C        DPCHEN      DIFFERENCE BETWEEN FICTITIOUS TUBE WALL PRESSURE AND
C                    SATURATION PRESSURE IN CHEN CORRELATION
C        DPTOTT      SUM OF TWO PHASE ACCELERATION,FRICTIONAL AND
C                    GRAVITATIONAL PRESSURE DROP COMPONENTS
C        DPTOT       SUM OF SINGLE OR SINGLE AND TWO PHASE PRESSURE DROP
C                    COMPONENTS
C        DTF         INNER WALL TEMPERATURE - SUBCOOLED FLUID TEMPERATURE
C        DTSAT       INNER WALL - SATURATION TEMPERATURE
C        E           TEST SECTION OUTER WALL THERMOCOUPLE EMF
C        EGT         NUCLEATE BOILING CORRECTION FACTOR IN GUERRIERI AND
C                    TALTY CORRELATION
C        ENTHAL      HEAT INPUT CALCULATED FROM MEASURED INLET AND EXIT
C                    FLUID TEMPERATURES
C        F           FANNING FRICTION FACTOR
C        FC          CHEN F FACTOR, RATIO OF TWO PHASE REYNOLDS NO. TO THE
C                    LIQUID REYNOLDS NO. BASED ON THE LIQUID FRACTION OF THE
C                    FLOW
C        GA          MASS VELOCITY
C        HA          HEATED AREA OF TEST SECTION BASED ON INSIDE DIAMETER
C        HBOIL       EXPERIMENTAL BOILING HEAT TRANSFER COEFFICIENT
C        HCH         HEAT TRANSFER COEFFICIENT CALCULATED USING CHAWLA
C                    CORRELATION
C        HCNB        SINGLE PHASE FORCED CONVECTION HEAT TRANSFER COEFFICIENT
C                    BASED ON THE DITTUS-BOELTER CORRELATION EMPLOYING AN ALL
C                    LIQUID REYNOLDS NO.
C        HCMIC       CHEN MICROCONVECTIVE HEAT TRANSFER COEFFICIENT
C        HCMAC       CHEN MACROCONVECTIVE HEAT TRANSFER COEFFICIENT
C        HCTOT       SUM OF CHEN MICROCONVECTIVE AND MACROCONVECTIVE HEAT
C                    TRANSFER COEFFICIENTS
C        HDB         SINGLE PHASE DITTUS AND BOELTER HEAT TRANSFER
C                    COEFFICIENT
C        HESDU       SINGLE PHASE HEAT TRANSFER COEFFICIENT CALCULATED
C                    USING THE ENGINEERING SCIENCES DATA UNIT CORRELATION
C        HEVAP       ENTHALPY OF EVAPORATION
C        HF          FLUID ENTHALPY AT INCREMENTS ALONG TUBE
C        HFLUX       HEAT FLUX
C        HGT         HEAT TRANSFER COEFFICIENT CALCULATED USING THE GUERRIERI
C                    AND TALTY CORRELATION
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      C     HFSAT     SATURATED LIQUID ENTHALPY
      C     HLY       HEAT TRANSFER COEFFICIENT CALCULATED USING THE LAVIN
      C               AND YOUNG CORRELATION
      C     HMS       SUBCOOLED BOILING HEAT TRANSFER COEFFICIENT CALCULATED
      C               USING THE MOLES AND SHAW CORRELATION
      C     HNBLY     SINGLE PHASE HEAT TRANSFER COEFFICIENT BASED ON THE
      C               SIEDER AND TATE EQUATION USING AN ALL LIQUID REYNOLDS
      C               NUMBER
      C               SUBCOOLED BOILING HEAT TRANSFER COEFFICIENT CALCULATED
      C               USING PAPELL CORRELATION
      C     HSG       HEAT TRANSFER COEFFICIENT CALCULATED USING THE SCHROCK
      C               AND GROSSMAN CORRELATION
      C     HST       SINGLE PHASE SIEDER AND TATE HEAT TRANSFER COEFFICIENT
      C     HSUB      EXPERIMENTAL SINGLE PHASE OR SUBCOOLED BOILING HEAT
      C               TRANSFER COEFFICIENT
      C     HVAP      SATURATED VAPOUR ENTHALPY
      C     IDATA     COUNTER FOR INCREMENTING THE PROCESSING OF DATA SETS
      C     L         LENGTH OF HEATED PORTION OF TEST SECTION
      C     N         POSITION NUMBER
      C               (N=1-START OF HEATED SECTION,N=2-POSITION OF FIRST
      C               THERMOCOUPLE,N=73 -END OF HEATED SECTION)
      C     NDATA     NO. OF DATA SETS
      C     P         FLUID PRESSURE AT POSITIONS ALONG TEST SECTION ASSUMING
      C               A LINEAR PRESSURE DROP FROM THE INLET TO EXIT FLANGE
      C               TAPPINGS
      C     PE        FLUID PRESSURE AT EXIT TEST SECTION FLANGE TAPPING
      C     PI        FLUID PRESSURE AT INLET TEST SECTION FLANGE TAPPING
      C     PO        PRESSURE AT COMMENCEMENT OF HEATED SECTION
      C     POW       MEASURED POWER TO TEST SECTION (VOLTS * AMPS)
      C     POWLOS    HEAT LOSS FROM TEST SECTION TO SURROUNDINGS
      C     PR        REDUCED PRESSURE
      C     PRNF      PRANDTL NO. BASED ON FILM TEMPERATURE PROPERTIES
      C     PRNO      PRANDTL NO. BASED ON SUBCOOLED TEMPERATURE PROPERTIES
      C     PSAT      SATURATION PRESSURE
      C     PWALL     SATURATION PRESSURE CORRESPONDING TO INNER WALL
      C               TEMPERATURE IN CHEN CORRELATION
      C     RECHEN    MODIFIED REYNOLDS NO. IN CHEN CORRELATION
      C     REFR      PRODUCT OF ALL LIQUID REYNOLDS AND FROUDE NOS.
      C     RENO      LIQUID REYNOLDS NO. BASED ON SUBCOOLED TEMPERATURE
      C               PROPERTIES
      C     RENUM     LIQUID REYNOLDS NO. BASED ON SATURATED TEMPERATURE
      C               PROPERTIES
      C     RHO       FLUID DENSITY AT THE TEST SECTION INLET TEMPERATURE
      C     RHOLIQ    FLUID DENSITY AT SATURATION TEMPERATURE
      C     RHOLFQ    FLUID DENSITY AT SUBCOOLED TEMPERATURE
      C     RHOVAP    VAPOUR DENSITY AT SATURATION TEMPERATURE
      C     RHOVFQ    VAPOUR DENSITY AT SUBCOOLED TEMPERATURE
      C     RISQ      MEASURED POWER TO TEST SECTION (I **2 R)
      C     RSTAR     RADIUS OF MINIMUM SIZE THERMODYNAMICALLY STABLE BUBBLE
      C     SPVLIQ    SATURATED LIQUID SPECIFIC VOLUME
      C     SPVVAP    SATURATED VAPOUR SPECIFIC VOLUME
      C     STNO      SERIES TEST NO.
      C     SUB       DIFFERENCE BETWEEN SATURATED AND SUBCOOLED FLUID
      C               ENTHALPY
      C     SUBCL     SATURATION - SUBCOOLED FLUID TEMPERATURE
      C     SURTEN    SURFACE TENSION AT SATURATION TEMPERATURE
      C     TCLIQF    LIQUID THERMAL CONDUCTIVITY BASED ON FILM TEMPERATURE
      C     TE        FLUID TEMPERATURE AT TEST SECTION EXIT
      C     TESTNO    TEST NO OF DAY
      C     TF        BULK FLUID TEMPERATURE
      C     TFILM     FILM TEMPERATURE
      C     TFSAT     SATURATION TEMPERATURE
      C     THCLIQ    THERMAL CONDUCTIVITY OF LIQUID AT SATURATION TEMPERATURE
      C     THCLFQ    THERMAL CONDUCTIVITY OF LIQUID AT SUBCOOLED TEMPERATURE
      C     THCVAP    THERMAL CONDUCTIVITY OF VAPOUR AT SATURATION TEMPERATURE
      C     TI        FLUID TEMPERATURE AT TEST SECTION INLET
      C     TK        THERMAL CONDUCTIVITY OF TEST SECTION MATERIAL
      C     TLY       REDUCED INNER WALL TEMPERATURE
      C     TR        REDUCED TEMPERATURE
      C     TWI       TEST SECTION INNER WALL TEMPERATURE
      C     TWO       TEST SECTION OUTER WALL TEMPERATURE
      C     VEL       FLUID INLET VELOCITY
      C     VISLIQ    LIQUID VISCOSITY AT SATURATION TEMPERATURE
      C     VISLFQ    LIQUID VISCOSITY AT SUBCOOLED TEMPERATURE
      C     VISVAP    VAPOUR VISCOSITY AT SATURATION TEMPERATURE
      C     VISWAL    LIQUID VISCOSITY AT INNER WALL TEMPERATURE
      C     VOLTS     TEST SECTION VOLTAGE DROP
      C     VSLIQF    LIQUID VISCOSITY AT FILM TEMPERATURE
      C     X         VAPOUR QUALITY
      C     XTT       MARTINELLI PARAMETER
      C     Y         STATION NO. AFTER LIQUID REACHES SATURATION ENTHALPY
      C     Z         RECIPROCAL OF MARTINELLI PARAMETER
```

```
C      ZK,ZN      CONSTANT AND EXPONENT IN EQUATION FOR FIT OF CHENS
C                 REYNOLDS NO. F FACTOR
C
C
C
C
C
C                                 ********************
C                            ***** PROGRAM  LISTING *****
C                                 ********************
C
C
C
       INTEGER TESTNO,STNO,Y
       REAL L
C
       DIMENSION A(13),B(13),C(13),D(13),E(73),P(73),TWO(73),TWI(73),TK(7
      33),TF(73),TR(73),PR(73),TFSAT(73),HF(73),SUB(73),X(73),CPLIQ(73),D
      4TSAT(73),HBOIL(73),XTT(73),VISLIQ(73),VISVAP(73),SPVLIQ(73),SPVVAP
      5(73),Z(73),FC(73),RENUM(73),RECHEN(73),S(73)
       DIMENSION PWALL(73),DPCHEN(73),HCMIC(73),HCMAC(73),HCTOT(73),THCLI
      3Q(73),SURTEN(73),HEVAP(73),RHOVAP(73),HCNB(73),RSTAR(73),DEL(73),E
      5GT(73),HGT(73),BO(73),HSG(73),TLY(73),VISWAL(73),HNBLY(73),HLY(73)
      7,SUBCL(73),DTF(73),HSUB(73),TFILM(73),CPLIQF(73),VSLIQF(73)
       DIMENSION TCLIQF(73),PRNF(73),RENO(73),PRNO(73),HESDU(73),HMS(73),
      4HPAP(73),HDB(73),HST(73),RHOLIQ(73),HFSAT(73),HVAP(73),CPVAP(73),T
      4HCVAP(73),PSAT(73),ALPHA(73),VISLFQ(73),CPLFQ(73),THCLFQ(73),RHO(7
      33),VEL(73),AVREN(73),F(73),RHOLFQ(73)
       DIMENSION RHOVFQ(73),FR(73),REFR(73),CF(73),CE(73),DC(73),BC(73),H
      1CH(73)
       DIMENSION DATE(2)
C
C
C
C
C      POLYNOMIAL COEFFICIENTS FOR MONOCHLOROBENZENE
```

See Note 1, Page 199

```
C
       DATA A/8248.86,-3213.73,-2584.38,4977.66,2393.23,-38.8033,-.011346
      16,1.07081,-.36404,904.624,49.8086,19.7075,-179.724/
       DATA B/-26923.9,12737.6,9481.1,-17639.8,-8158.71,153.419,2.04195,-
      21.36449,1.3977,-2748.82,-205.545,108.556,813.066/
       DATA C/33757.6,-16976.2,-11223.3,22434.8,11211.6,-194.735,-.243593
      1,-.121226,-1.74702,3164.49,329.53,-244.894,-1260.03/
       DATA D/-14583.3,7646.52,4985.88,-9710.1,-4724.22,83.1821,-.201078,
      2.484130,.736661,-1263.93,-146.217,116.351,672.037/
C
C
C
C      READ INPUT DATA
C      ---------------
C
       IDATA=0
       READ( 5,902) NDATA
   902 FORMAT(I2)
   903 READ( 5,30) DATE,TESTNO,STNO,RP
    30 FORMAT(2A4,1X,I2,1X,I3,1X,F4.2)
       READ( 5,40) PI,PE,TI,TE,FLOW,VOLTS,AMPS
    40 FORMAT()
       READ( 5,42)(E(I),I=2,73)
    42 FORMAT()
C
C      END OF INPUT DATA
C
C
C      COMMENCE PROGRAM CALCULATIONS
C      -----------------------------
C
C
C     DEFINE TEST SECTION DIMENSIONS AND THERMOCOUPLE SPACING,
C      CALCULATE FLOW CROSS SECTIONAL AND HEATED SURFACE AREAS,
C      MASS VELOCITY AND MEASURED POWER INPUT
C
       L=1.8288
       DI=.01265
       DELTAL=0.0254
       CSA=.7854*DI**2
       HA=3.1416*DI*L
       GA=FLOW/CSA
       POW=VOLTS*AMPS*.001
C
C      CORRECTION OF MEASURED POWER INPUT FOR HEAT LOSS TO SURROUNDINGS
C
       ACTPOW=(.958*POW)-.372
```

```
      POWLOS=POW-ACTPOW
      HFLUX=ACTPOW/HA
C
C     CHECK ON POWER INPUT USING W=I**2 R ASSUMING A MEAN ELECTRICAL
C     RESISTIVITY OF 113 MIC-OHM CM (TEST SECTION RESISTANCE=.0284 OHM)
      RISQ=AMPS**2*.0234*.001
C
C
C
C     CONVERSION OF THERMOCOUPLE EMF S TO TEMPERATURES AND EVALUATION OF
C     WALL TEMPERATURE DROP AND INNER WALL TEMPERATURES ALONG TUBE
C
      DO 41 N=2,73
      IF(E(N)-20.6)37,37,38
C     EMF-TEMP RELATIONSHIP FOR CU-CON THERMOCOUPLES BETWEEN 0 AND 400
C     DEG C
   37 TWO(N)=25.886297*E(N)-.61954869*E(N)**2+.022181644*E(N)**3-.000355
     3009*E(N)**4
      GO TO 39
C     EMF-TEMP RELATIONSHIP FOR CU-CON THERMOCOUPLES BETWEEN 400 AND 600
C     DEG C,(3RD ORDER FIT TO EXPERIMENTAL DATA)
   38 TWO(N)=111.782+10.8989*E(N)+.210921*E(N)**2-.00295912*E(N)**3
C     THERMAL CONDUCTIVITY OF NIMONIC 75 IN W/MDEG C
   39 TK(N)=12.56+.0157*TWO(N)
C     TUBE INNER WALL TEMP. CALCULATED ASSUMING A MEAN VALUE OF THERMAL
C     CONDUCTIVITY AT T = TWO AND UNIFORM ELECTRICAL RESISTIVITY
      TWI(N)=TWO(N)-(HFLUX*.775/TK(N))
   41 CONTINUE
C
C                          ********************
C
C     CALCULATE PRESSURE DROP BETWEEN INLET AND EXIT PRESSURE
C     TAPPINGS AND PRESSURE AT COMMENCEMENT OF HEATED SECTION
C
      DELTAP=PI-PE
      P0=PI-DELTAP*.1905/2.23139
C
C
C     DETERMINE LIQUID ENTHALPY AT INLET ASSUMING THAT IT IS EQUAL TO
C     THE SATURATION ENTHALPY AT THE SAME TEMPERATURE.OTHER THERMO-
C     PHYSICAL PROPERTIES AT INLET CALCULATED FOR PRESSURE DROP EVALUATION
C     AND CALCULATION OF SINGLE PHASE ENTHALPY INPUT
C
C
      N=1
      P(N)=P0
      TF(N)=TI
      TR(N)=(TI+273.2)/632.4
      HF(N)=A(3)+B(3)*TR(N)+C(3)*TR(N)**2+D(3)*TR(N)**3
      CPLIQ(N)=A(6)+B(6)*TR(N)+C(6)*TR(N)**2+D(6)*TR(N)**3
      VISLIQ(N)=A(8)+B(8)*TR(N)+C(8)*TR(N)**2+D(8)*TR(N)**3
      RHO(N)=A(1)+B(1)*TR(N)+C(1)*TR(N)**2+D(1)*TR(N)**3
      VEL(N)=GA/RHO(N)
      P(N)=P0-DELTAP*.0254/2.23139
      PR(N)=P(N)/45.2
C
C     CALCULATE SATURATION TEMPERATURE FROM A 6TH ORDER POLYNOMIAL WHICH
C     IS A FUNCTION OF THE REDUCED PRESSURE
C
```

See Note 1, Page 199

```
      TFSAT(N)=120.195+1088.1*PR(N)-4026.67*PR(N)**2+10122.9*PR(N)**3-14
     1646.4*PR(N)**4+11065.1*PR(N)**5-3372.72*PR(N)**6
      TR(N)=(TFSAT(N)+273.2)/632.4
C
C     CALCULATE SATURATION ENTHALPY AND INLET SUBCOOLING
C
      HFSAT(N)=A(3)+B(3)*TR(N)+C(3)*TR(N)**2+D(3)*TR(N)**3
      SUB(N)=HFSAT(N)-HF(N)
C
C     INCREMENT STEPS ALONG TUBE AND TEST WHETHER  THE END OF THE
C     HEATED SECTION HAS BEEN REACHED
C
  100 N=N+1
      IF(N-73.5)101,101,102
C
C     CALCULATE LIQUID OR TWO PHASE ENTHALPY AT EACH INCREMENT ALONG
C     THE TUBE ASSUMING UNIFORM HEAT INPUT
C
  101 HF(N)=HF(N-1)+4.*HFLUX*DELTAL/(GA*DI)
      P(N)=P(N-1)-DELTAP*.0254/2.23139
C     LINEAR PRESSURE DROP ASSUMED BETWEEN INLET AND EXIT PRESSURE
C     TAPPINGS
      PR(N)=P(N)/45.2
      TFSAT(N)=120.195+1088.1*PR(N)-4026.67*PR(N)**2+10122.9*PR(N)**3-14
     1646.4*PR(N)**4+11065.1*PR(N)**5-3372.72*PR(N)**6
```

```
      TR(N)=(TFSAT(N)+273.2)/632.4
      HFSAT(N)=A(3)+B(3)*TR(N)+C(3)*TR(N)**2+D(3)*TR(N)**3
C
C     TEST WHETHER FLUID HAS REACHED SATURATION ENTHALPY
C
      IF(HF(N)-HFSAT(N))104,104,103
C
C     SATURATED BOILING CORRELATIONS
C     -----------------------------
C
C
C     EVALUATE SATURATED FLUID THERMOPHYSICAL PROPERTIES WHICH ARE 3RD
C     ORDER POLYNOMIALS OF REDUCED TEMPERATURE
C     NOTE:HVAP,THCVAP AND CPVAP ARE NOT EMPLOYED IN THE PRESENT
C     PROGRAM CALCULATIONS
C
  103 RHOLIQ(N)=A(1)+B(1)*TR(N)+C(1)*TR(N)**2+D(1)*TR(N)**3
      RHOVAP(N)=A(2)+B(2)*TR(N)+C(2)*TR(N)**2+D(2)*TR(N)**3
C     RHOLIQ AND RHOVAP UNITS ARE KG/M**3
      HFSAT(N)=A(3)+B(3)*TR(N)+C(3)*TR(N)**2+D(3)*TR(N)**3
      HEVAP(N)=A(4)+B(4)*TR(N)+C(4)*TR(N)**2+D(4)*TR(N)**3
      HVAP(N)=A(5)+B(5)*TR(N)+C(5)*TR(N)**2+D(5)*TR(N)**3
C     HFSAT,HEVAP AND HVAP UNITS ARE KJ/KG
      CPLIQ(N)=A(6)+B(6)*TR(N)+C(6)*TR(N)**2+D(6)*TR(N)**3
      CPVAP(N)=A(7)+B(7)*TR(N)+C(7)*TR(N)**2+D(7)*TR(N)**3
C     CPLIQ AND CPVAP UNITS ARE KJ/KG DEGK
      VISLIQ(N)=A(8)+B(8)*TR(N)+C(8)*TR(N)**2+D(8)*TR(N)**3
      VISVAP(N)=A(9)+B(9)*TR(N)+C(9)*TR(N)**2+D(9)*TR(N)**3
C     VISLIQ AND VISVAP UNITS ARE MILLI NEW.SEC/M**2
      THCLIQ(N)=A(10)+B(10)*TR(N)+C(10)*TR(N)**2+D(10)*TR(N)**3
      THCVAP(N)=A(11)+B(11)*TR(N)+C(11)*TR(N)**2+D(11)*TR(N)**3
C     THCLIQ AND THCVAP UNITS ARE MILLI-WATT/M DEG.K
      SURTEN(N)=A(12)+B(12)*TR(N)+C(12)*TR(N)**2+D(12)*TR(N)**3
C     SURTEN UNITS ARE MILLI NEW./M
      PSAT(N)=A(13)+B(13)*TR(N)+C(13)*TR(N)**2+D(13)*TR(N)**3
C     PSAT UNITS ARE BAR
      SPVLIQ(N)=1./RHOLIQ(N)
      SPVVAP(N)=1./RHOVAP(N)
C
C     CALCULATE WALL SUPERHEAT,EXPERIMENTAL SATURATED BOILING HEAT
C     TRANSFER COEFFICIENT AND MARTINELLI PARAMETER
C
      DTSAT(N)=TWI(N)-TFSAT(N)
      HBOIL(N)=HFLUX/DTSAT(N)
      X(N)=(HF(N)-HFSAT(N))/HEVAP(N)
      IF(X(N)-1.0)67,68,68
   68 X(N)=0.999
   67 XTT(N)=(VISLIQ(N)/VISVAP(N))**.1*(SPVLIQ(N)/SPVVAP(N))**.5*((1./X(
     3N))-1.)**.9
C
C     CALCULATE VOID FRACTION ASSUMING NO SLIP
C     ---------------------------------------
C
      ALPHA(N)=1./(1.-(RHOVAP(N)/RHOLIQ(N)*(X(N)-1./X(N))))
C
C     SATURATED BOILING CORRELATIONS
C     ------------------------------
C
C     CHEN CORRELATION FOR SATURATED BOILING
C     --------------------------------------
C
```

See Note 2, Page 199

```
C     DETERMINATION OF COEFFICIENT AND EXPONENT FOR CALCULATING F AS
C     A FUNCTION OF THE RECIPROCAL OF THE MARTINELLI PARAMETER
C
      Z(N)=1./XTT(N)
      IF(Z(N)-0.2)70,70,71
   70 ZK=2.4
      ZN=.38
      GO TO 80
   71 IF(Z(N)-0.3)72,72,73
   72 ZK=2.27
      ZN=.346
      GO TO 80
   73 IF(Z(N)-0.6)74,74,75
   74 ZK=2.47
      ZN=.412
      GO TO 80
   75 IF(Z(N)-2.0)76,76,77
   76 ZK=2.80
      ZN=.655
      GO TO 80
   77 IF(Z(N)-10.0)78,78,79
   78 ZK=2.67
      ZN=.719
```

```
      GO TO 80
   79 ZK=2.80
      ZN=.699
   80 FC(N)=ZK*Z(N)**ZN
      RENUM(N)=GA*DI*1000./VISLIQ(N)
      RECHEN(N)=RENUM(N)*FC(N)**(-1.25)
C
C     DETERMINATION OF COEFFICIENT AND EXPONENT FOR CALCULATING S AS
C     A FUNCTION OF THE MODIFIED REYNOLDS NO.
C
      IF(RECHEN(N)-30000.)81,81,82
   81 CN=10.643
      SN=-.264
      GO TO 87
   82 IF(RECHEN(N)-50000.)83,83,84
   83 CN=44.22
      SN=-.402
      GO TO 87
   84 IF(RECHEN(N)-80000.)85,85,86
   85 CN=131.9
      SN=-.5032
      GO TO 87
   86 IF(RECHEN(N)-100000.)43,43,44
   43 CN=4560.0
      SN=-.817
      GO TO 87
   44 IF(RECHEN(N)-200000.)45,45,46
   45 CN=1820.0
      SN=-.737
      GO TO 87
   46 IF(RECHEN(N)-400000.)47,47,48
   47 CN=358416.0
      SN=-1.17
   87 S(N)=CN*RENUM(N)**SN
      GO TO 88
   48 S(N)=0.1
   88 TR(N)=(TWI(N)+273.2)/632.4
      IF(TR(N)-.9855)89,89,90
   89 PWALL(N)=A(13)+B(13)*TR(N)+C(13)*TR(N)**2+D(13)*TR(N)**3
      DPCHEN(N)=(PWALL(N)-P(N))*100000.
      HCMIC(N)=.00122*((THCLIQ(N)*.001)**.79*(CPLIQ(N)*1000.)**.45*RHOLI
     4Q(N)**.49)/((SURTEN(N)*.001)**.5*(VISLIQ(N)*0.001)**.29*(HEVAP(N)*
     21000.)**0.24*RHOVAP(N)**.24)*DTSAT(N)**.24*DPCHEN(N)**.75*S(N)*.00
     31
      GO TO 91
C     OUT OF RANGE OF FLUID PROPERTY CORRELATION (350 C)
   90 HCMIC(N)=0.0
   91 HCMAC(N)=.023*(GA*(1.-X(N))*DI/(VISLIQ(N)*.001))**.8*(VISLIQ(N)*10
     400.*CPLIQ(N)/THCLIQ(N))**.4*THCLIQ(N)*FC(N)*1.0E-06/DI
      HCTOT(N)=HCMIC(N)+HCMAC(N)
C
C                                  ********************
C
C     GUERREIRI AND TALTY CORRELATION
C     -------------------------------
C
      HCNB(N)=HCMAC(N)/FC(N)
      RSTAR(N)=(2.*8.3143*TFSAT(N)**2.*SURTEN(N)*.001)/(P(N)*1.0E+05*HEV
     2AP(N)*DTSAT(N)*112.6)
      DEL(N)=10.*VISLIQ(N)*.001/RHOLIQ(N)*(4.*RHOLIQ(N)/(DELTAP*1.0E+05*
     6DI/L))**0.5
      EGT(N)=.187*(RSTAR(N)/DEL(N))**(-.5555)
      IF(EGT(N)-1.0)50,50,51
   50 HGT(N)=HCNB(N)*3.4*Z(N)**0.45
      GO TO 52
   51 HGT(N)=3.4*Z(N)**0.45*EGT(N)*HCNB(N)
C
C                                  ********************
C
C     SCHROCK AND GROSSMAN CORRELATION
C     --------------------------------
C
   52 ASG=7390.
      BSG=.00015
      CSG=.66
      BO(N)=HFLUX/(GA*HEVAP(N))
      HSG(N)=ASG*(BO(N)+BSG*Z(N)**CSG)*.023*(GA*DI/(VISLIQ(N)*.001))**.8
     2*(VISLIQ(N)*1000.*CPLIQ(N)/THCLIQ(N))**.333*THCLIQ(N)*1.0E-06/DI
C
C                                  ********************
C
C     CHAWLA CORRELATION FOR SATURATED BOILING
C     ----------------------------------------
```

```
C
      FR(N)=(GA*(1.-X(N)))**2/(RHOLIQ(N)**2*9.81*DI)
      REFR(N)=FR(N)*GA*1000.*(1.-X(N))*DI/VISLIQ(N)
      CF(N)=((1.-X(N))/X(N))*REFR(N)**(-.1666)*(RHOLIQ(N)/RHOVAP(N))**(-
     2.9)*(VISLIQ(N)/VISVAP(N))**(-0.5)
      IF(CF(N)-.001)55,55,56
   55 CE(N)=10.0*CF(N)
      GO TO 29
   56 CE(N)=0.316*CF(N)**0.5
   29 DC(N)=DI*(1.-(1.+((1.-X(N))/(X(N)*CE(N)*(RHOLIQ(N)/RHOVAP(N)))))**
     2(-0.5))
      IF(REFR(N)-109.)57,57,58
   57 BC(N)=0.0066*REFR(N)**.475*(X(N)/(1.-X(N)))*(RHOLIQ(N)/RHOVAP(N))*
     2*0.3*(VISLIQ(N)/VISVAP(N))**0.3*(GA*1000.*(1.-X(N))*DI/VISLIQ(N))*
     2*0.35*(VISLIQ(N)*1000.*CPLIQ(N)/THCLIQ(N))**0.42
      GO TO 59
   58 BC(N)=.015*REFR(N)**.3*(X(N)/(1.-X(N)))*(RHOLIQ(N)/RHOVAP(N))**0.3
     3*(VISLIQ(N)/VISVAP(N))**0.8*(GA*1000.*(1.-X(N))*DI/VISLIQ(N))**0.3
     65*(VISLIQ(N)*1000.*CPLIQ(N)/THCLIQ(N))**0.42
   59 HCH(N)=BC(N)*THCLIQ(N)*1.0E-06/DC(N)
C
C                              ********************
C
C     LAVIN AND YOUNG CORRELATION
C     ---------------------------
C
      CLY=3.79
      TLY(N)=(TWI(N)+273.2)/632.4
      IF(TLY(N)-.9855)92,92,93
   92 VISWAL(N)=A(8)+B(8)*TLY(N)+C(8)*TLY(N)**2+D(8)*TLY(N)**3
      HNBLY(N)=.023*(GA*(1.-X(N))*DI/(VISLIQ(N)*0.001))**.8*(VISLIQ(N)*1
     2000.*CPLIQ(N)/THCLIQ(N))**.333*(VISLIQ(N)/VISWAL(N))**.14*THCLIQ(N
     3)*1.0E-06/DI
      HLY(N)=HNBLY(N)*CLY*(1.0+X(N)/(1.0-X(N)))**1.16/BO(N)**0.1
      GO TO 61
C     OUT OF RANGE OF FLUID PROPERTY CORRELATION (350 C)
   93 HLY(N)=0.0
C
C                              ********************
C
C
C     TWO PHASE REGION PRESSURE DROP CALCULATION
C     ------------------------------------------
C
C     PRESSURE DROP CALCULATION USING HOMOGENEOUS MODEL
C     AVERAGE REYNOLDS NO. OVER SATURATED BOILING REGION CALCULATED
C     USING A MEAN TWO PHASE VISCOSITY
C
   61 AVREN(N)=GA*1000.*DI/(X(N)*VISVAP(N)+((1.-X(N))*VISLIQ(N)))
      F(N)=.046*AVREN(N)**(-0.2)
   62 DELPTF=.158103*F(N)*GA**2*SPVLIQ(N)*((N-Y-1)*.0254+.2427)*(1.+((SP
     2VVAP(N)-SPVLIQ(N))/SPVLIQ(N))*X(N)*0.5)
   63 DELPTA=GA**2*(SPVVAP(N)-SPVLIQ(N))*X(N)*.001
   64 DELPTG=(9.81*((N-Y-1)*.0254+.2427)*ALOG(1.+(SPVVAP(N)-SPVLIQ(N))/S
     2PVLIQ(N)*X(N)))/((SPVVAP(N)-SPVLIQ(N))*X(N))*.001
   65 DPTOTT=DELPTF+DELPTA+DELPTG
   66 DPTOT=DPTOTS+DPTOTT
      DPBAR=DPTOT*.01
   94 GO TO 100
C
C                              ********************
C
C
C     SINGLE PHASE OR SUBCOOLED BOILING CALCULATIONS
C     ----------------------------------------------
C
  104 Y=N+1
C
C     CALCULATE EXPERIMENTAL SINGLE PHASE OR SUBCOOLED BOILING
C     HEAT TRANSFER COEFFICIENT
C
      TF(N)=TF(N-1)+4.*HFLUX*DELTAL/(GA*CPLIQ(N-1)*DI)
      SUBCL(N)=TFSAT(N)-TF(N)
      DTF(N)=TWI(N)-TF(N)
      SUB(N)=HFSAT(N)-HF(N)
  106 HSUB(N)=HFLUX/DTF(N)
C
C
C
C     CALCULATION OF SUBCOOLED FLUID PROPERTIES
C
      TFILM(N)=(TWI(N)+TF(N))/2.0
      TR(N)=(TFILM(N)+273.2)/632.4
```

See Note 3, Page 200

```
      CPLIQF(N)=A(6)+B(6)*TR(N)+C(6)*TR(N)**2+D(6)*TR(N)**3
      VSLIQF(N)=A(8)+B(8)*TR(N)+C(8)*TR(N)**2+D(8)*TR(N)**3
      TCLIQF(N)=A(10)+B(10)*TR(N)+C(10)*TR(N)**2+D(10)*TR(N)**3
      PRNF(N)=VSLIQF(N)*1000.*CPLIQF(N)/TCLIQF(N)
      TR(N)=(TF(N)+273.2)/632.4
      RHOVFQ(N)=A(2)+B(2)*TR(N)+C(2)*TR(N)**2+D(2)*TR(N)**3
      RHOLFQ(N)=A(1)+B(1)*TR(N)+C(1)*TR(N)**2+D(1)*TR(N)**3
      VISLFQ(N)=A(8)+B(8)*TR(N)+C(8)*TR(N)**2+D(8)*TR(N)**3
      CPLFQ(N)=A(6)+B(6)*TR(N)+C(6)*TR(N)**2+D(6)*TR(N)**3
      THCLFQ(N)=A(10)+B(10)*TR(N)+C(10)*TR(N)**2+D(10)*TR(N)**3
      RENO(N)=GA*DI*1000./VISLFQ(N)
      PRNO(N)=VISLFQ(N)*1000.*CPLFQ(N)/THCLFQ(N)
C
C     SINGLE PHASE AND SUBCOOLED BOILING CORRELATIONS
C     ---------------------------------------------
C
C
C     ENGINEERING SCIENCES DATA UNIT NO. 67016 CORRELATION
C     ----------------------------------------------------
C
      HESDU(N)=EXP(-3.796-.205*ALOG(RENO(N))-.505*ALOG(PRNO(N))-.0255*(A
     2LOG(PRNO(N))**2))*RENO(N)*PRNO(N)*THCLFQ(N)*1.0E-06/DI
C
C                              ********************
C
C
C     MOLES AND SHAW CORRELATION
C     --------------------------
C
      TR(N)=(TFSAT(N)+273.2)/632.4
      RHOLIQ(N)=A(1)+B(1)*TR(N)+C(1)*TR(N)**2+D(1)*TR(N)**3
      RHOVAP(N)=A(2)+B(2)*TR(N)+C(2)*TR(N)**2+D(2)*TR(N)**3
      CPLIQ(N)=A(6)+B(6)*TR(N)+C(6)*TR(N)**2+D(6)*TR(N)**3
      HEVAP(N)=A(4)+B(4)*TR(N)+C(4)*TR(N)**2+D(4)*TR(N)**3
      HMS(N)=HESDU(N)*78.5*PRNF(N)**0.46*(HEVAP(N)/(CPLIQ(N)*SUBCL(N)))*
     2*0.5*(HFLUX*RHOLIQ(N)/(HEVAP(N)*RHOVAP(N)*GA))**0.67*(RHOVAP(N)/RH
     6OLIQ(N))**0.7
C
C                              ********************
C
C     PAPELL CORRELATION
C     ------------------------
C
      HPAP(N)=HESDU(N)*90.0*((HFLUX*RHOLIQ(N)/(HEVAP(N)*RHOVAP(N)*GA))*(
     6HEVAP(N)/(CPLIQ(N)*SUBCL(N)))**1.2*(RHOVAP(N)/RHOLIQ(N))**1.08)**.
     77
C
C                              ********************
C
C     DITTUS AND BOELTER
C     ------------------
C
      HDB(N)=.023*RENO(N)**0.8*PRNO(N)**0.4*THCLFQ(N)*1.0E-06/DI
C
C                              ********************
C
C     SIEDER AND TATE
C     ---------------
C
      HST(N)=.027*RENO(N)**0.8*PRNO(N)**0.333*(VSLIQF(N)/VISLFQ(N))**0.1
     24*THCLFQ(N)*1.0E-06/DI
C
C                              ********************
C
C
C     SINGLE PHASE REGION PRESSURE DROP CALCULATION
C     ---------------------------------------------
C
C     PRESSURE DROP CALCULATION EMPLOYS HOMOGENEOUS MODEL
C     AVERAGE RE.NO. CALCULATED USING MEAN OF INITIAL AND FINAL LIQUID
C     VISCOSITY VALUES
C
   21 AVREN(N)=GA*DI*1000./(((VISLFQ(N)+VISLIQ(1))/2.))
      F(N)=.046*AVREN(N)**(-0.2)
   22 DELPSF=158.103*F(N)*GA**2*((1./RHOLFQ(N))+(1./RHO(1)))*((N-1)*.02
     254+.1905)*0.5*.001
   23 DELPSA=((1./RHOLFQ(N)+(1./RHO(1)))/2.-(1./RHO(1)))*GA**2*.001
   24 DELPSG=9.81*((N-1)*.0254+.1905)*(RHOLFQ(N)+RHO(1))*0.5*.001
   25 DPTOTS=DELPSF+DELPSA+DELPSG
      DPTOT=DPTOTS
      DPBAR=DPTOT*.01
C
```

```
      C                         ********************
      C
      C
      C     ENTHALPY INPUT CALCULATED USING THE MEAN FLUID SPECIFIC
      C     HEAT VALUES AND MEASURED INLET AND EXIT TEMPERATURES
      C     (NOT VALID WHEN SATURATED BOILING OCCURS)
      C
            ENTHAL=FLOW*(TE-TI)*(CPLIQ(1)+CPLFQ(N))/2.0
      C
      C                         ********************
      C
            GO TO 100
      C
      C     PRINT OUT OF COMPUTED RESULTS
      C     -----------------------------
      C
        102 N=2
            WRITE(6,11)DATE,TESTNO,STNO,RP
         11 FORMAT(1H1,9HTEST DATE,10X,2A4,2X,17HTEST NO. OF DAY -,1X,I2,3X,17
           1HSERIES TEST NO. -,1X,I3,6X,18HREDUCED PRESSURE -,1X,F4.2)
      C
            WRITE( 6,31)
         31 FORMAT(/1X,72HINLET PRESS   EXIT PRESS    INLET TEMP   EXIT TEMP
           1 FLOW   TEST SECTION)
      C
            WRITE( 6,32)
         32 FORMAT(5X,68HBAR           BAR           DEG C        DEG C     KG/S
           6   VOLTS   AMPS)
      C
            WRITE( 6,33)PI,PE,TI,TE,FLOW,VOLTS,AMPS
         33 FORMAT(2X,F7.3,6X,F7.3,9X,F6.1,6X,F6.1,4X,F6.4,1X,F6.2,2X,F6.1)
      C
            WRITE( 6,34)
         34 FORMAT(/1X,'PRESS.DROP    INLET SUB.    MASS VEL.    INLET VEL.
           2 HEAT FLUX')
      C
            WRITE( 6,35)
         35 FORMAT(5X,'BAR          KJ/KG        KG/M**2 S        M/S          KW/
           2M**2')
      C
            WRITE( 6,36)DELTAP,SUB(1),GA,VEL(1),HFLUX
         36 FORMAT(2X,F6.3,7X,F6.1,9X,F6.1,7X,F6.3,8X,F6.1)
      C
            WRITE( 6,26)POW,RISQ,ENTHAL,POWLOS,ACTPOW
         26 FORMAT(/4X,'POWER',9X,'POWER',9X,'POWER',9X,'POWER',6X,'CORRECTED'
           2,/,4X,'(V*A)',8X,'(I**2R)',7X,'(M.CP.T)',8X,'LOSS',8X,'POWER',/,5X
           3,'KW',12X,'KW',12X,'KW',12X,'KW',11X,'KW',/,3X,F6.2,8X,F6.2,8X,F6.
           42,9X,F5.2,6X,F6.2)
      C
            WRITE( 6,12)
         12 FORMAT(/2X,'CALCULATED SINGLE PHASE PRESSURE DROP   CALCULATED TWO
           2 PHASE PRESSURE DROP         TOTAL     TOTAL')
      C
            WRITE( 6,13)
         13 FORMAT(1X,'FRICTION   ACCEL       GRAV      TOTAL     FRICTION   ACCE
           1L       GRAV      TOTAL   PRESS DROP PRESS DROP')
      C
            WRITE( 6,14)
         14 FORMAT(1X,'<                         UNITS FOR PRESSURE DROP COMPONENTS
           2 ARE KN/M**2                    >    BAR')
      C
            WRITE( 6,15)DELPSF,DELPSA,DELPSG,DPTOTS,DELPTF,DELPTA,DELPTG,DPTOT
           2T,DPTOT,DPBAR
         15 FORMAT(2X,F6.2,3X,F6.2,5X,F6.2,2X,F7.2,4X,F6.2,4X,F6.2,5X,F6.2,2X,
           3F7.2,4X,F7.2,3X,F6.3)
            IF(N-Y)121,122,122
      C
      C     PRINTOUT OF SUBCOOLED REGION RESULTS TABLE
      C
        121 WRITE( 6,123)
        123 FORMAT(/52X,16HSUB-COOLED FLUID)
      C
            WRITE( 6,124)
        124 FORMAT(1X,'POS FLUID OUTER INNER FLUID SAT N TSAT    TWI     SUB
           1H      H        H        H        H                 ',/,5X,'PRESS TEMP  TE
           2MP  TEMP  TEMP  - TF  - TF   COOL.  SUB   M-S   PAP  ESDU   D-B
           3S-T              ',/,6X,'BAR  DEG C DEG C DEG C DEG C DEG C DEG C
           4KJ/KG <     UNITS FOR H ARE KW/M**2 C    > ')
      C
        779 WRITE( 6,27)N,P(N),TWO(N),TWI(N),TF(N),TFSAT(N),SUBCL(N),DTF(N),S
           3UB(N),HSUB(N),HMS(N),HPAP(N),HESDU(N),HDB(N),HST(N)
         27 FORMAT(2X,I2,F6.2,F6.1,F6.1,F6.1,F6.1,1X,F5.1,1X,F5.1,1X,F6.1,F6.2
           1,F6.2,F6.2,F6.2,F6.2,F6.2)
```

```
C
      N=N+1
      IF(N-73.5)128,600,600
  123 IF(N-Y)779,122,122
C
C     PRINTOUT OF SATURATED REGION RESULTS TABLE
C
  122 WRITE( 6,129)
  129 FORMAT(/52X,15HSATURATED FLUID)
C
      WRITE( 6,130)
  130 FORMAT(1X,'POS FLUID OUTER INNER SAT N  TWI  QUAL   1/    VOID
     1H      H       H       H       H       H       H          H',/,5X,'PRESS TE
     2MP  TEMP  TEMP  -TSAT ITY     XTT   FRAC   BOIL   MIC    MAC    TOT
     3     G-T     S-G      L-Y     CHAW',/,6X,'BAR  DEG C DEG C DEG C DEG C
     4                    <                  UNITS FOR H ARE KW/M**2 C
     5        >')
C
  133 WRITE( 6,26)N,P(N),TWO(N),TWI(N),TFSAT(N),DTSAT(N),X(N),Z(N),ALPHA
     1(N),HBOIL(N),HCMIC(N),HCMAC(N),HCTOT(N),HGT(N),HSG(N),HLY(N),HCH(N
     2)
   26 FORMAT(2X,I2,F6.2,F6.1,F6.1,F6.1,F6.1,F5.3,F3.3,F5.3,F7.2,F7.2,F7.
     12,F7.2,F7.2,F7.2,F7.2,F7.2)
C
      N=N+1
      IF(N-73.5)133,600,600
C
C     PRINTOUT OF ADDITIONAL SUBCOOLED REGION RESULTS TABLE
C
  600 WRITE( 6,256)
  256 FORMAT(/,52X,'SUB-COOLED FLUID')
C
C
      WRITE( 6,257)
  257 FORMAT(1X,'POS TFILM CLIQF VLIQF TLIQF PR.NF CPLFQ VSLFQ TCLFQ PR.
     1NO REN.NO  ROLFQ RHVAP CPLIQ HEVAP H LIQ                         ',/,5X,
     2'DEG C  KJ/  MN S/  MW/            KJ/  MN S/  MW/',17X,'KG/    KG/
     3KJ/    KJ/    KJ/',/,11X,'KG C  M**2    M K',6X,'KG C  M**2    M K',17
     4X,'M**3  M**3 KG C   KG      KG')
C
      N=2
  260 WRITE( 6,258)N,TFILM(N),CPLIQF(N),VSLIQF(N),TCLIQF(N),PRNF(N),CPLF
     1Q(N),VISLFQ(N),THCLFQ(N),PRNO(N),RENO(N),RHOLFQ(N),RHOVAP(N),CPLIQ
     2(N),HEVAP(N),HF(N)
  258 FORMAT(2X,I2,F6.1,F6.3,F5.3,1X,F6.1,F6.3,F6.3,F5.3,1X,F6.1,F6.3,F8
     1.0,F6.1,F6.1,F6.3,F6.1,F6.1)
C
      N=N+1
      IF(N-73.5)259,700,700
  259 IF(N-Y)260,261,261
C
C     PRINT OUT OF ADDITIONAL SATURATED REGION RESULTS TABLE
C
  261 WRITE( 6,262)
  262 FORMAT(/52X,'SATURATED FLUID')
C
C     PRINT OUT PARAMETERS WHICH DO NO VARY OVER THE SATURATED
C     BOILING REGION
C
      WRITE(6,53)BO(73)
   53 FORMAT(//,2X,'BOILING NO. = ',F8.5,//)
C
      WRITE( 6,263)
  263 FORMAT(1X,'POS ROLIQ RHVAP HEVAP CPLIQ VSLIQ VISVAP THCLIQ SUTEN
     1REYNUM RECHEN  PWALL HCNB   RSTAR     DEL    FR.NO   CF       BC',/
     2,6X,'KG/    KG/    KJ/    KJ/  MN S/  MN S/  MW/    MN/M',18X,'BAR
     3KW/      M.           M.',/,6X,'M**3  M**3  KG    KG C  M**2    M**2   M
     4K',31X,'M**2C')
C
  265 WRITE( 6,264)N,RHOLIQ(N),RHOVAP(N),HEVAP(N),CPLIQ(N),VISLIQ(N),VIS
     2VAP(N),THCLIQ(N),SURTEN(N),RENUM(N),RECHEN(N),PWALL(N),HCNB(N),RST
     3AR(N),DEL(N),FR(N),CF(N),BC(N)
  264 FORMAT(2X,I2,F6.1,F6.1,F6.1,F6.3,F5.3,2X,F6.4,F7.2,F6.2,F8.0,F8.0,
     1F6.2,F6.2,E9.3,E9.3,F6.3,F8.4,F6.1)
C
      N=N+1
      IF(N-73.5)265,700,700
  700 IDATA=IDATA+1
  603 IF(NDATA-IDATA)602,602,601
  601 GO TO 903
  602 STOP
      END
```

Note 1

The following changes were required for processing biphenyl-biphenyl oxide data:

(i) 3rd order polynomial coefficients (Table 13) in lines 283-392.

(ii) Critical temperature of 770.2 K in lines 378, 392, 415, 535, 664, 669 and 694.

(iii) Critical pressure of 32.04 bar in lines 385 and 412.

(iv) Molecular weight of 165 in line 557.

(v) Replacement of the 6th order polynomial for calculating the saturation temperature as a function of reduced pressure in lines 390-391 and 413-414 by the following:-

```
TFSAT(N) = 183.155 + 354.99*PR(N) - 51761.6*PR(N)**2
         + 510424.0*PR(N)**3 - 2890910.0*PR(N)**4
         + 8534430.0*PR(N)**5 - 10147800.0*PR(N)**6
```

Note 2

The Chen F_c and S_c factors of Fig. 9 were fitted to an equation of the type $y = ax^n$.

(a) $F_c = k(1/X_{tt})^n$

$^1/X_{tt}$	k	n
.1 - .2	2.4	.38
.2 - .3	2.27	.346
.3 - .6	2.47	.412
.6 - 2.0	2.80	.655
2.0 - 10.0	2.67	.719
10.0 - 100.0	2.80	.699

(b) $S_c = c(Re)^n$

where $Re = Re_L \times F_c^{-1.25}$

$Re_L \times F_c^{-1.25}$	c	n
$1.5 \times 10^4 - 3.0 \times 10^4$	10.643	-.264
$3.0 \times 10^4 - 5.0 \times 10^4$	44.22	-.402
$5.0 \times 10^4 - 8.0 \times 10^4$	131.9	-.5032
$8.0 \times 10^4 - 1.0 \times 10^5$	4560.	-.817
$1.0 \times 10^5 - 2.0 \times 10^5$	1820.	-.737
$2.0 \times 10^5 - 4.0 \times 10^5$	358416.	-1.17
$4.0 \times 10^5 \longrightarrow$	$S_c = 0.1$	

Note 3

The two-phase factor ε used for the Chawla correlation shown in Fig. 10 was taken to be the value at $e/D = 1 \times 10^{-4}$ applicable to commercial drawn tubing. For values of the abscissa of Fig. 10 greater than .001 ε was 10 x the abscissa value. For values less than .001 ε was .316 x (abscissa value)$^{0.5}$.

SPECIMEN OUTPUT OF DATA REDUCTION COMPUTER PROGRAM (PAGES 202-5)

The initial portion of the print-out gives the test identification, experimental conditions, power input comparison figures and the pressure drop components as calculated using the homogeneous theory. There then follows two sets of derived results for each thermocouple position along the test section from inlet to exit in cases where the saturated liquid enthalpy has been exceeded. Position 2 corresponds to thermocouple No. 71 in Fig. 24 and Position 72 to thermocouple No. 1.

In the example shown since the wall temperature was above the saturation temperature sub-cooled boiling conditions were present from the commencement of the heated length to position No. 28 (thermocouple No. 45 in Fig. 24). Between position Nos. 28 and 29 the saturated liquid enthalpy was exceeded and net boiling was assumed to have commenced. Wall dry-out conditions were experienced in the test in question, the position of the commencement of the dry-out front being at around position No.68 (thermocouple No. 5 in Fig. 24).

TEST DATE 11/02/75 TEST NO. OF DAY - 9 SERIES TEST NO. - 158 REDUCED PRESSURE - .39

INLET PRESS BAR	EXIT PRESS BAR	INLET TEMP DEG C	EXIT TEMP DEG C	FLOW KG/S	TEST SECTION VOLTS	TEST SECTION AMPS
18.228	18.094	254.8	284.2	.0785	19.04	655.5

PRESS.DROP BAR	INLET SUB. KJ/KG	MASS VEL. KG/M**2 S	INLET VEL. M/S	HEAT FLUX KW/M**2
.134	57.3	624.6	.767	159.4

POWER (V*A) KW	POWER (I**2R) KW	POWER (M.CP.T) KW	POWER LOSS KW	CORRECTED POWER KW
12.48	12.20	4.52	.90	11.58

CALCULATED SINGLE PHASE PRESSURE DROP FRICTION	ACCEL	GRAV	TOTAL	CALCULATED TWO PHASE PRESSURE DROP FRICTION	ACCEL	GRAV	TOTAL	TOTAL PRESS DROP	TOTAL PRESS DROP
< UNITS FOR PRESSURE DROP COMPONENTS ARE KN/M**2								>	BAR
.34	.02	6.78	7.13	1.69	2.58	3.55	7.83	14.96	.150

SUB-COOLED FLUID

POS	FLUID PRESS BAR	OUTER TEMP DEG C	INNER TEMP DEG C	FLUID TEMP DEG C	SAT N TEMP DEG C	TSAT - TF DEG C	TWI - TF DEG C	SUB COOL. KJ/KG	H SUB	H M-S	H PAP	H ESDU	H D-B	H S-T
									< UNITS FOR H ARE KW/M**2 C >					
2	18.21	297.9	290.9	255.9	284.1	28.2	35.0	55.3	4.56	3.89	3.24	1.53	1.54	1.65
3	18.21	296.7	289.6	256.9	284.1	27.2	32.7	53.2	4.87	3.97	3.35	1.54	1.54	1.65
4	18.21	298.1	291.0	257.9	284.1	26.2	33.1	51.1	4.81	4.05	3.46	1.54	1.55	1.66
5	18.21	297.2	290.1	258.9	284.1	25.2	31.2	49.1	5.10	4.14	3.59	1.54	1.55	1.66
6	18.21	297.0	290.0	259.9	284.1	24.2	30.1	47.0	5.30	4.23	3.72	1.54	1.55	1.67
7	18.21	297.9	290.9	260.9	284.1	23.2	29.9	45.0	5.32	4.33	3.86	1.55	1.56	1.67
8	18.20	297.5	290.5	261.9	284.1	22.2	28.6	42.9	5.58	4.43	4.02	1.55	1.56	1.68
9	18.20	297.5	290.5	262.9	284.1	21.1	27.6	40.8	5.78	4.54	4.19	1.55	1.56	1.68
10	18.20	297.9	290.9	263.9	284.1	20.1	26.9	38.8	5.92	4.67	4.38	1.56	1.57	1.69
11	18.20	298.1	291.0	265.0	284.1	19.1	26.1	36.7	6.11	4.80	4.58	1.56	1.57	1.69
12	18.20	297.2	290.1	266.0	284.1	18.1	24.2	34.6	6.59	4.94	4.81	1.56	1.57	1.70
13	18.20	298.1	291.0	267.0	284.1	17.1	24.1	32.6	6.62	5.09	5.06	1.57	1.58	1.70
14	18.20	298.1	291.0	268.0	284.0	16.1	23.1	30.5	6.91	5.26	5.33	1.57	1.58	1.71
15	18.19	297.7	290.7	269.0	284.0	15.1	21.7	28.5	7.35	5.44	5.65	1.58	1.59	1.71
16	18.19	298.1	291.0	270.0	284.0	14.0	21.0	26.4	7.58	5.65	6.00	1.58	1.59	1.72
17	18.19	298.4	291.4	271.0	284.0	13.0	20.4	24.3	7.82	5.87	6.41	1.58	1.59	1.72
18	18.19	297.9	290.9	272.0	284.0	12.0	18.8	22.3	8.46	6.13	6.87	1.59	1.60	1.73
19	18.19	297.4	290.3	273.0	284.0	11.0	17.3	20.2	9.21	6.42	7.42	1.59	1.60	1.73
20	18.19	298.3	291.2	274.0	284.0	10.0	17.2	18.1	9.27	6.75	8.06	1.59	1.60	1.74
21	18.18	298.4	291.4	275.0	284.0	9.0	16.4	16.1	9.75	7.13	8.84	1.60	1.61	1.74
22	18.18	298.1	291.0	276.0	284.0	8.0	15.0	14.0	10.63	7.59	9.80	1.60	1.61	1.75
23	18.18	296.8	289.8	277.0	284.0	6.9	12.7	12.0	12.50	8.15	11.02	1.60	1.62	1.76
24	18.18	297.4	290.3	278.1	284.0	5.9	12.3	9.9	12.99	8.83	12.61	1.61	1.62	1.76
25	18.18	297.7	290.7	279.1	284.0	4.9	11.6	7.8	13.72	9.72	14.80	1.61	1.62	1.77
26	18.18	297.7	290.7	280.1	284.0	3.9	10.6	5.8	15.03	10.93	18.01	1.62	1.63	1.77
27	18.18	297.4	290.3	281.1	284.0	2.9	9.2	3.7	17.24	12.74	23.25	1.62	1.63	1.76
28	18.17	298.1	291.0	282.1	284.0	1.9	8.9	1.6	17.82	15.84	33.52	1.62	1.64	1.78

SATURATED FLUID

POS	FLUID PRESS BAR	OUTER TEMP DEG C	INNER TEMP DEG C	SAT N TEMP DEG C	TWI -TSAT DEG C	QUALITY	1/ XTT	VOID FRAC	H BOIL	H MIC	H MAC	H TOT	H G-T	H S-G	H L-Y	H CHAW
									< UNITS FOR H ARE KW/M**2 C >							
29	18.17	297.5	290.5	284.0	6.5	.002	.011	.024	24.35	4.62	.71	5.33	3.51	13.82	11.44	.01

30	18.17	298.3	291.2	283.9	7.3	.012	.054	.129	21.96	3.44	1.29	4.73	7.61	13.98	11.49	.05
31	18.17	297.5	290.5	283.9	6.6	.022	.094	.213	24.30	3.03	1.58	4.61	9.15	14.09	11.52	.09
32	18.17	297.7	290.7	283.9	6.7	.031	.133	.283	23.64	3.12	1.79	4.90	10.77	14.18	11.56	.14
33	18.17	298.8	291.7	283.9	7.8	.041	.172	.341	20.41	3.63	1.95	5.58	12.99	14.26	11.62	.18
34	18.16	297.0	290.0	283.9	6.0	.051	.210	.391	26.36	2.79	2.08	4.87	12.23	14.34	11.64	.23
35	18.16	297.7	290.7	283.9	6.8	.061	.248	.434	23.58	3.26	2.19	5.45	13.92	14.41	11.69	.28
36	18.16	296.7	289.6	283.9	5.7	.071	.287	.471	27.94	2.74	2.28	5.02	13.40	14.48	11.72	.32
37	18.16	297.7	290.7	283.9	6.8	.080	.325	.504	23.53	3.27	2.39	5.66	15.47	14.54	11.78	.37
38	18.16	297.4	290.3	283.9	6.4	.090	.364	.533	24.81	3.10	2.48	5.58	15.68	14.60	11.82	.42
39	18.16	296.1	289.1	283.9	5.2	.100	.404	.559	30.70	2.49	2.57	5.05	14.46	14.66	11.85	.47
40	18.16	297.0	290.0	283.9	6.1	.110	.444	.582	26.20	2.93	2.65	5.57	16.33	14.72	11.91	.52
41	18.15	297.0	290.0	283.9	6.1	.120	.484	.604	26.17	2.93	2.72	5.65	16.84	14.78	11.96	.57
42	18.15	296.7	289.6	283.9	5.7	.129	.525	.623	27.76	2.76	2.79	5.54	16.75	14.84	12.00	.62
43	18.15	297.5	290.5	283.9	6.6	.139	.566	.641	24.03	3.20	2.85	6.05	18.61	14.89	12.06	.67
44	18.15	297 5	290.5	283.9	6.6	. 9	. 0	.657	24.01	3.20	2.92	6 12	19.05	14.95	2. 1	. 3
44	18.15	297.5	290.5	283.9	6.6	.149	.608	.657	24.01	3.20	2.92	6.12	19.05	14.95	12.11	.73
45	18.15	296.7	289.6	283.9	5.8	.159	.651	.672	27.67	3.13	3.02	6.15	17.98	15.00	12.15	.78
46	18.15	297.5	290.5	283.8	6.7	.169	.694	.685	23.96	3.63	3.12	6.75	19.86	15.06	12.21	.83
47	18.14	297.0	290.0	283.8	6.1	.178	.738	.698	26.01	3.34	3.22	6.56	19.32	15.11	12.26	.88
48	18.14	297.5	290.5	283.8	6.7	.188	.783	.710	23.92	3.64	3.32	6.95	20.59	15.17	12.32	.94
49	18.14	297.5	290.5	283.8	6.7	.198	.829	.721	23.89	3.64	3.41	7.05	20.93	15.22	12.37	.99
50	18.14	297.4	290.3	283.8	6.5	.208	.875	.732	24.52	3.54	3.50	7.04	20.93	15.28	12.43	1.04
51	18.14	296.5	289.4	283.8	5.6	.218	.922	.742	28.35	3.05	3.59	6.64	19.58	15.33	12.47	1.10
52	18.14	297.0	290.0	283.8	6.2	.227	.971	.751	25.86	3.35	3.67	7.02	20.86	15.39	12.53	1.15
53	18.14	298.6	291.6	283.8	7.8	.237	1.020	.760	20.55	4.25	3.75	8.00	24.00	15.44	12.61	1.21
54	18.13	297.7	290.7	283.8	6.9	.247	1.070	.768	23.17	3.76	3.83	7.59	22.70	15.49	12.66	1.26
55	18.13	297.0	290.0	283.8	6.2	.257	1.121	.776	25.80	3.36	3.91	7.27	21.61	15.55	12.71	1.32
56	18.13	297.9	290.9	283.8	7.1	.267	1.174	.783	22.55	3.86	3.99	7.85	23.52	15.60	12.78	1.38
57	18.13	297.7	290.7	283.8	6.9	.276	1.227	.790	23.11	3.76	4.06	7.83	23.42	15.66	12.84	1.43
58	18.13	298.4	291.4	283.8	7.6	.286	1.282	.797	20.94	4.17	4.13	8.30	24.96	15.72	12.91	1.49
59	18.13	299.0	291.9	283.8	8.1	.296	1.338	.803	19.56	4.47	4.20	8.67	26.13	15.77	12.98	1.55
60	18.13	301.1	294.0	283.8	10.3	.306	1.395	.809	15.51	5.65	4.27	9.96	29.95	15.83	13.07	1.61
61	18.12	299.1	292.1	283.8	8.3	.316	1.454	.815	19.12	4.58	4.34	8.92	26.86	15.89	13.12	1.66
62	18.12	298.1	291.0	283.7	7.3	.325	1.514	.821	21.89	3.98	4.41	8.39	25.08	15.95	13.17	1.72
63	18.12	296.8	289.8	283.7	6.1	.335	1.576	.826	26.34	3.29	4.47	7.76	22.77	16.00	13.23	1.78
64	18.12	296.0	288.9	283.7	5.2	.345	1.639	.831	30.82	2.80	4.53	7.33	20.99	16.06	13.29	1.84
65	18.12	296.0	288.9	283.7	5.2	.355	1.704	.836	30.79	2.80	4.59	7.39	21.11	16.12	13.36	1.90
66	18.12	297.5	290.5	283.7	6.8	.365	1.770	.841	23.52	3.69	4.65	8.35	24.64	16.19	13.45	1.96
67	18.11	297.9	290.9	283.7	7.1	.374	1.839	.846	22.33	3.90	4.71	8.61	25.48	16.25	13.53	2.02
68	18.11	308.4	301.4	283.7	17.7	.384	1.909	.850	9.00	10.06	4.77	14.83	42.40	16.31	13.74	2.08
69	18.11	322.0	315.1	283.7	31.4	.394	1.981	.854	5.08	18.69	4.82	23.51	58.44	16.37	13.99	2.14
70	18.11	343.9	337.2	283.7	53.5	.404	2.055	.859	2.98	34.43	4.87	39.30	78.88	16.44	14.32	2.20
71	18.11	389.9	383.4	283.7	99.7	.413	2.132	.863	1.60	.00	4.93	4.93	111.86	16.50	.00	2.27
72	18.11	399.8	393.4	283.7	109.7	.423	2.210	.867	1.45	.00	4.99	4.99	118.29	16.57	.00	2.33
73	18.11	399.8	393.4	283.7	109.7	.433	2.291	.870	1.45	.00	5.06	5.06	118.59	16.64	.00	2.39

SUB-COOLED FLUID

POS	TFILM	CLIQF	VLIQF	TLIQF	PR.NF	CPLFQ	VSLFQ	TCLFQ	PR.NO	REN.NO	ROLFQ	RHVAP	CPLIQ	HEVAP	H LIQ
	DEG C	KJ/ KG C	MN S/ M**2	MW/ M K		KJ/ KG C	MN S/ M**2	MW/ M K			KG/ M**3	KG/ M**3	KJ/ KG C	KJ/ KG	KJ/ KG
2	273.4	1.973	.114	76.7	2.920	1.898	.128	79.7	3.046	61779.	812.2	60.7	2.034	210.1	411.8
3	273.3	1.972	.114	76.7	2.921	1.902	.127	79.5	3.037	62204.	810.5	60.7	2.034	210.1	413.9
4	274.5	1.979	.113	76.5	2.914	1.906	.126	79.4	3.029	62633.	808.8	60.7	2.034	210.1	415.9
5	274.5	1.979	.113	76.5	2.914	1.909	.125	79.2	3.021	63065.	807.0	60.7	2.034	210.1	418.0
6	274.9	1.981	.112	76.4	2.911	1.913	.124	79.0	3.013	63500.	805.3	60.7	2.034	210.1	420.0
7	275.9	1.986	.112	76.2	2.906	1.917	.124	78.8	3.005	63936.	803.5	60.7	2.034	210.1	422.1
8	276.2	1.988	.111	76.2	2.905	1.921	.123	78.7	2.997	64379.	801.8	60.6	2.034	210.1	424.1
9	276.7	1.991	.111	76.1	2.902	1.925	.122	78.5	2.989	64823.	800.0	60.6	2.034	210.1	426.2

10	277.4	1.994	.110	76.0	2.899	1.929	.121	78.3	2.982	65271.	798.2	60.6	2.034	210.1	428.2
11	278.0	1.998	.110	75.9	2.896	1.934	.120	78.2	2.974	65722.	796.3	60.6	2.034	210.1	430.3
12	278.1	1.998	.110	75.9	2.896	1.938	.119	78.0	2.967	66175.	794.5	60.6	2.034	210.1	432.3
13	279.0	2.003	.109	75.7	2.891	1.942	.119	77.8	2.960	66632.	792.6	60.6	2.034	210.1	434.4
14	279.5	2.006	.109	75.6	2.889	1.947	.118	77.6	2.953	67092.	790.7	60.6	2.034	210.1	436.4
15	279.8	2.008	.109	75.5	2.888	1.952	.117	77.5	2.947	67556.	788.8	60.6	2.033	210.2	438.5
16	280.5	2.012	.108	75.4	2.885	1.956	.116	77.3	2.940	68024.	786.9	60.6	2.033	210.2	440.5
17	281.2	2.016	.108	75.3	2.882	1.961	.115	77.1	2.934	68491.	785.0	60.6	2.033	210.2	442.6
18	281.4	2.017	.107	75.3	2.881	1.966	.115	76.9	2.928	68964.	783.0	60.6	2.033	210.2	444.6
19	281.7	2.019	.107	75.2	2.880	1.971	.114	76.8	2.922	69439.	781.0	60.6	2.033	210.2	446.7
20	282.6	2.025	.107	75.0	2.876	1.976	.113	76.6	2.916	69918.	779.0	60.6	2.033	210.2	448.7
21	283.2	2.028	.106	74.9	2.874	1.981	.112	76.4	2.911	70399.	777.0	60.6	2.033	210.2	450.8
22	283.5	2.030	.106	74.9	2.873	1.987	.111	76.2	2.906	70884.	775.0	60.6	2.033	210.2	452.8
23	283.4	2.030	.106	74.9	2.873	1.992	.111	76.0	2.900	71371.	772.9	60.6	2.033	210.2	454.9
24	284.2	2.034	.105	74.7	2.871	1.998	.110	75.9	2.896	71862.	770.8	60.5	2.033	210.2	456.9
25	284.9	2.039	.105	74.6	2.868	2.004	.109	75.7	2.891	72355.	768.7	60.5	2.033	210.2	459.0
26	285.4	2.042	.105	74.5	2.867	2.009	.108	75.5	2.887	72852.	766.6	60.5	2.033	210.2	461.0
27	285.7	2.044	.104	74.5	2.866	2.015	.108	75.3	2.882	73351.	764.5	60.5	2.033	210.2	463.1
28	286.6	2.050	.104	74.3	2.863	2.021	.107	75.1	2.878	73853.	762.3	60.5	2.033	210.2	465.1

SATURATED FLUID

BOILING NO. = .00121

POS	ROLIQ KG/ M**3	RHVAP KG/ M**3	HEVAP KJ/ KG	CPLIQ KJ/ KG C	VSLIQ MN S/ M**2	VISVAP MN S/ M**2	THCLIQ MW/ M K	SUTEN MN/M	REYNUM	RECHEN	PWALL BAR	HCNB KW/ M**2C	RSTAR M.	DEL M.	FR.NO	CF	BC
29	758.2	60.5	210.3	2.033	.106	.0151	74.79	4.83	74791.	214913.	19.83	1.64	.230-07	.797-05	5.447	2.2644	1.2
30	758.2	60.5	210.3	2.033	.106	.0151	74.79	4.83	74788.	99999.	20.02	1.63	.207-07	.797-05	5.340	.3801	6.8
31	758.2	60.5	210.3	2.033	.106	.0151	74.79	4.83	74785.	76877.	19.83	1.62	.229-07	.797-05	5.235	.2065	12.5
32	758.2	60.5	210.3	2.033	.106	.0151	74.80	4.83	74782.	65226.	19.88	1.60	.223-07	.797-05	5.130	.1413	18.1
33	758.2	60.5	210.3	2.033	.106	.0151	74.80	4.83	74778.	57817.	20.16	1.59	.193-07	.797-05	5.026	.1071	23.7
34	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74775.	52713.	19.69	1.58	.249-07	.797-05	4.924	.0861	29.2
35	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74772.	49025.	19.88	1.56	.223-07	.797-05	4.823	.0718	34.7
36	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74769.	46064.	19.60	1.55	.264-07	.797-05	4.722	.0615	40.2
37	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74766.	43048.	19.88	1.54	.222-07	.797-05	4.623	.0537	45.7
38	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74763.	40609.	19.78	1.52	.234-07	.797-05	4.525	.0476	51.1
39	758.3	60.5	210.3	2.033	.106	.0151	74.80	4.83	74760.	38517.	19.46	1.51	.290-07	.797-05	4.428	.0427	56.5
40	758.3	60.4	210.3	2.033	.106	.0151	74.81	4.83	74756.	36694.	19.69	1.50	.248-07	.797-05	4.331	.0367	61.9
41	758.3	60.4	210.3	2.032	.106	.0151	74.81	4.83	74753.	35086.	19.69	1.48	.247-07	.797-05	4.236	.0353	67.2
42	758.4	60.4	210.3	2.032	.106	.0151	74.81	4.83	74750.	33652.	19.60	1.47	.262-07	.797-05	4.142	.0325	72.6
43	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.83	74747.	32360.	19.83	1.46	.227-07	.797-05	4.050	.0300	77.8
44	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.84	74744.	31012.	19.83	1.44	.227-07	.797-05	3.958	.0279	83.1
45	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.84	74741.	29337.	19.60	1.43	.262-07	.797-05	3.867	.0260	88.3
46	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.84	74738.	27827.	19.83	1.42	.227-07	.797-05	3.777	.0243	93.5
47	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.84	74734.	26459.	19.69	1.40	.246-07	.797-05	3.689	.0229	98.6
48	758.4	60.4	210.4	2.032	.106	.0151	74.81	4.84	74731.	25211.	19.83	1.39	.226-07	.798-05	3.601	.0215	103.7
49	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74728.	24068.	19.83	1.38	.226-07	.798-05	3.514	.0204	108.8
50	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74725.	23015.	19.78	1.36	.232-07	.798-05	3.429	.0193	113.8
51	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74722.	22042.	19.55	1.35	.268-07	.798-05	3.345	.0183	118.8
52	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74719.	21140.	19.69	1.34	.245-07	.798-05	3.261	.0174	123.8
53	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74716.	20299.	20.11	1.32	.194-07	.798-05	3.179	.0166	128.7
54	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74712.	19515.	19.88	1.31	.219-07	.798-05	3.098	.0158	133.6
55	758.5	60.4	210.4	2.032	.106	.0151	74.82	4.84	74709.	18780.	19.69	1.30	.244-07	.798-05	3.018	.0151	138.5
56	758.6	60.3	210.4	2.032	.106	.0151	74.82	4.84	74706.	18090.	19.92	1.28	.214-07	.798-05	2.938	.0144	143.3

57	758.6	60.3	210.5	2.032	.106	.0151	74.82	4.84	74703.	17440.	19.88	1.27	.219-07	.798-05	2.860	.0138 148.0
58	758.6	60.3	210.5	2.032	.106	.0151	74.83	4.84	74700.	15827.	20.07	1.25	.198-07	.798-05	2.783	.0133 152.8
59	758.6	60.3	210.5	2.032	.106	.0151	74.83	4.84	74697.	16248.	20.21	1.24	.185-07	.798-05	2.708	.0127 157.5
60	758.6	60.3	210.5	2.032	.106	.0151	74.83	4.84	74693.	15699.	20.79	1.23	.147-07	.798-05	2.633	.0122 162.1
61	758.6	60.3	210.5	2.032	.106	.0151	74.83	4.84	74690.	15177.	20.26	1.21	.181-07	.798-05	2.559	.0118 166.7
62	758.6	60.3	210.5	2.032	.106	.0151	74.83	4.84	74687.	14682.	19.97	1.20	.207-07	.798-05	2.486	.0113 171.3
63	758.7	60.3	210.5	2.032	.106	.0151	74.83	4.85	74684.	14209.	19.64	1.19	.250-07	.798-05	2.414	.0109 175.8
64	758.7	60.3	210.5	2.032	.106	.0151	74.83	4.85	74681.	13759.	19.41	1.17	.292-07	.798-05	2.344	.0105 180.3
65	758.7	60.3	210.5	2.032	.106	.0151	74.83	4.85	74678.	13328.	19.41	1.16	.292-07	.798-05	2.274	.0102 184.7
66	758.7	60.3	210.5	2.031	.106	.0151	74.83	4.85	74675.	12916.	19.83	1.14	.223-07	.798-05	2.206	.0098 189.1
67	758.7	60.3	210.5	2.031	.106	.0151	74.84	4.85	74671.	12521.	19.92	1.13	.212-07	.798-05	2.138	.0095 193.4
68	758.7	60.3	210.5	2.031	.106	.0151	74.84	4.85	74668.	12143.	22.91	1.11	.853-08	.798-05	2.072	.0092 197.7
69	758.7	60.3	210.5	2.031	.106	.0151	74.84	4.85	74665.	11779.	27.23	1.10	.482-08	.798-05	2.006	.0089 201.9
70	758.7	60.3	210.5	2.031	.106	.0151	74.84	4.85	74662.	11450.	35.47	1.09	.283-08	.798-05	1.942	.0086 206.1
71	758.8	60.3	210.6	2.031	.106	.0151	74.84	4.85	74659.	11080.	13.09	1.07	.152-08	.798-05	1.879	.0083 210.3
72	758.8	60.2	210.6	2.031	.106	.0151	74.84	4.85	74656.	10724.	12.54	1.06	.138-08	.798-05	1.817	.0081 214.3
73	758.8	60.2	210.6	2.031	.106	.0151	74.84	4.85	74653.	10382.	12.54	1.04	.138-08	.798-05	1.755	.0078 218.4

APPENDIX 3 - THERMODYNAMIC & TRANSPORT PROPERTIES OF THE TEST FLUIDS

A3.1

The thermophysical property data employed in the data reduction exercise are given in Tables 11 and 12 for Monochlorobenzene and Biphenyl-biphenyl oxide respectively. To facilitate their use in the data reduction computer program these property values were fitted to 3rd order polynomials as a function of reduced temperature. The polynomial coefficients derived in this latter exercise are given for both fluids in Table 13. Since only a small proportion of the property values given in Tables 11 and 12 could be obtained from the literature or manufacturers information use had to be made of property estimation techniques. The remainder of this Appendix is thus concerned with detailing the prediction methods adopted and the data sources consulted in compiling the property data for the two test fluids.

A3.2 Monochlorobenzene

Since experimental information on the thermodynamic properties of monochlorobenzene was almost non existent for the temperature range of interest predicted values were exclusively employed in respect of the following properties:- saturation pressure, liquid density, vapour density, liquid enthalpy, latent heat and vapour enthalpy. Three tabulations of thermodynamic properties of monochlorobenzene were available, each of which had been produced by a computer program employing different prediction techniques viz.:-

(i) The three parameter corresponding states method as used by Smith[79] which employed the Pitzer accentric factor as the third correlating parameter.

(ii) The Martin-Hou equation of state as programmed by Mohammed[80] using the procedure and constants for monochlorobenzene developed by Burnside[81].

TABLE 11 : Thermophysical properties of monochlorobenzene between 170 & 330^{o}C.

TEMP.	SAT. PRESS.	LIQUID DENSITY	VAPOUR DENSITY	LIQUID* ENTHALPY	LATENT HEAT	VAPOUR ENTHALPY	LIQUID SPECIFIC HEAT	VAPOUR SPECIFIC HEAT	LIQUID VISCOS.	VAPOUR VISCOS.	LIQUID THERMAL COND.	VAPOUR THERMAL COND.	SURFACE TENSION
C	MN/m^2	kg/m^3	kg/m^3	kJ/kg.	kJ/kg.	kJ/kg.	kJ/kgK	kJ/kgK	mNs/m^2	mNs/m^2	mW/mK	mW/mK	mN/m
170.0	.2565	935.5	8.5	264.1	290.5	554.6	1.664	1.231	.222	.0113	96.9	17.3	15.50
175.0	.2857	929.4	9.4	272.5	287.5	560.0	1.676	1.242	.215	.0114	95.9	17.6	15.03
180.0	.3173	923.4	10.4	281.0	284.4	565.4	1.690	1.253	.209	.0116	94.8	17.9	14.58
185.0	.3516	916.6	11.4	289.5	281.3	570.8	1.702	1.264	.202	.0117	93.3	18.3	14.00
190.0	.3885	909.9	12.6	298.2	278.1	576.3	1.714	1.274	.196	.0118	92.5	18.6	13.55
195.0	.4283	903.3	13.8	306.9	274.9	581.8	1.728	1.285	.190	.0120	91.4	18.9	13.06
200.0	.4710	896.1	15.2	315.7	271.6	587.3	1.741	1.296	.186	.0121	90.1	19.2	12.51
205.0	.5167	889.7	16.6	323.7	269.0	592.7	1.754	1.306	.179	.0123	89.3	19.6	12.08
210.0	.5661	882.6	18.1	331.6	266.6	598.2	1.768	1.317	.173	.0124	88.4	19.9	11.60
215.0	.6190	874.9	19.8	339.8	263.9	603.7	1.780	1.327	.168	.0126	87.2	20.2	11.08
220.0	.6757	868.1	21.6	348.0	261.1	609.1	1.795	1.337	.162	.0127	86.2	20.6	10.58
225.0	.7363	860.6	23.5	356.4	258.2	614.6	1.809	1.348	.158	.0129	85.2	20.9	10.08
230.0	.8011	852.5	25.6	365.0	255.0	620.0	1.821	1.358	.155	.0131	84.3	21.2	9.64
235.0	.8702	844.6	27.8	373.7	251.8	625.5	1.836	1.368	.150	.0133	83.3	21.6	9.17
240.0	.9438	836.8	30.2	382.6	248.3	630.9	1.850	1.378	.144	.0134	82.5	21.9	8.75
245.0	1.0221	828.5	32.8	391.5	244.7	636.2	1.884	1.388	.136	.0136	81.6	22.2	8.29
250.0	1.1053	820.3	35.6	400.7	240.8	641.5	1.900	1.397	.132	.0138	80.7	22.5	7.80
255.0	1.1935	811.7	38.6	410.0	236.8	646.8	1.916	1.407	.128	.0140	79.6	22.8	7.33
260.0	1.2870	802.6	41.8	419.4	232.6	652.0	1.932	1.416	.123	.0142	78.9	23.1	6.94
265.0	1.3860	793.0	45.3	429.1	228.1	657.2	1.950	1.426	.119	.0144	77.8	23.4	6.46
270.0	1.4906	783.7	49.0	438.9	223.5	662.4	1.968	1.435	.115	.0146	76.9	23.7	6.13
275.0	1.6011	774.0	53.0	448.9	218.5	667.4	1.990	1.445	.112	.0148	76.1	24.0	5.61
280.0	1.7176	763.9	57.4	459.1	213.3	672.4	2.014	1.454	.108	.0151	75.2	24.3	5.16
285.0	1.8404	753.6	62.1	469.5	207.8	677.3	2.039	1.463	.105	.0152	74.3	24.6	4.74
290.0	1.9696	742.4	67.2	480.0	202.0	682.0	2.064	1.472	.102	.0156	73.4	24.9	4.34
295.0	2.1054	731.0	72.7	490.8	195.9	686.7	2.094	1.481	.098	.0158	72.5	25.1	3.93
300.0	2.2482	718.9	78.8	501.8	189.4	691.2	2.130	1.490	.095	.0162	71.8	25.4	3.57
305.0	2.3979	706.7	85.4	513.1	182.5	695.6	2.174	1.498	.092	.0165	70.8	25.6	3.15
310.0	2.5550	693.5	92.7	524.6	175.1	699.7	2.226	1.507	.090	.0168	69.9	25.9	2.78
315.0	2.7194	679.3	100.8	536.4	167.2	703.6	2.290	1.515	.087	.0172	68.9	26.0	2.40
320.0	2.8916	664.5	109.8	548.5	158.8	703.3	2.360	1.524	.084	.0176	67.8	26.1	2.06
325.0	3.0716	648.1	119.9	561.0	149.6	710.6	2.440	1.532	.082	.0180	66.7	26.5	1.71
330.0	3.2596	630.5	131.6	573.9	139.6	713.5	2.520	1.540	.080	.0186	65.5	26.7	1.38

* Liquid enthalpy = 0 at 0^{o}C.

TEMP.	SAT. PRESS.	LIQUID DENSITY	VAPOUR DENSITY	LIQUID* ENTHALPY	LATENT HEAT	VAPOUR ENTHALPY	LIQUID SPECIFIC HEAT	VAPOUR SPECIFIC HEAT	LIQUID VISCOS.	VAPOUR VISCOS.	LIQUID THERMAL COND.	VAPOUR THERMAL COND.	SURFACE TENSION
C	MN/m^2	kg/m^3	kg/m^3	kJ/kg.	kJ/kg.	kJ/kg.	kJ/kgK	kJ/kgK	mNs/m^2	mNs/m^2	mW/mK	mW/mK	mN/m
230.0	.0537	877.0	2.2	408.7	309.8	718.5	2.181	1.643	.310	.0097	113.8	20.2	19.23
235.0	.0608	872.0	2.5	419.6	307.7	727.3	2.193	1.656	.300	.0098	113.1	20.6	18.77
240.0	.0686	868.0	2.9	430.3	305.6	735.9	2.210	1.669	.290	.0099	112.4	20.9	18.40
245.0	.0767	863.0	3.2	441.7	303.5	745.2	2.223	1.682	.281	.0100	111.7	21.3	17.95
250.0	.0865	857.9	3.6	453.1	301.5	754.6	2.235	1.695	.270	.0101	111.0	21.6	17.49
255.0	.0999	853.0	4.0	463.8	299.4	763.2	2.252	1.708	.260	.0102	110.3	22.0	17.06
260.0	.1089	848.0	4.4	474.7	297.3	777.2	2.264	1.720	.250	.0103	109.6	22.4	16.63
265.0	.1197	844.0	4.8	486.1	294.7	780.8	2.281	1.733	.245	.0104	108.9	22.7	16.29
270.0	.1324	839.0	5.3	497.3	292.6	789.9	2.294	1.745	.240	.0105	108.2	23.1	15.87
275.0	.1471	834.0	5.8	509.2	290.0	799.2	2.306	1.758	.230	.0106	107.5	23.5	15.46
280.0	.1629	828.9	6.3	520.8	288.0	808.8	2.323	1.770	.220	.0107	106.9	23.8	15.04
285.0	.1795	824.0	6.9	532.6	285.6	818.2	2.336	1.782	.215	.0108	106.2	24.2	14.64
290.0	.1972	819.0	7.4	543.8	283.1	826.9	2.348	1.794	.210	.0109	105.5	24.6	14.25
295.0	.2168	814.0	8.1	555.7	280.5	836.2	2.365	1.806	.205	.0110	104.8	25.0	13.85
300.0	.2383	809.1	8.7	567.5	277.9	845.4	2.378	1.818	.200	.0111	104.1	25.3	13.48
305.0	.2618	803.9	9.5	579.9	275.4	855.3	2.394	1.829	.195	.0112	103.4	25.7	13.08
310.0	.2854	798.0	10.2	592.0	273.1	865.1	2.407	1.841	.190	.0113	102.7	26.1	12.65
315.0	.3109	793.1	11.0	604.1	270.5	874.6	2.419	1.852	.185	.0114	102.0	26.4	12.29
320.0	.3384	787.9	12.1	615.9	268.0	883.9	2.436	1.864	.180	.0115	101.3	26.8	11.90
325.0	.3678	782.0	13.2	628.0	265.4	893.4	2.449	1.875	.175	.0116	100.6	27.2	11.46
320.0	.3972	777.0	14.3	640.6	262.6	903.2	2.465	1.886	.170	.0117	100.0	27.5	11.11
335.0	.4306	772.1	15.5	652.7	259.6	912.3	2.478	1.897	.165	.0118	99.3	27.9	10.76
340.0	.4650	766.0	16.8	665.2	256.6	921.8	2.491	1.908	.160	.0119	98.6	28.3	10.35
345.0	.5032	760.1	18.1	677.3	254.2	931.5	2.507	1.919	.155	.0120	97.9	28.7	9.96
350.0	.5443	754.9	19.4	689.9	251.2	941.1	2.520	1.929	.150	.0121	97.2	29.0	9.61

* Liquid enthalpy = 0 at 12^{o}C.

TABLE 12 : Thermophysical properties of Biphenyl-biphenyl oxide between 230 and 350^{o}C.

FLUID PROPERTY	UNITS	COEFFICIENTS FOR MONOCHLOROBENZENE				COEFFICIENTS FOR BIPHENYL-BIPHENYL OXIDE			
		A	B	C	D	A	B	C	D
Pressure	bar	-179.724	813.066	-1260.03	672.037	-86.1235	424.423	-706.063	397.152
Liquid Density	kg/m^3	8248.86	-26923.9	33757.6	-14583.3	1680.18	-2361.29	2685.56	-1459.1
Vapour Density	kg/m^3	-3213.73	12737.6	-16976.2	7646.52	-734.278	3262.0	-4891.31	2485.48
Liquid Enthalpy	kJ/kg	-2584.38	9481.1	-11223.3	4985.88	-87.632	-370.222	2086.07	-544.869
Latent Heat	kJ/kg	4977.66	-17639.8	22434.8	-9710.1	642.221	-1050.79	1368.05	-824.125
Vapour Enthalpy	kJ/kg	2393.28	-8158.71	11211.6	-4724.22	554.665	-1421.32	3454.53	-1369.18
Liq. Sp. Heat	kJ/kgK	-38.8633	153.419	-194.735	83.1821	.727834	2.37343	-.371775	.218399
Vap. Sp. Heat	kJ/kgK	-.0113466	2.04195	-.243593	-.201078	-.200124	3.57577	-1.10501	-.0762112
Liquid Viscosity	mNs/m^2	1.07081	-1.36449	-.121226	.48413	.118691	4.32818	-9.91645	5.70539
Vapour Viscosity	mNs/m^2	-.36404	1.3977	-1.74702	.736661	.000131574	.013093	.00385324	-.00219343
Liq. Ther. Cond.	mW/mK	904.624	-2748.82	3164.49	-1263.93	220.6	-257.905	204.22	-91.3999
Vap. Ther. Cond.	mW/mK	49.8086	-205.545	329.53	-146.217	14.4374	-69.315	168.666	-75.0746
Surface Tension	mN/m	19.7075	108.556	-244.894	116.351	98.6139	-203.46	166.87	-63.4757

Fluid property in stated units = $A + B.T_r + C.T_r^2 + D.T_r^3$

where T_r = reduced temperature, T/T_c

Table 13 Coefficients for 3rd order polynomial representation of thermophysical properties of monochlorobenzene and Biphenyl-biphenyl oxide.

(iii) Data of the Monsanto Corporation[82] which had been produced using the Hirschfelder-Buehler-McGee-Sutton equation of state.

A comparison of the predictions for each of these methods in respect of saturation pressure, liquid and vapour sp. volume and latent heat is given in Table 14 together with the available experimental values of these properties as obtained by Young[83]. The property values as calculated by the Martin-Hou equation of state were selected for incorporation in Table 11 in view of their better overall agreement with the experimental data.

The liquid specific heat of monochlorobenzene was calculated from the correlation of Reid & Sobell[84]. The latter is a three parameter corresponding states correlation for estimating the heat capacities of saturated liquids at reduced temperatures in the range .7 to .95. It is based on the generalised Lydersen et al tables[85] and involves six figures and two equations to determine the effect of increasing the pressure on the ideal gas until a saturated liquid results. The method can be represented by the following equation:-

$$Cp = f(Cp^o, p/p_c, Z_c, Tb_r) \qquad \text{(Eq. A3.1)}$$

where Cp^o = heat capacity of ideal gas at that temperature.

p/p_c = reduced vapour pressure.

Z_c = critical compressibility.

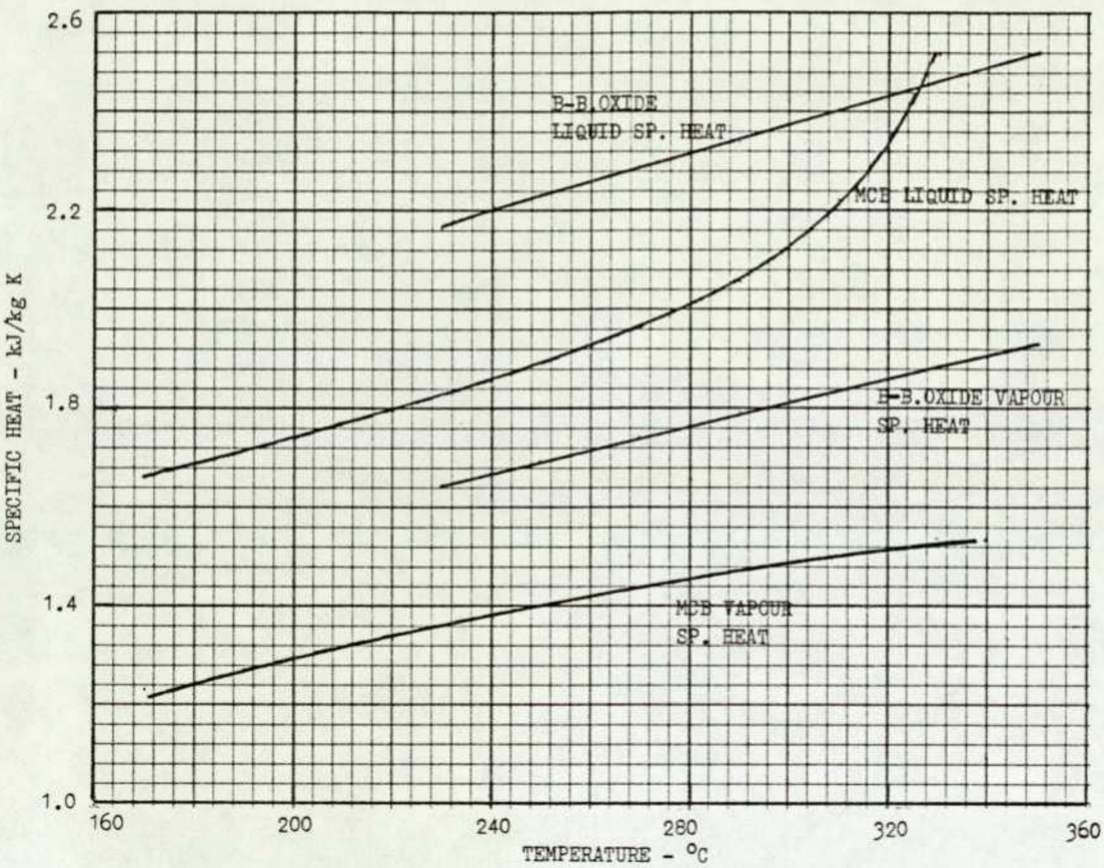
Tb_r = Tb/T_c = reduced boiling point temperature.

A graph of liquid specific heat versus temperature derived using the foregoing method is shown in the summary of the specific heat, viscosity, thermal conductivity and surface tension data for both test fluids in Fig. 58.

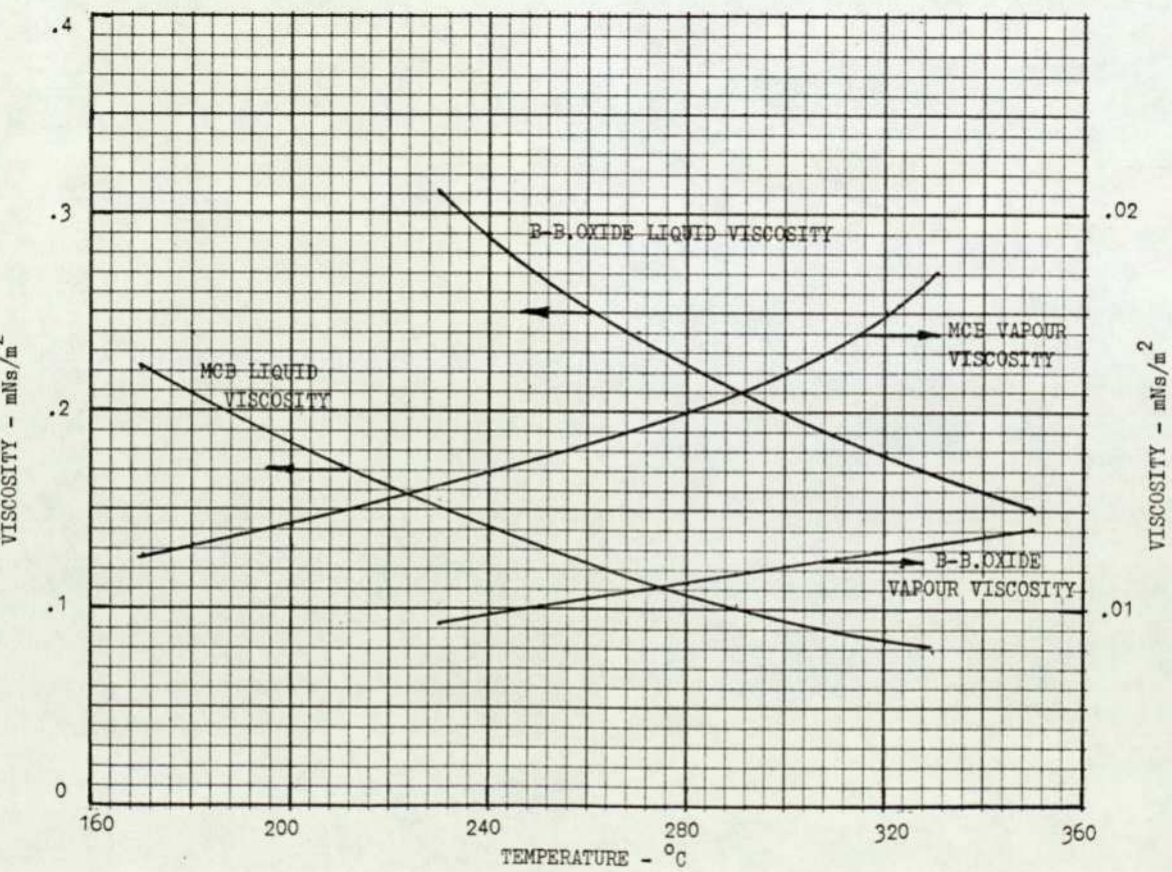
The vapour phase specific heat was assumed to be equal to the ideal or zero pressure specific heat Cp^o. The latter was expressed as a series expansion in absolute temperature[85], viz.:

$$Cp^o = A + B.T + C.T^2 + D.T^3 \qquad \text{(Eq. A3.2)}$$

the values of the constants in the above expression in which Cp^o has the units of kJ/(kg. mole ^oK), where:

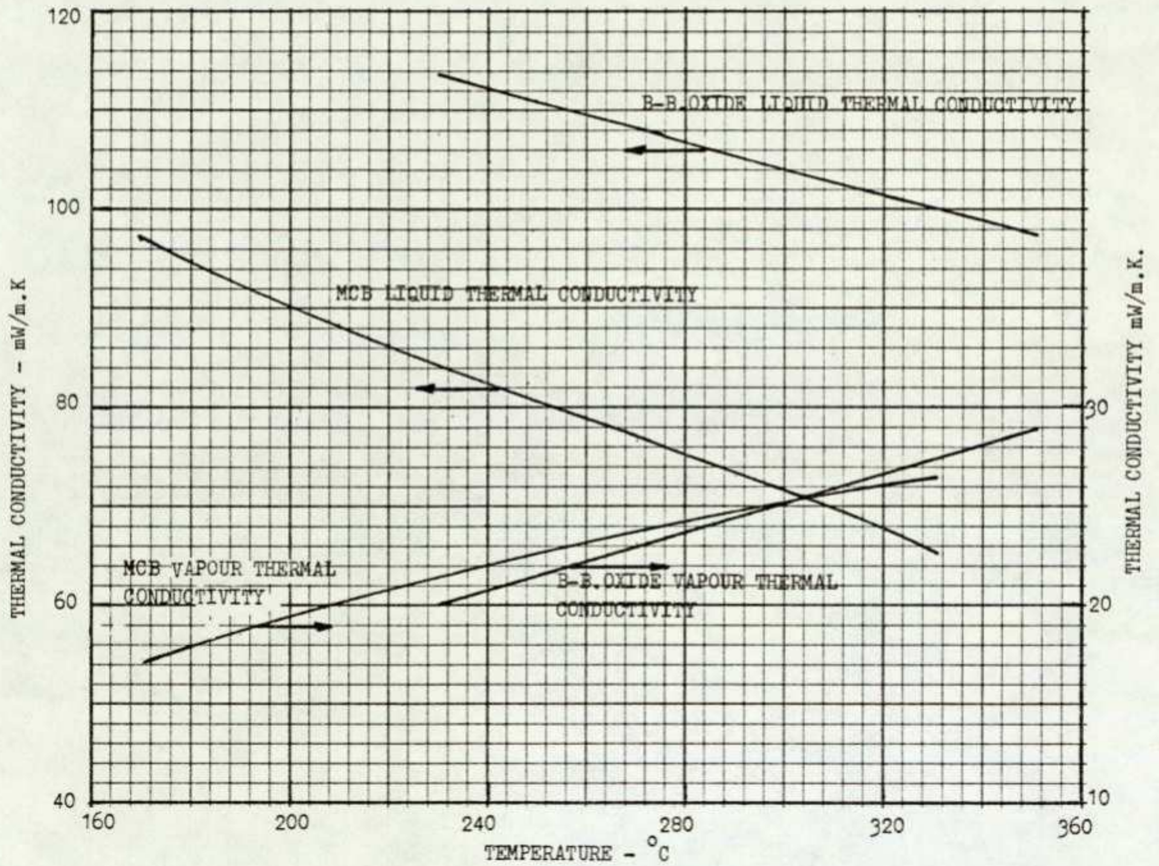


(A) LIQUID AND VAPOUR SPECIFIC HEAT

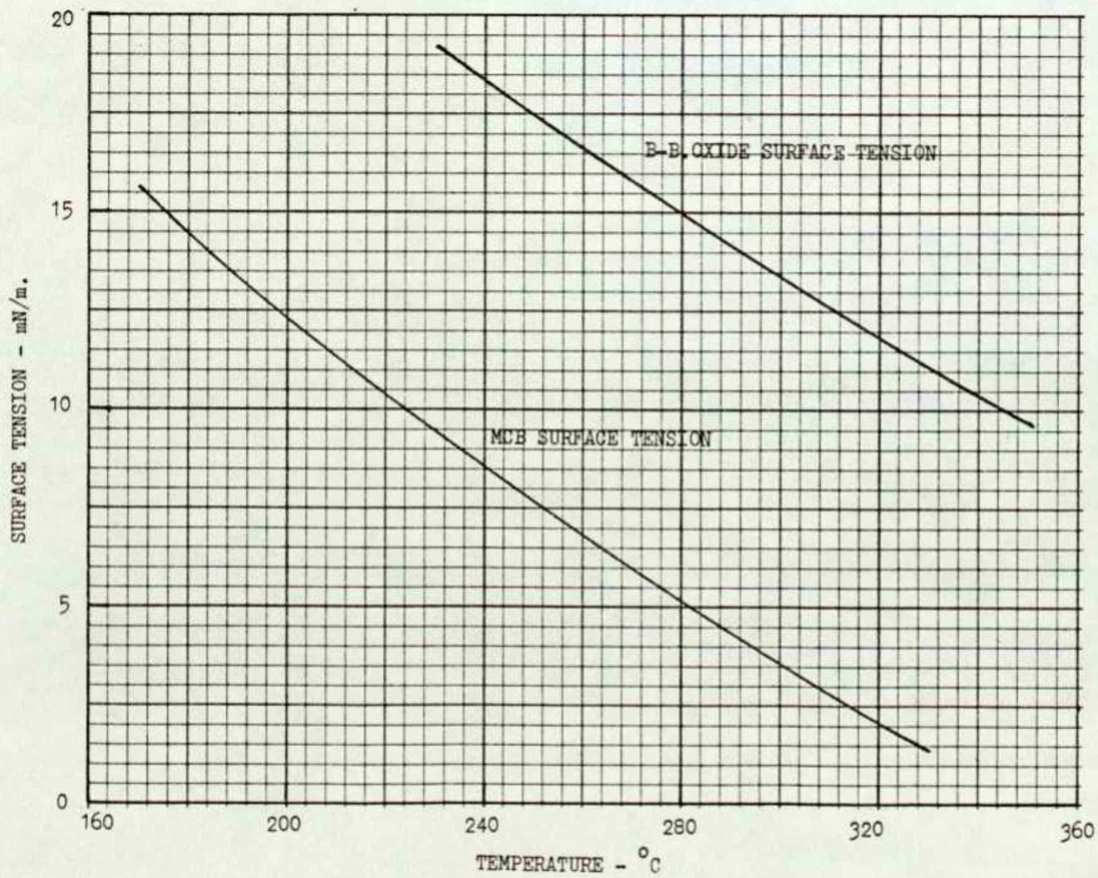


(B) LIQUID AND VAPOUR VISCOSITY

FIG.58 SUMMARY OF THERMOPHYSICAL PROPERTIES OF TEST FLUIDS



(E) LIQUID AND VAPOUR THERMAL CONDUCTIVITY



(D) SURFACE TENSION

FIG.58 CONCLUDED

TEMP. °C	PROPERTY UNITS	PITZER CORRESPONDING STATES METHOD	H-B-M-S EQ. OF STATE	MARTIN-HOU EQ. OF STATE	EXPERIMENTAL DATA OF YOUNG
160	Pressure MN/m^2	.2050	.2047	.2050	.2045
185		.3531	.3539	.3516	.3514
210		.5726	.5735	.5661	.5638
235		.8763	.8814	.8702	.8712*
260		1.2935	1.2965	1.2870	1.2862
285		1.8366	1.8413	1.8404	N.A.
310		2.5456	1.5414	2.555	N.A.
160	Liquid Sp. Volume $m^3/kg.10^3$	1.068	1.058	1.054	1.054
185		1.108	1.097	1.091	1.092
210		1.151	1.141	1.133	1.134
235		1.205	1.193	1.184	1.185*
260		1.266	1.256	1.246	1.247
285		1.347	1.336	1.327	N.A.
310		1.456	1.445	1.442	N.A.
160	Vapour Sp. Volume $m^3/kg.$	.1471	.1490	.1450	.1474
185		.0880	.0889	.0863	.0890
210		.0547	.0560	.0551	.0553
235		.0358	.0367	.0359	.0361*
260		.0239	.0248	.0239	.0240
285		.0162	.0171	.0161	N.A.
310		.0109	.0117	.0108	N.A.
160	Enthalpy of Evaporation kJ/kg.	300.2	306.6	296.3	298.3
180		284.8	292.1	281.3	285.3
210		267.9	276.3	266.6	268.7
235		250.0	258.7	251.8	252.6*
260		230.4	239.4	232.6	230.9
285		206.6	217.1	207.8	N.A.
310		175.9	189.8	175.1	N.A.

N.A. - Denotes experimental data not available.

* - Denotes linearly interpolated experimental value.

TABLE 14 : Comparison between calculated and experimental thermodynamic data for Monochlorobenzene.

A = - 4.7966, B = .38338, C = -.10579 x 10^{-3}, D = .66264 x 10^{-7}

which had been previously determined by Burnside[81] from a least squares fit to the spectroscopic data for monochlorobenzene of Whiffen[86].

The liquid viscosity experimental data given by Timmermans[87] for temperatures up to 240°C were extrapolated to 330°C using the method of Thorpe & Rodger[88]. The constants α, β and C given below were calculated using experimental values of the viscosity at 200, 220 and 240°C for use in the following expression:-

$$\mu_L = C/(1 + \alpha T + \beta T^2) \qquad \text{(Eq. A3.3)}$$

where α = -.00534, β = .00003907 and C = .00278

No experimental values of the viscosity of monochlorobenzene vapour could be found in the literature. The 'residual viscosity' correlation of Jossi et al[85] was used to derive vapour viscosity values for the temperature range up to 330°C. For non polar gases the following equation was used to determine the residual viscosity ($\mu-\mu^o$), for values of reduced density below 0.3:-

$$\xi(\mu-\mu^o) = (11.0\ e^{1.584\rho_r} - 11.0)(10^{-5}) \qquad \text{(Eq. A3.4)}$$

where: μ = viscosity, centipoises

$$\xi = \frac{T_c^{1/6}}{M^{\frac{1}{2}}\ p_c^{2/3}} \qquad \text{(Eq. A3.5)}$$

ρ_r = reduced density. = ρ/ρ_c

μ^o is the low pressure viscosity at the same temperature which for non-polar gases at reduced temperatures below 1.5 is given by the expression:-

$$\xi\mu^o = (34.0)(10^{-5}).\ T_r^{.94} \qquad \text{(Eq. A3.6)}$$

where: T_r = reduced temperature, T/T_c and ξ is as defined in Eq. A3.5 in which T_c = critical temperature °K, p_c = critical pressure, atmospheres and M = molecular weight.

The upper limit for experimental data on the thermal conductivity of liquid monochlorobenzene is given in the NEL compilation[89] as 120°C. Resort was therefore necessary to a thermal conductivity estimation method to calculate this property over the 170-330°C temperature range of interest. After an evaluation exercise had been undertaken of the several estimation techniques available[85] the viscosity values as given by the method of Stiel & Thodos were selected for use. This latter correlation bears a similarity to the previous one for vapour viscosity in the use of a 'residual' thermal conductivity ($k - k^o$) which was defined as a function of T_c, p_c, v_c, M & ρ_r. Since over the temperature range 170-330°C the reduced density, ρ_r takes values from 1.7 - 2.5 for monochlorobenzene it was necessary to use two of the expressions for residual thermal conductivity viz.:-

for $0.5 < \rho_r < 2.0$

$$(k-k^o)\gamma Z_c^5 = (13.1)(10^{-8})(e^{.67\rho_r} - 1.069) \qquad \text{(Eq. A3.7)}$$

For $2.0 < \rho_r < 2.8$

$$(k-k^o)\gamma Z_c^5 = (2.976)(10^{-8})(e^{1.155\rho_r} + 2.016) \qquad \text{(Eq. A3.8)}$$

where: k = thermal conductivity, cal/cm.sec.°K.

$$\gamma = \frac{T_c^{1/6} M^{\frac{1}{2}}}{p_c^{2/3}} \qquad \text{(Eq. A3.9)}$$

Z_c = Critical compressibility factor = $\frac{p_c v_c}{RT_c}$

k^o is the low pressure thermal conductivity at the same temperature which was calculated using the following expression applicable to aromatic hydrocarbons for reduced temperatures, T_r below 1.0:

$$\frac{k^o\gamma}{Cp} = (.455)(10^{-5})\ T_r \qquad \text{(Eq. A3.10)}$$

where Cp (cal/gmole °K) is the low pressure specific heat Cp^o (Eq. A3.2).

The vapour thermal conductivity was calculated in an identical manner as for the liquid phase from the Stiel & Thodos correlation, in this case using the following expression for the residual thermal conductivity for reduced densities below 0.5 in place of Eqs. A3.7 or A3.8:-

$$(k-k^o)\ \gamma\ Z_c^5 = (14.0)(10^{-8})(e^{-.535\rho_r} - 1) \qquad \text{(Eq. A3.11)}$$

The surface tension was calculated using the Sugden correlation[85]:-

$$\sigma^{.25} = (P) \quad (\rho_L - \rho_G) \qquad \text{(Eq. A3.11)}$$

where σ is the surface tension (dynes/cm.), ρ_L, ρ_G are the liquid and vapour densities (gm moles/cm^3) and P is a constant for a particular fluid known as the Parachor. This latter quantity has been shown to be an additive function of the atoms and groups in the molecule and to be nearly temperature independent. A value of the parachor of 244.3, as given by Quale[90], was employed for the monochlorobenzene calculations.

A3.3 Biphenyl-biphenyl oxide.

Unlike the previous fluid biphenyl-biphenyl oxide has been used as a thermal fluid for several decades and thus its properties are relatively well documented in manufacturers literature. Thermophysical property data on biphenyl-biphenyl oxide manufactured under 3 different trade names was available from the following sources:-

(i) The Dow Chemical Co. (Dowtherm A)

(ii) Imperial Chemical Industries Ltd. (Thermex).

(iii) Bayer, Germany (Diphyl).

Of the foregoing the ICI values were selected to be incorporated in Table 12 in respect of the following properties:- saturation pressure, liquid and vapour densities, liquid enthalpy, enthalpy of evaporation, vapour enthalpy, liquid specific heat and liquid viscosity. Apart from two companion publications[91][92] concerning liquid specific heat and surface tension no references could be traced in the literature to confirm whether or not the values selected were the most appropriate. Differences are present between the various manufacturers data for these foregoing properties as shown in Table 15 particularly in respect of liquid viscosity.

The vapour specific heat was assumed, as for monochlorobenzene to be equal to Cp^o. The coefficients for the estimation of Cp^o by Eq. A3.2 were calculated using the group contribution method of Rihani & Doraiswamy[85]. The values of A, B, C and D determined for biphenyl-biphenyl oxide were: -63.878, .92825, $-.59176 \times 10^{-3}$ and $.13885 \times 10^{-6}$ respectively.

TEMP. °C.	FLUID PROPERTY UNITS	DOW CHEMICAL CO.	ICI LTD.	BAYER A.G.
160	Saturation pressure kN/m^2	6.62	6.57	7.63
210		31.9	31.9	35.2*
260		108.1	108.9	112.8
310		285.4	285.4	298.7*
360		629.6	628.8	651.3
160	Liquid Density kg/m^3	945.3	942.0	945.0
210		899.4	895.0	900.5*
260		850.1	847.0	855.0
310		796.5	797.1	803.2*
360		736.5	742.2	759.1
160	Vapour Density kg/m^2	.306	.30	.34
210		1.33	1.25	1.46*
260		4.18	4.37	4.40
310		10.5	10.2	11.2
360		22.6	22.5	24.2
160	Enthalpy of Evaporation kJ/kg.	335.2	334.9	325.3
210		317.2	317.2	307.3*
260		296.8	297.2	287.9
310		273.0	273.0	263.5*
360		245.4	244.9	234.0
240	Liquid Specific Heat kJ/(kg.K)	2.149	2.210	2.132
260		2.198	2.264	2.175
280		2.262	2.323	2.216
300		2.302	2.378	2.261
320		2.348	2.436	2.312
340		2.401	2.491	2.371
240	Liquid Viscosity mNs/m^2	.380	.290	.298
260		.357	.250	.265
280		.342	.220	.233
300		.330	.200	.205
320		.320	.180	.185
340		.312	.160	.168

* Denotes linearly interpolated value.

TABLE 15 : Comparison between manufacturers data for some thermophysical properties of biphenyl-biphenyl oxide.

Calculated values of the vapour viscosity were available from the Dowtherm Handbook(6) which indicate that this property is a linear function of temperature in the range 90-370°C.

Experimental values for the thermal conductivity of liquid biphenyl-biphenyl oxide up to 250°C were available from the work of Ziebland & Burton(93) which were linearly extrapolated to 350°C using the expression (T = °C) :-

$$k_L \ (mW/m^{\circ}K) = 139.0 - .138\ (T - 47) \qquad \text{(Eq. A3.12)}$$

For the remaining properties the method of Stiel & Thodos was again used to estimate the thermal conductivity of biphenyl-biphenyl oxide vapour for the temperature range 230-350°C. Similarly the parachor method was used to calculate the surface tension. A value of the parachor of 395 was employed in the latter calculation, this being the weighted mean of the values for the constituents i.e. biphenyl and biphenyl oxide which were calculated from the molecular structure by the method of Sugden.

APPENDIX 4 - ERROR ANALYSIS

A4.1

The data from any experiment can only be interpreted within the limits of the accuracy and reliability of the measurements. The purpose of this Appendix is to estimate the uncertainty in the measured and derived test quantities. These quantities are the main independent variables of the study viz: system pressure, mass velocity, heat flux and inlet temperature or sub-cooling and in the derived values of the experimental boiling heat transfer coefficients. The values reported are the expected maximum uncertainties and thus most of the data should fall within the limits quoted.

A4.2 System Pressure (at exit of test section).

This was derived from observations of:-

(i) The reference gas pressure as measured by the Heise gauge and

(ii) the difference between the loop fluid pressure and the reference gas pressure as measured by a low range differential pressure transducer.

The uncertainty in the measurement of the system pressure is thus essentially composed of the basic accuracies of the Heise gauge and the pressure transducer and the accuracy to which they could both be read. The least uncertainty was associated with the Heise gauge which was stated to be accurate to better than 0.1% of its full scale reading. Parallax reading errors were minimised by a reflecting mirror on the instrument scale. These reading errors which would be essentially constant from test to test would have been within $\pm$ 3.4 kN/m^2 ($\pm$ 0.5 psi). The pressure transducers were periodically taken down and checked using a low pressure air supply against a mercury manometer. The calibrated accuracy of the pressure transducers was thus quite high, say within 2% over their working range. However, as mentioned previously, small pressure fluctuations were present in the transducer connecting lines which limited the accuracy to which they could be read to about $\pm$ 10% ($\pm$ 3.44 kN/m^2). Thus taking all the factors affecting accuracy into account it is estimated that a maximum overall error of ±17.2 kN/m^2 (± 2 psi) could exist in system pressure measurements. For the monochlorobenzene tests, depending on the absolute pressure level the measurement uncertainty would be between ± .5 - 3.0%. With the lower pressures involved in the biphenyl-biphenyl oxide tests series the corresponding figures would be ± 3.3 - 7.0%.

A4.3 Mass Velocity

The volumetric flow rate through the loop was measured by a turbine flow meter. This was converted to a mass flow rate figure by a hand calculation from a large scale calibration graph for the flow meter and a knowledge of the fluid density as inferred from a temperature measurement slightly upsteam of the meter. Ignoring errors in the hand calculation the basic accuracy in flow measurement is thus a function of:-

(i) The accuracy of the turbine flow meter.

(ii) The accuracy to which the flow meter could be read.

(iii) The accuracy of fluid temperature measurement and

(iv) The reliability of the fluid density values employed in the flow rate calculations.

Regarding (i) above the turbine flow meter was calibrated using water prior to the commencement of the experimental programme and also approximately midway through the monochlorobenzene tests. The results of these calibration exercises are included with the manufacturers figures in Fig. 26 , where they are shown to be in good agreement with the latter. The calibrated accuracy of the turbine flow meter is thus of the order of ± .05% over the linear metering range. The output of the turbine flow meter was displayed on a digital frequency meter and for the majority of the tests was constant to within ± 5 counts/sec. resulting in an average uncertainty of say ± 1-2% over the frequency range employed. Significant variations in flow rate only occurred during tests when dry wall conditions were present. In the latter cases a test run was abandoned whenever a nominal 5% reduction in flow due to filter blockage occurred. The fluid temperature was measured by a sheathed

Cr-Al thermocouple immersed directly in the flow. This latter thermocouple had been calibrated to ± .4°C in an oil bath using an NPL certified mercury in glass thermometer as the reference standard. As in the case with the other thermocouples it was connected to the data logger which had a measurement accuracy of ± .05% with a resolution of ± 1 digit. The uncertainty in the measurement of the fluid temperature at the flow meter thus amounts to ± .75°C say ± 1.0°C. For monochlorobenzene a change in fluid temperature of 1°C results in a change of liquid density of approximately 0.22 kg/m^3. The maximum uncertainty in the density calculation was ± .025% at the highest flow metering temperature of 190°C employed in the tests when ρ_L = 910 kg/m^3. In the case of biphenyl-biphenyl oxide the corresponding figure was ± .10% based on a density variation of .925 kg/m^3 per °C and a maximum temperature at the flow meter of 207°C (ρ_L = 898 kg/m^3).

The specific volume values for monochlorobenzene determined experimentally by Young(83) are considered by Timmermans(87) to be precise. Thus no uncertainty limits have been considered in the case of this fluid when converting the flow rates from volumetric to mass flow units. In the case of biphenyl-biphenyl oxide there is a slight difference in the density values in the manufacturers literature over the range of temperatures present in the test. At the flow meter where the temperature range was from 170-210°C the difference between the highest and lowest density values was about .5%. This latter figure was assumed to be the uncertainty in the density of liquid biphenyl-biphenyl oxide for the range in temperature at the flow meter.

In the case of monochlorobenzene when dry-out conditions were absent there was an overall uncertainty in flow rate measurement of approximately ± 2.5%. With dry-out conditions present the uncertainty was increased to around 5.5%. The corresponding figures for biphenyl-biphenyl oxide are ± 3.1% and ± 6.1% respectively. These latter figures have been taken as the uncertainty present in the mass velocity calculation (m/A) since a precise measurement of the test section bore had been made using an air gauging technique.

A4.4 Heat Flux.

The uncertainty in the heat flux calculation was essentially a function of the uncertainties in the measurements of the test section voltage and current and in the estimates of the heat loss to the surroundings. The tappings for voltage measurement were mounted on the upper and lower power clamps and the readings were displayed on a Solartron type LM 1420 digital volt meter in addition to being recorded by the data logger. The DVM figures were used as input data for the data reduction computer program. The uncertainty associated with the test section voltage measurements was estimated to be ± .5% taking into account the accuracy of the DVM (± .05%) and the presence of small line voltage fluctuations. The test section current was calculated from the output of a precision power shunt as recorded by the data logger. The uncertainty associated with this calculation was assumed to be ± .5% which was the quoted accuracy of the power shunt.

As stated previously a heat loss relationship was derived from the single phase experiments when the electrical power input (V x I) could be compared with the measured enthalpy rise ($m.Cp_L.\Delta T$). Considering the uncertainty involved in determining this latter quantity it is evident that the heat loss estimate for a particular test had possible error limits of up to ± 10%. For the majority of the net boiling tests which were carried out at a heat input of around 9 kW the uncertainty in the heat loss estimate created a corresponding uncertainty in the applied heat flux calculation of ± 8.9% which was exclusive of any uncertainties in the actual test section voltage and current measurement themselves. When the latter uncertainties are considered as well the overall uncertainty in the heat flux values are of the order of say ± 10%.

A4.5 Inlet Sub-Cooling

The difference between the saturated liquid enthalpy and the actual liquid enthalpy at any position along the test section up to the net boiling point is termed the amount of sub-cooling. A parameter which is usually controlled in loop experiments is the amount of sub-cooling which is present at the test section inlet. The inlet sub-cooling was derived here from a measurement of the actual fluid temperature and a calculated value of the saturation temperature. The latter quantity was determined from an inlet pressure measurement which was converted to a reduced pressure basis for use in a polynomial representation of saturation temperature as a function of reduced pressure. Thus the uncertainties in the inlet sub-cooling calculation arise from the uncertainties in:-

(i) The inlet temperature measurement.

(ii) Inlet pressure measurement.

(iii) The polynomial representing saturation temperature as a function of reduced pressure.

As previously mentioned both the test section inlet and exit thermocouples were calibrated up to 400°C using a Platinum 13% Rhodium-Platinum thermocouple as the reference standard. The guaranteed accuracy of such a thermocouple is stated as being within $\pm$ 1°C at the gold point (1064.43°C). However for the range over which it was used (20-600°C) an improved accuracy of $\pm$ 0.5°C can confidently be expected(94). During the calibration process the output of the Platinum-13% Rhodium-Platinum thermocouple was measured on a Cropico P3 potentiometer which had an accuracy of .04%. The addition of this instrument uncertainty gives an overall uncertainty in measurement of the absolute temperature of the calibration furnace at 400°C of $\pm$ .64°C. This latter figure has been taken to be the fundamental accuracy of the inlet and exit fluid temperature measurement thermocouples. It represents an improvement by a factor of nearly 5 on the measurement tolerance of the thermocouples as bought in ($\pm$ 3°C up to 400°C). To arrive at the overall uncertainty in inlet temperature measurement the data logger accuracy must be taken into account. At 400°C this created an additional uncertainty of ± .45°C giving overall error limits of approximately ± 1.1°C.

The test section inlet pressure was measured in an identical manner as detailed for the exit pressure in A4.2. The uncertainties in determining the saturation temperature from this measured pressure emanated from two sources:-

(i) The accuracy of the polynomial representation in comparison to experimental saturation pressure-temperature data and,

(ii) the influence of system pressure measurement uncertainties of the order of ± 17.2 kN/m2 on the calculated saturation temperature.

Regarding (i) in the case of monochlorobenzene, for the three temperatures shown in Table 14 for which experimental data is given (210, 235 and 260°C) the calculated saturation temperatures were 209.7, 235.4, and 259.8°C respectively. Thus it is assumed that the polynomial for saturation temperature as a function of reduced pressure was accurate to within ± 0.5°C. The influence of system pressure measurement uncertainties on the calculated saturation temperature was greatest at the lowest system pressures employed in the tests. For monochlorobenzene at about 0.5 MN/m^2 an uncertainty in pressure measurement of ± 17.2 kN/m^2 affected the calculated saturation temperature by ± 1.1°C. The corresponding figure for the maximum system pressure tests of about 3.0 MN/m^2 was ± 0.5°C. Thus the total uncertainty in the saturation temperature calculations for monochlorobenzene ranged between ± 1.0 to ± 1.6°C for the highest and lowest system pressure tests respectively.

The maximum uncertainty in the calculation of the sub-cooling occurred when the uncertainty tolerances combined to give the greatest uncertainty between the saturation and actual fluid temperatures at a particular point. For the extreme ranges of system pressure employed in the monochlorobenzene tests this maximum uncertainty was ± 2.1 to ± 2.7°C which corresponded to a maximum uncertainty in the sub-cooling calculation of approximately $\pm$ 5.0 kJ/kg. at both system pressures. In the case of biphenyl-biphenyl oxide the 6th order polynomial representing the saturation temperature as a function of reduced pressure was accurate to within $\pm$ .1°C of the manufacturers data over the temperature range 230-350°C. The lowest system pressure employed in the tests with this fluid was about .25 MN/m^2 where the pressure measurement uncertainty previously discussed created a saturation temperature uncertainty of $\pm$ 3.75°C. This corresponded to a sub-cooling uncertainty of about $\pm$ 8.6 kJ/kg. For the highest system pressure tests of about .52 MN/m^2 the uncertainty in the calculation of the saturation temperature was $\pm$ 2.1°C which corresponded to a maximum sub-cooling uncertainty of $\pm$ 5.2 kJ/kg. for the tests conducted at these pressures.

A4.6 Heat Transfer Coefficients.

The heat transfer coefficient h when net boiling was present was calculated from:-

$$h = \phi/(T_w - T_{sat})$$

The uncertainty in heat flux ϕ and the local saturation temperature T_{sat} have been previously discussed. The overall uncertainty in T_w was a combination of the following:-

(i) The calibration error of the wall thermocouples.

(ii) Data logger errors.

(iii) Curve fitting errors in converting the thermocouple emf output to temperature.

(iv) Errors in the calculation of the wall temperature drop due to uncertainties in the value of the test section material thermal conductivity and wall thickness.

The insulated test section wall thermocouples were calibrated in an identical manner as described in A4.5 for the sheathed thermocouples with the exception that the furnace temperature was taken up to around 600°C. It was estimated that the combination of calibration and data logger errors led to uncertainty in temperature measurements of ± 1.0°C at 400°C and ± 1.2°C at 600°C. The additional uncertainties introduced by the curve fitting process were ± .2°C in the temperature range 0-400°C[77] and ± .4°C from 400-600°C. Thus it is considered that the overall uncertainty in the test section outer wall temperature measurement was ± 1.2°C at 400°C and ± 1.6°C at 600°C.

The uncertainty in the calculation of the temperature drop through the tube wall was a function of the dimensional tolerances and the accuracy of the thermal conductivity data for the tube wall material. Both of the foregoing uncertainties were however minimised by virtue of the relatively low heat fluxes employed in the test programme. For the highest heat flux tests the temperature drop through the wall was approximately 10°C and thus the maximum errors attributable to tube wall thickness variation (± .01 mm) was .06°C which reduced as the heat flux was lowered. The literature source for the thermal conductivity data for Nimonic 75[39] makes no reference to possible error limits on the values quoted. However in a rejoinder[95] to a discussion of another paper[96] on thermal conductivity measurements where an identical technique to the Nimonic 75 determinations was employed the error limits are stated to be ± 2%. For the maximum heat fluxes employed the latter error limits would create a maximum uncertainty of ± 0.2°C. Adding the maximum uncertainty in the calculation of the wall temperature drop (say ± .3°C) to the uncertainties involved in the outer wall temperature measurements gives the overall uncertainty in inner wall temperature determination as ± 1.5°C and ±1.9°C for metal temperatures up to 400°C and 600°C respectively.

The maximum uncertainty in the heat transfer coefficient calculation arose when the heat flux and wall - saturation temperature difference was lowest. In the monochlorobenzene experiments the lowest values of wall - saturation temperature difference were present at the highest system pressure tests where they were nominally about 4°C. Considering the maximum uncertainty limits previously discussed for T_w and T_{sat} (1.6°C and 1.2°C) this latter figure could range between 1.2 and 6.8°C. Taking the heat flux measurement uncertainty into account results in the derived value for the heat transfer coefficient at a heat flux of 57 kW/m^2 being between 7.5 and 52.2 $kW/m^{2\circ}C$ i.e. about - 50% or + 270% of the nominal value of 14.2 $kW/m^{2\circ}C$. At the lowest pressure tests where the temperature difference was around 9°C the uncertainties combined to give substantially reduced overall error limits on the heat transfer coefficient calculation for the same heat flux of - 27% and + 23% about the nominal value of 6.3 $kW/m^{2\circ}C$.

APPENDIX 5 - THERMAL DECOMPOSITION OF MONOCHLOROBENZENE

A5.1

In a previous report prepared by the writer[1] it had been concluded that thermal stability was the most important factor to be considered in selecting a Rankine cycle working fluid. When this latter fact became evident it was considered desirable to have information on the chemical changes which occurred in the fluid during its residence time in the loop so that ~~the~~ some measure of the thermal stability of the fluid could be obtained. As there was a gas chromatography apparatus available (Plate 22) work was initiated on developing a procedure employing this technique for the chemical analysis of monochlorobenzene fluid samples. In the event however this aspect of the investigation was not taken to a conclusion for lack of time and because the loop facility was unsuitable for such thermal stability studies since it was only intermittently operated for a few hours at a time. Despite the lack of quantitative information on the thermal decomposition of monochlorobenzene it is nevertheless considered to be worthwhile to record the procedures adopted for the analysis work in this Appendix together with examples of specimen chromatograms obtained during the course of the investigation for future reference.

A5.2

In gas chromatography[97] the various species of components in a mixture can be separated out on a molecular basis in a column containing a stationary and a moving phase. The latter is the carrier gas into which the sample is injected which then passes into the separating column. This separating column is a solid or a liquid coated solid inert support and constitutes the stationary phase. As the sample mixture is swept along the column the various species are selectively absorbed and desorbed at different rates and are separated and eluted in the carrier gas. The presence of the separated species in the carrier gas at the exit of the column is indicated

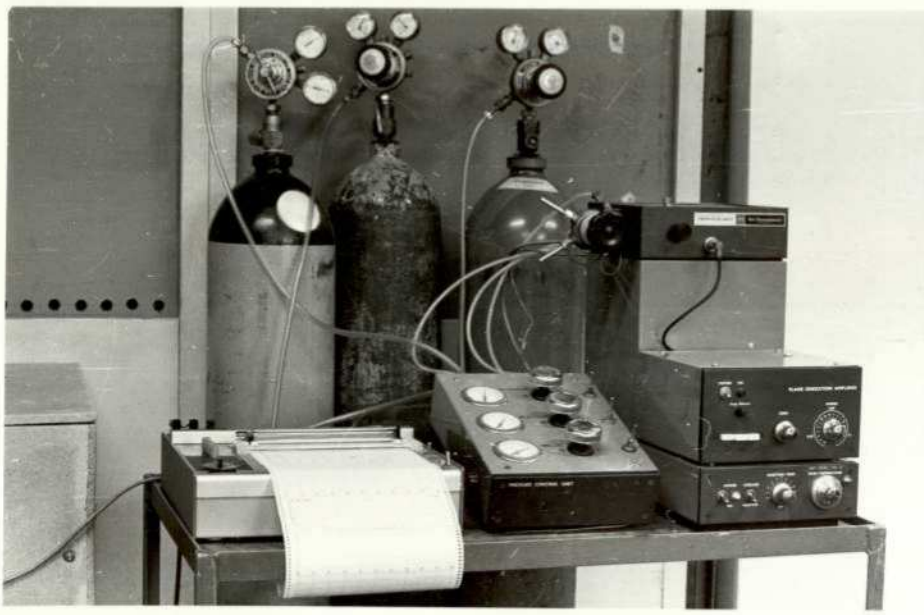


PLATE 22 - Gas Chromatography Equipment

by a detector from which a response is obtained corresponding to a change in the properties of the carrier gas. In the work reported here a flame ionisation detector was employed to detect these property changes. With this method of detection the effluent gas at the exit of the column is mixed with hydrogen and burnt in air. Ions and electrons formed in the flame enter an electrode gap, decrease the gap resistance which permits a current to flow in an electrical circuit giving a measure of the amount of a particular constituent in the original sample eluted by the column at that stage in time. The electrical signal from the detector is amplified and displayed as a peak on a strip chart recorder. A schematic of a gas chromatography system is illustrated in Fig. 59.

A5.3

The gas chromatography apparatus used was a standard Perkin-Elmer model F11 (No. C1206) fitted with a flame ionisation detector (FID). On the recommendation of the Department of Chemistry, Combustion Research Section[98] the column used was 4 m in length, made from .125" o.d. stainless steel tubing packed with 11.5% Silicone oil type MS550 and 11.5% Bentone 34 supported on 80-100 mesh Chromosorb W (see Table 16). Before use this column was conditioned to produce a stable base line by heating for the following consecutive periods with a carrier gas flow rate of 10 ml/min.:- 50°C for 1 hr., 100°C for 3 hrs., and 150°C for 24 hrs.

A5.4

Several chromatograms were obtained at different injection block oven temperature settings and carrier gas flowrates before the final operating conditions were selected. These were a constant oven temperature of 100°C, injector temperature setting 3 and N_2 carrier gas flow rate of 10 ml/min. Gas pressure control unit settings were:- N_2 19 lbs/in.^{2}, H_2 21 lbs/in^2 and Air 16.5 lbs/in^2. Samples to be analysed were injected through a rubber septum by a Hamilton microlitre syringe (size 0-10 µl). The output signal of the gas chromatograph was recorded as a trace using a Servoscribe

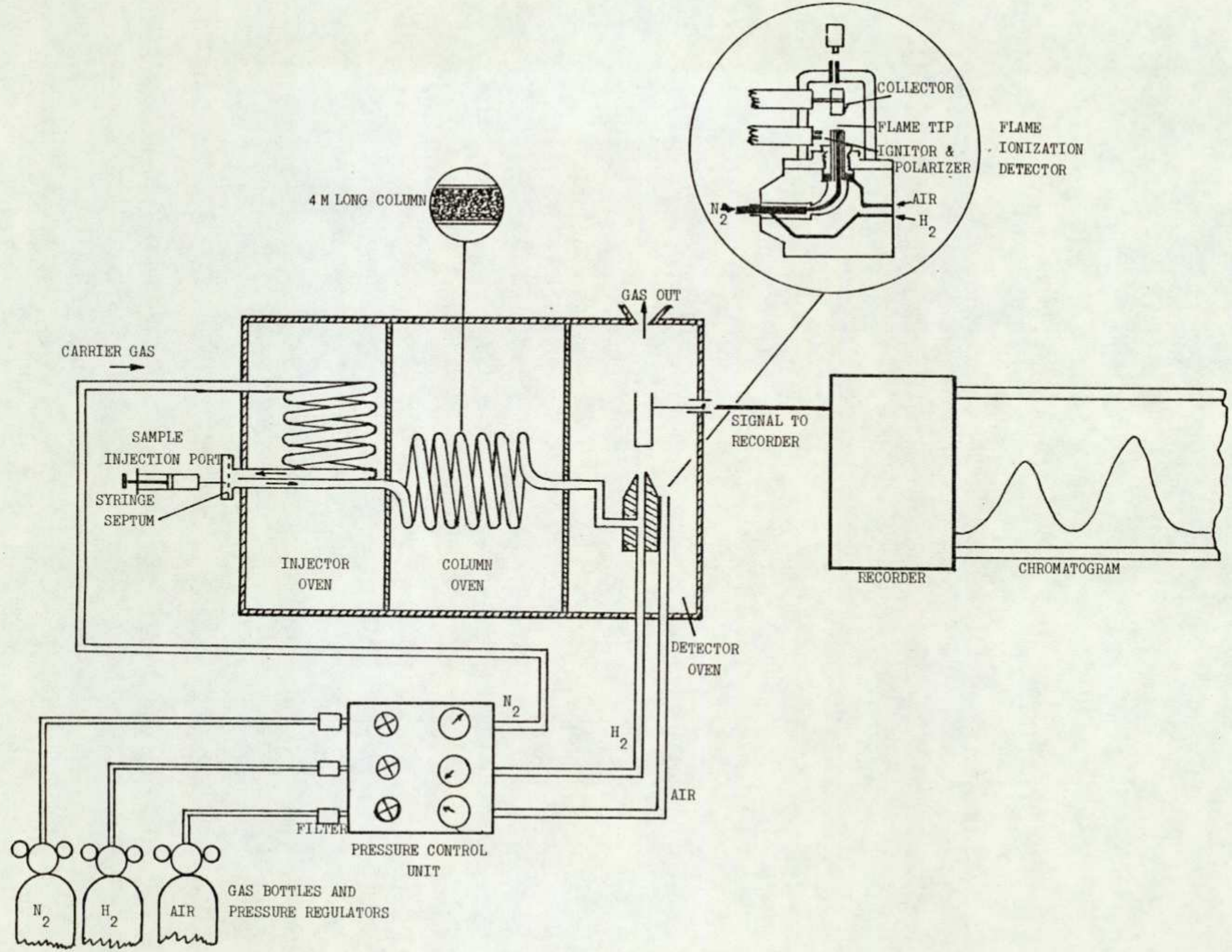


FIG 59: COMPONENTS OF A GAS CHROMATOGRAPH

Perkin-Elmer Ref. No. 0496-0788
Serial No. 26463
Stainless steel .125" dia. x 4 m long.
Liquid phase: Silicone fluid MS550 (11.5 wt.%)*
Bentone 34 (11.5 wt.%)**
Support: 80 to 100 mesh Chromosorb W (77.0 wt.%)***
Temp. Range: 50 - 200°C
Activity: Non-polar.
Applications: Aromatic hydrocarbons, alkyl xylenes

* - a non-polar involatile silicone oil
** - dimethyldioctadecyl ammonium bentonite
*** - a grade of diatomaceous silica.

TABLE 16: Specification of gas chromatograph column.

		Typical Analysis	Specification
Appearance		Clear liquid	Clear liquid
Colour (Hazen Units)		5	-
Density at 20°C			1.105-1.107
Specific Gravity at 15.5/15.5°C		1.112	1.111-1.113
Water	H_2O%	0.017	0.03 max.
Acidity	HCl%	not detected	not detected
Free chlorine	Cl%	not detected	not detected
Benzene	ppm	112	
Paradichlorobenzene	ppm	50	
Orthodichlorobenzene	ppm	20	
Residue on evaporation	ppm	3.5	10 max.
Distillation at 760 mm Hg			
Range 2-97%		0.2°C (contains the temperature 131.7°C).	0.3° max. (shall contain the temperature 131.7°C).

TABLE 17: Typical analysis and specification of monochlorobenzene(3).

single channel pen recorder (type RE 511 No. R1916) on the 100 mV range with a chart speed of 1 cm/min.

A5.5

The monochlorobenzene employed in the heat transfer tests was a general purpose grade(99) manufactured by ICI. This chemical is produced on a large scale by the catalytical chlorination of benzene which yields both monochlorobenzene and dichlorobenzene which are separated by distillation. The commercial grade contains traces of benzene, ortho-dichlorobenzene, para-dichlorobenzene and higher isomers as impurities. The manufacturers analysis(3) for monochlorobenzene is given in Table 17. A chromatogram of an unused sample of monochlorobenzene is shown in Fig. 60. As can be seen one impurity was eluted before the monochlorobenzene and another after. These impurities were confirmed as being benzene and either ortho- or para-dichlorobenzene respectively by injecting in a calibration blend of these compounds and noting that the retention time before elution was the same as for the unused monochlorobenzene sample. It was not possible with particular settings used to separate out the ortho- and para- isomers of dichlorobenzene.

A5.6

Since the loop was drained down each day with fresh fluid being added to the make-up tank to compensate for any losses, it was only possible to compare fluid samples taken before and after a single days operation. A 'before' fluid sample was taken from the drainage point located between the pre-heater and the test section (see Fig. 11) whilst the loop was being brought up to its operating condition. The 'after' fluid sample was taken from the same point whilst the loop was being run down in temperature prior to being drained. After the initial fill of the loop at commencement of operation no further fluid was added to the system from the make-up tank since any leakage from the high pressure circuit was negligible. The chromatograms obtained before and after the test series nos. 218-224 inclusive are shown in Figs. 61 and 62 respectively. These were tests carried out at the highest reduced pressure, p_r = .67 with a saturation temperature of 325°C. Dry wall conditions were present during test Nos. 223 and 224 so that it was expected that a measurable amount of fluid decomposition would have occurred. The first test run (218) of the series commenced at 1514 hrs. on the day of operation and the last (224) at 1615 hrs. As an approximation it can be assumed that the test fluid was at an average maximum temperature of 300°C for 3 hrs. and that about 30% of the fluid inventory was at these conditions at any given time.

A5.7

Comparison of Figs. 61 and 62 indicates that there was a small increase in the concentration of benzene and dichlorobenzene after heating. An equation describing the decomposition reaction which would produce this situation is the following in which 2 moles of monochlorobenzene disproportionate to form benzene and dichlorobenzene:-

$$2.C_6H_5Cl = C_6H_6 + C_6H_4Cl_2$$

It is highly likely however that the decomposition reaction was much more complicated than that given above as indicated by the work of Cullis & Priday[(100)] and Cullis & Manton[(101)]. Whilst the work of these authors was conducted at temperatures in excess of those considered here they showed that the main gaseous decomposition products were hydrogen chloride and hydrogen. Since gas phase samples were not taken in the investigation it was not possible to confirm whether the latter were included amongst the breakdown products here.

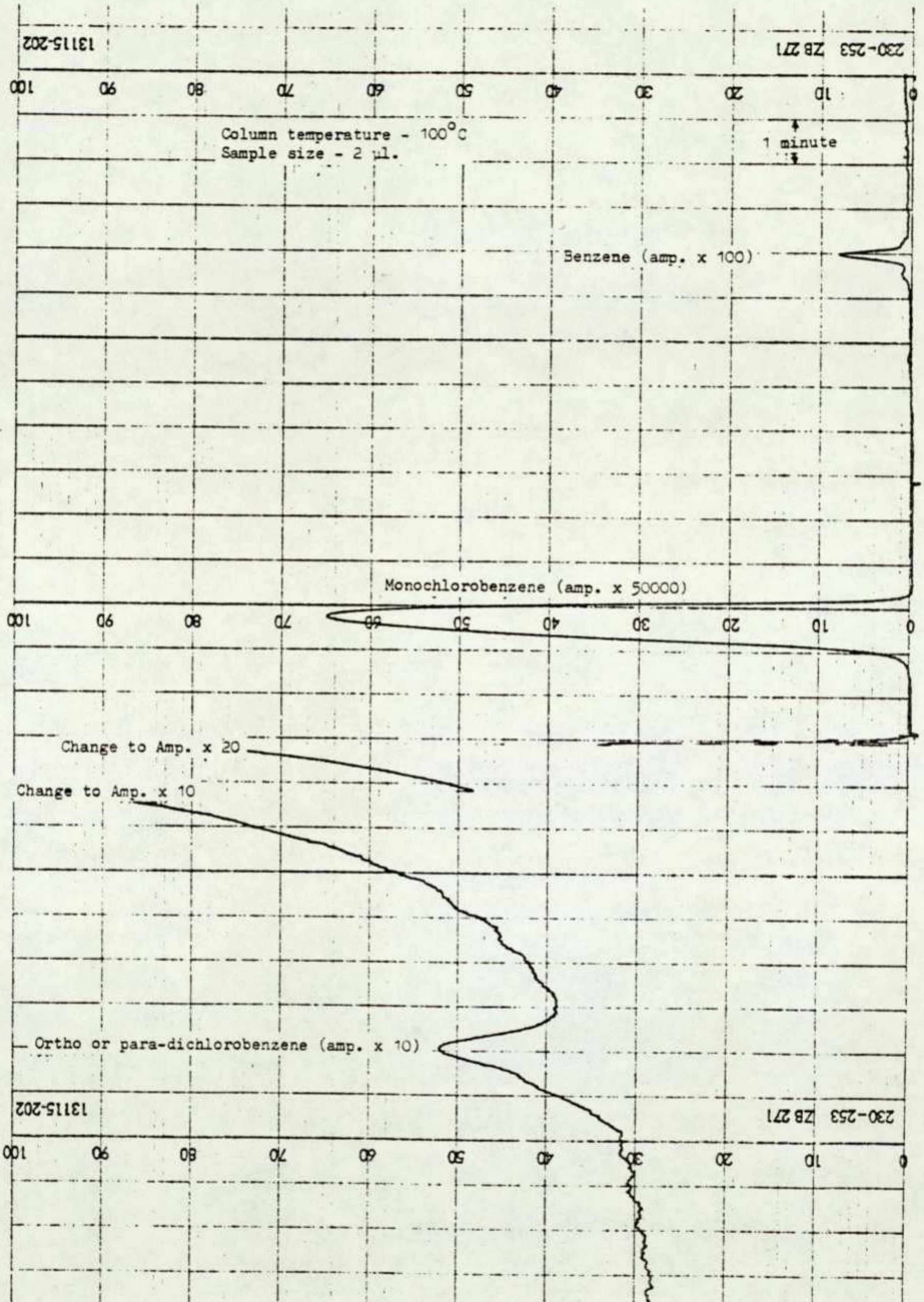


FIG.60 CHROMATOGRAM OF UNUSED MONOCHLOROBENZENE LIQUID SAMPLE

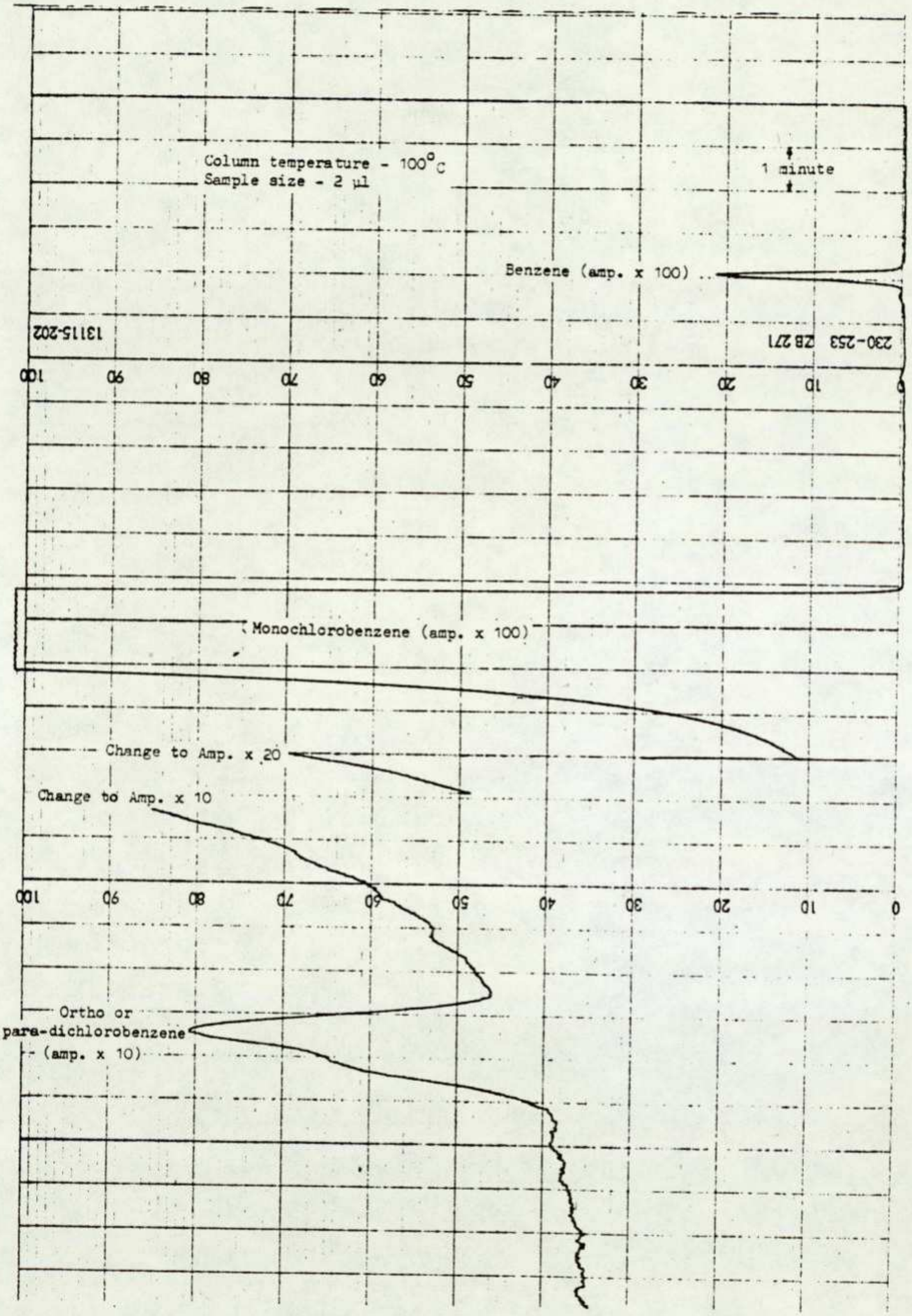


FIG.61 CHROMATOGRAM OF CHLOROBENZENE LIQUID SAMPLE PRIOR TO HEATING

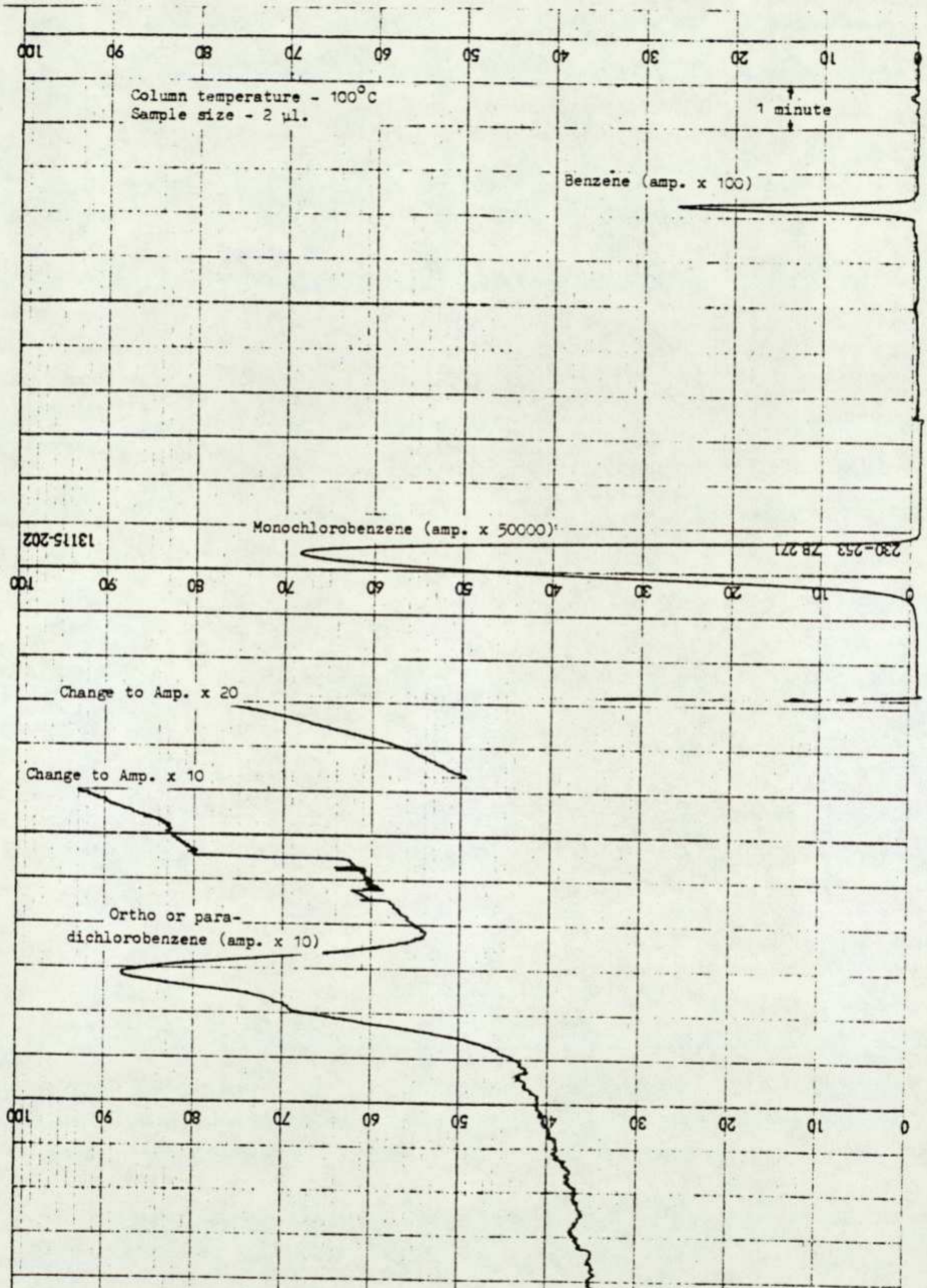


FIG.62 CHROMATOGRAM OF MONOCHLOROBENZENE LIQUID SAMPLE AFTER HEATING

APPENDIX 6 - MEASUREMENT OF DISSOLVED AIR CONTENT IN MONOCHLOROBENZENE

A6.1

Dissolved gas effects have been shown by previous investigators to significantly effect heat transfer in flow boiling in both water[102] and organic fluids[103] and to be an important factor influencing thermal decomposition in the case of the latter[1]. Whilst no systematic study concerning the effect of dissolved gases was undertaken during the investigation it was considered to be desirable to know the dissolved gas content of the loop fluid either from published data or by a measurement. Since gas solubility data was not available for several of the candidate fluids under consideration an evaluation exercise was carried out on an existing apparatus to determine the dissolved gas content in monochlorobenzene at various temperatures for comparison with published data in order to assess the accuracy of the method, which was intended to be used for fluids for which no data was available. Details and results of this latter evaluation exercise are given in this Appendix.

A6.2

Gases are only miscible with liquids to a certain extent, the actual solubility being a function of pressure and temperature and the nature of the gas and liquid. Henry's Law states that the quantity of gas dissolved in a given quantity of solvent or solution is directly proportional to its partial pressure over the solution. Thus the amount of gas dissolved in a liquid can be determined if the proportionality constant, the solubility or Henry's Law constant for the particular gas-solute combination is known.

A6.3

The method of solubility measurement adopted to determine the Henry's Law constant for air in monochlorobenzene was based upon that described by Derry et al[104] using an existing apparatus as illustrated in Plate 23 and

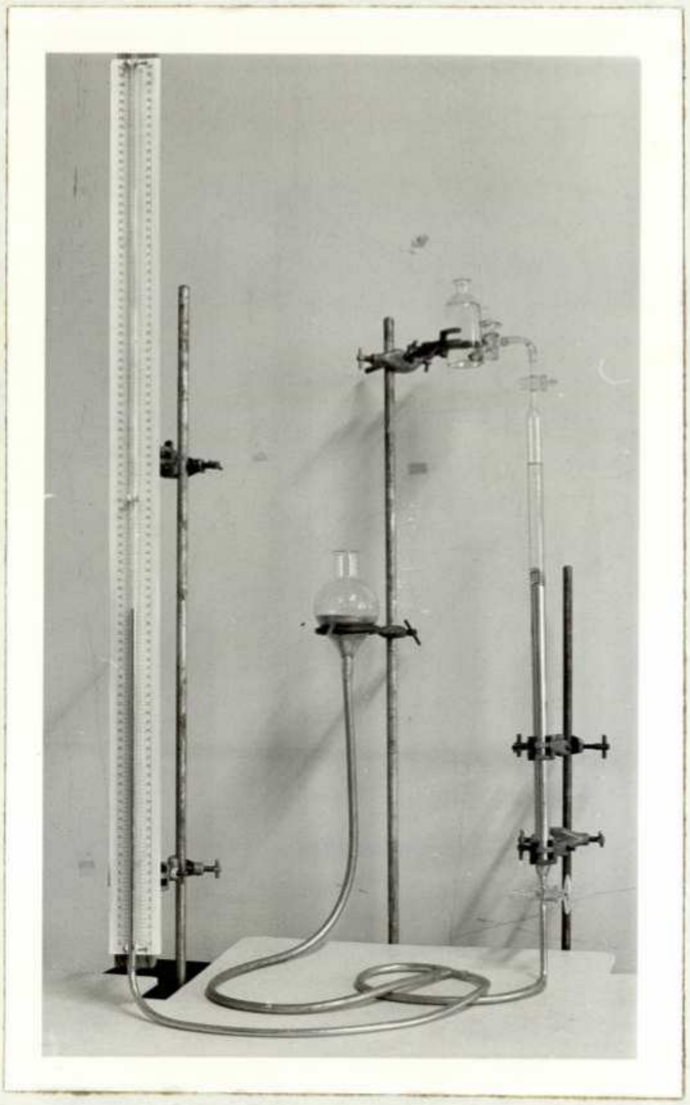


PLATE 23. Dissolved gas measurement apparatus

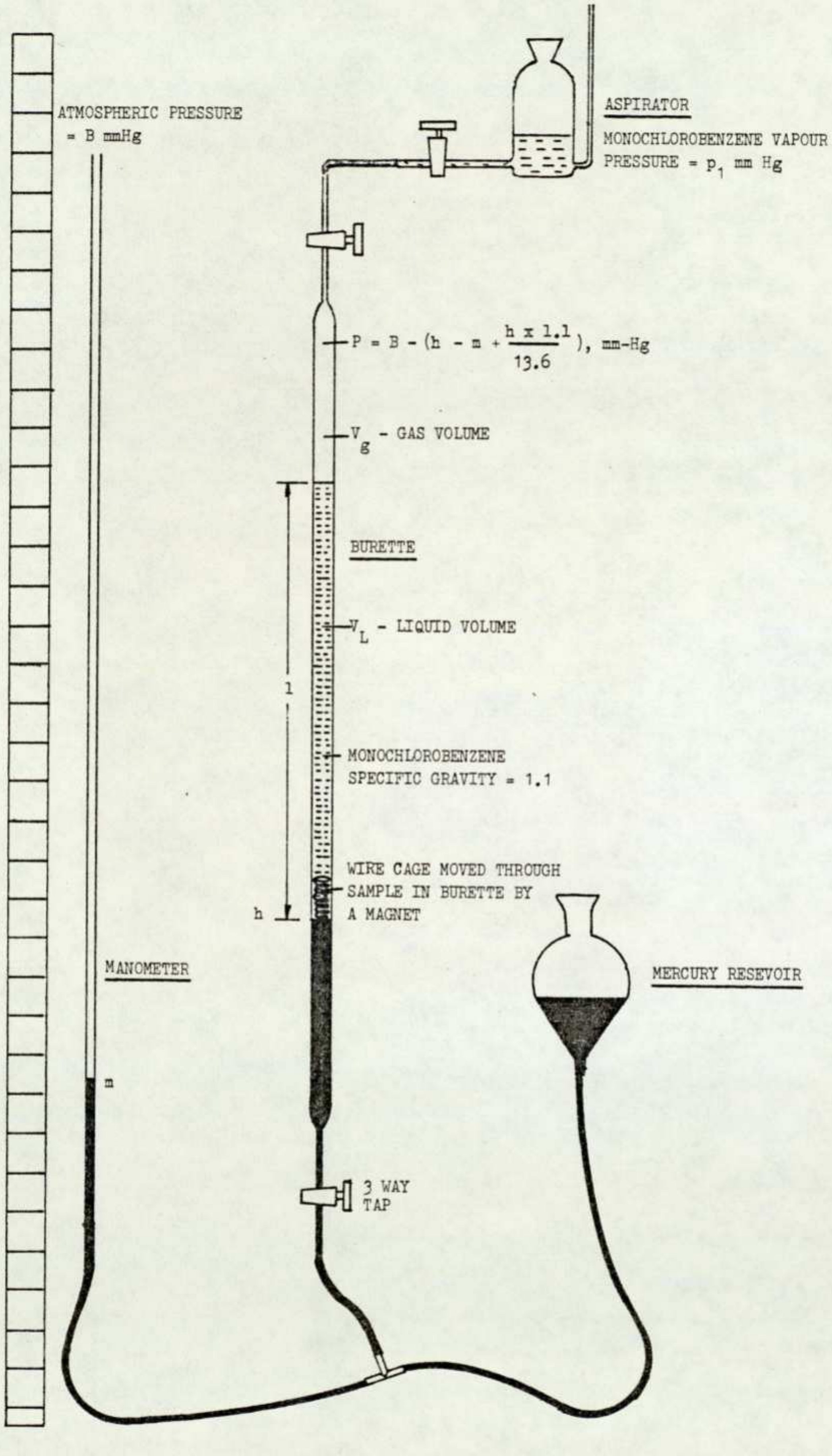


FIG. 63 SCHEMATIC OF DISSOLVED GAS MEASUREMENT APPARATUS

Fig. 63. An aspirator containing monochlorobenzene, which had been previously aerated for 30 minutes, was connected to the burette. The air in the burette and connecting piping was displaced through the monochlorobenzene by raising and lowering the mercury reservoir level a few times. After eliminating all the air a known quantity of monochlorobenzene was drawn into and isolated in the burette. A reduced pressure was then created in the burette by lowering the mercury reservoir to a selected level which caused air to come out of solution and collect in the top of the burette. To ensure that there were equilibrium conditions throughout the monochlorobenzene in the burette the sample was agitated by raising and lowering a wire cage within the burette using an external magnet. When all the air had been given off its volume within the burette was noted along with the reservoir and burette mercury heights and ambient air conditions. The mercury reservoir was then lowered to another level to create a new burette pressure and the process repeated.

A6.4

Assuming that the solubility of air in monochlorobenzene follows Henry's Law then[104]:

$$S = k\ p$$

Where: S = volume % of dissolved air (= volume (ml) of air measured at STP dissolved in 100 ml of monochlorobenzene).

p = partial pressure of air in the vapour with which the solution is in equilibrium.

k = solubility coefficient or Henry's constant having the units of volume %/mm Hg when the pressures are measured in mm of Mercury.

The amount of air dissolved in the aerated sample at a temperature T_1 and atmospheric pressure B is:

$$S_1 = k_1 \ (B - p_1)$$

Where: k_1 = solubility coefficient at temperature T_1.

p_1 = vapour pressure of monochlorobenzene at temperature T_1.

When the monochlorobenzene is partially degassed in the burette let S_2 = volume % of gas remaining in solution and S_v = volume % of gas in vapour space = $S_1 - S_2$.

$$S_2 = k_2 \ (P - p_2)$$

Where: k_2 = solubility coefficient at temperature T_2.

P = total pressure in vapour space.

p_2 = vapour pressure of monochlorobenzene in vapour space which is at a temperature T_2.

If V_G = volume occupied by vapour space in burette and V_L = volume occupied by monochlorobenzene in burette at temperature T_2 then:

$$S_V = \frac{V_G \ (P - p_2)}{760} \times \frac{273}{(273 + T_2)} \times \frac{100}{V_L}$$

$$= k_1 \ (B - p_1) - k_2 \ (P - p_2)$$

Thus: $$\frac{V_G \times 273 \times 100}{V_L \times (273 + T_2) \times 760} = \frac{k_1 \ (B - p_1) - k_2 \ (P - p_2)}{(P - p_2)}$$

In the experiment T_2 was the ambient laboratory temperature of about 20°C and p_2 (9mm Hg) was neglected in comparison with p_1, therefore:

$$\frac{.123 \ V_G}{V_L} = k_1 \ \frac{(B - p_1)}{P} - k_2$$

If Henry's Law holds the graph of $\frac{.123 \ V_G}{V_L}$ against $\frac{B - p_1}{P}$ should be a straight line, the value of k_1 being given by its slope. The value of P, the absolute pressure in the vapour space in the burette was given by the expression:

$$P = B - (h - m + \frac{1 \ \rho}{13.6})$$

Where: k = mercury height in burette.

m = " " " manometer.

l = height of monochlorobenzene column in the burette.

ρ = specific gravity of monochlorobenzene.

B = atmospheric pressure during experiment.

The volumes V_G and V_L were read directly from the burette, the latter being corrected for the immersed volume of the wire cage (.15 ml).

Table 18 gives the results for the measurements of the solubility coefficient at 20°C, 60°C, 80°C and 100°C. From these the values of $\frac{.123\ V_G}{V_L}$ and $\frac{B-p_1}{P}$ have been plotted as ordinate and absicca respectively in Fig. 64.

A6.5

As can be observed from Fig. 64 straight lines can be drawn through the data for each temperature considered which confirms the validity of Henry's Law for air in monochlorobenzene. The slopes of the lines gives the values of Henry's constant which are shown below along with the solubility calculated employing the appropriate air partial pressure.

Temperature oC	Henry's constant k vol %/mm Hg	Solubility cm^3 $gas_{(STP)}$/ cm^3 MCB
20 (p_1 = 751 mm Hg)	.016	.1202
60 (" = 694.5 ")	.0172	.1194
80 (" = 615.2 ")	.0187	.1150
100 (" = 467.2 ")	.0232	.1084

A6.6

Solubility data obtained by Horiuti[105] for Nitrogen and Oxygen in monochlorobenzene up to 80°C is contained in the compilation of Stephen and Stephen[106] and is reproduced in Table 19. The values given in Table 19 have been corrected to an STP basis (0°C, 760 mm Hg.) and these component solubilities have been used to arrive at the calculated air solubility figures shown in Table 20. Also given in Table 20 are the experimental solubilities determined in this work together with comparison data for water[106].

Temperature °C and experimental constants	Burette Hg level h - mm	Manometer Hg level m - mm	Total pressure in vapour space P mm Hg	$\frac{B-p_1}{P}$	V_G ml	$\frac{.123\ V_G}{V_L}$
20°C	1040.6	603.0	318.4	2.37	2.2	.0131
B = 765.5 mm Hg	1025.2	492.0	222.6	3.387	4.8	.0286
p_1 = 9 mm Hg	1008.7	420.0	167.1	4.512	7.8	.0465
l = 114.4 mm	983.9	355.0	126.9	5.94	12.3	.0733
s.g. MCB = 1.1	952.0	292.5	96.3	7.83	18.1	.108
V_L = 20.65 ml						
60°C	1108.2	667.0	321.5	2.196	2.2	.0134
B = 771.5 mm Hg	1087.3	522.0	196.5	3.587	5.8	.0349
p_1 = 65.5 mm Hg	1043.9	394.5	112.9	6.253	13.7	.0824
l = 113.3 mm	955.9	262.0	68.5	10.3	29.7	.1786
s.g. MCB = 1.1						
V_L = 20.6 ml						
80°C	1012.7	523.5	251.7	2.389	3.2	.0194
B = 750 mm Hg	1000.4	456.0	196.3	3.061	5.4	.0328
p_1 = 144.8 mm Hg	981.4	386.0	145.5	4.134	8.8	.0532
l = 112.8 mm	947.8	305.5	98.5	6.106	14.8	.09
s.g. MCB = 1.1	908.7	243.0	75.0	8.02	21.9	.132
V_L = 20.3 ml						
100°C	1011.0	578.0	328.0	1.442	1.8	.0109
B = 770 mm Hg	1000.6	478.5	238.7	1.981	3.6	.0217
p_1 = 292.8 mm Hg	985.7	398.5	173.6	2.725	6.25	.0376
l = 113.1 mm	965.2	334.5	130.0	3.638	10.0	.0602
s.g. MCB = 1.1	934.1	269.5	96.2	4.914	15.6	.0938
V_L = 20.40 ml						

Table 18. Results obtained in exercise to determine the solubility of air in monochlorobenzene at various temperatures.

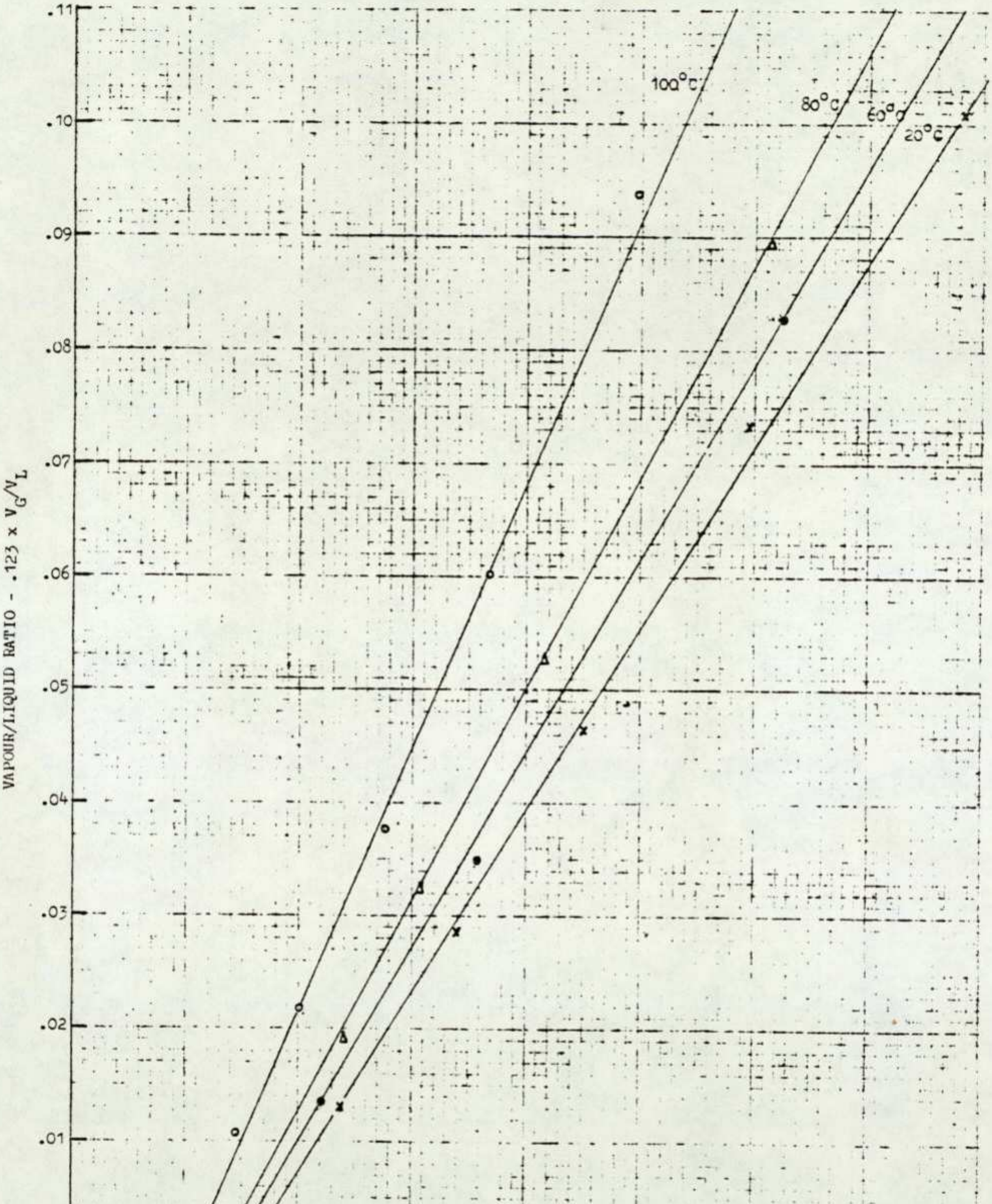


FIG. 64 Vapour-liquid ratio (corrected to STP) versus $(B-p_1)/P$ for air solubility determination in Monochlorobenzene.

Temperature C	N_2-Monochlorobenzene cm^3 gas/cm^3 MCB	O_2-Monochlorobenzene cm^3 gas/cm^3 MCB
0	.0881	.1748
10		.1804
20	.0994	.1863
25	.1020	.1890
30		.1915
40		.1974
40.1	.1116	
50		.2031
60		.2094
60.5	.1259	
70		.2163
80		.2214
80.3	.1399	

TABLE 19: SOLUBILITY OF NITROGEN AND OXYGEN IN MONOCHLOROBENZENE [105]

Temp. °C	Monochlorobenzene Solubility cm^3 gas(STP)/cm^3 MCB				Water Solubility cm^3 gas(STP)/cm^3 H_2O
	Data of Horiuti[105]			This work	Data of L.W. Winkler (1891)
	N_2	O_2	Air (calculated)	Air	Air
20	.0915	.1715	.1069	.1202	.0181
60	.0943	.1521	.1064	.1194	.0103
80	.0876	.1386	.0983	.1150	.0075
100	-	-	-	.1084	.00042

TABLE 20: LITERATURE AND EXPERIMENTALLY DETERMINED AIR SOLUBILITIES IN MONOCHLOROBENZENE ALONG WITH COMPARATIVE DATA FOR WATER

From this latter Table it can be seen that the experimentally determined solubilities, which showed the expected decrease with increasing temperature, are 12-15% greater than the literature values which were rated by Markham & Kobe[107] to be of the highest reliability. Since the method of Derry et al[104] employed here was similarly considered by Batino and Clever[108] to be reliable the difference between the experimental and literature values can probably be attributable to a combination of manometer level reading errors, the possibilities that equilibrium conditions were not established in the aeration of the fluid samples in the first instance, temperature variations in the nominally constant temperature bath, not enough time being given for the sample to be thoroughly degassed at each data point or slight air leakage into the burette vapour space during sample degassing.

A6.7

During the start-up phase of loop operation the fluid in the make-up tank in the case of monochlorobenzene was degassed under a vacuum of 507 torr (10 ins. Hg) at an average temperature of 100°C for 30 minutes. Using the Henry's Law constant value at 100°C of .0232 vol %/mm Hg the dissolved gas content for the loop fluid can be determined as follows:

make-up tank pressure = 507 mm Hg.

Vapour pressure of monochlorobenzene at 100°C = 293 mm Hg.

Partial pressure of air in make-up tank = 507 - 293 = 214 mm Hg.

$\therefore$ dissolved gas content = .0232 x 214 = 4.96 $ml_{air}/100\ ml_{MCB}$

APPENDIX 7 - VOID FRACTION MEASUREMENT AT TEST SECTION EXIT

A7.1

The vapour volumetric fraction or void fraction is an important parameter in two-phase flow studies. A knowledge of the void fraction is required to calculate the slip ratio (liquid ÷ vapour phase velocities) and certain components of pressure drop. Since there are widely varying flow regimes in two-phase flow it has been suggested[29] that an expression for the local heat transfer coefficient along an evaporator tube should include the void fraction, particularly when non-equilibrium flow conditions are involved such as in the case of sub-cooled and low quality boiling.

A7.2

A system employing the gamma-ray attenuation technique was designed so as to determine the void fraction at a position immediately above the upper test section power clamp. In the event this system was not developed to the extent necessary for confidence to be placed in the void fraction measurements obtained by the time the rig commissioning tests were completed. Since the experimental programme with the rig could not be delayed for further evaluation work the gamma attenuation apparatus was used in its state of development at that time. The purpose of this Appendix is to record the work undertaken on void fraction measurement with the gamma attenuation technique together with the results obtained and a discussion of the possible sources of errors between the actual and measured void fractions.

A7.3

The gamma-ray attentuation method of void fraction measurement is a well established technique in two-phase flow work[109]. Gamma rays are attenuated as they pass through matter in such a way that the decrease in gamma-ray intensity with distance is proportional to intensity i.e.:-

$$dI/dz = \mu I \qquad \text{(Eq. A7.1)}$$

where:

I is the gamma-ray beam intensity

z = the space co-ordinate in the beam direction.

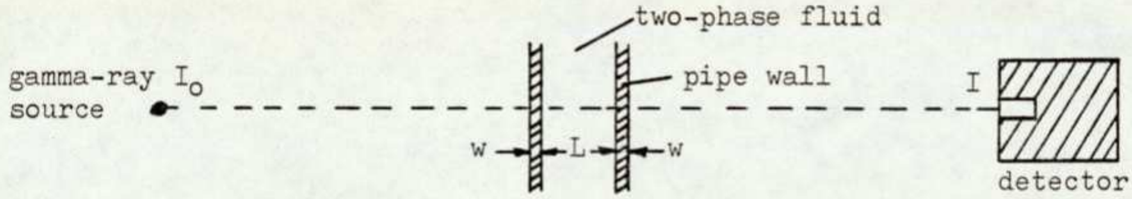
μ = the attentuation or linear mass absorption coefficient which is a function of the material properties and the gamma-ray (or photon) energy.

For a uniform beam of monoenergetic gamma-rays which have passed through an attenuating material of thickness t Eq.A7.1, may be integrated to give:

$$I = I_o e^{-\mu t} \quad \text{(Eq. A7.2)}$$

Where I_o and I are the incident and transmitted ray intensities respectively.

The above relationship applies equally to a laminated material configuration and for the particular case of a two-phase mixture in a steel pipe:



$$I = I_o e^{-\mu_s w} e^{-\mu_f L} e^{-\mu_s w}$$

μ_s = linear mass absorption coefficient for pipe wall.

μ_f = " " " " " two-phase fluid.

If the flowing fluid can be considered as homogeneous its properties can be obtained from the relation:

$$\mu_f = \alpha\mu_G + (1 - \alpha)\mu_L$$

where α is the void fraction and suffices G and L refer to the vapour and liquid phases respectively.

Now the gamma-ray intensities measured by the detector when the pipe is full and empty (i.e. 100% liquid and 100% vapour) are:-

$I_1 = I_o e^{(-2\mu_s w)} \; e^{(-\mu_L L)}$ for full pipe case

$I_2 = I_o e^{(-2\mu_s w)} \; e^{(-\mu_G L)}$ for empty pipe case

$$\therefore \frac{I_2}{I_1} = e^{-(\mu_L - \mu_G)L}$$

Thus for any intermediate mixture of vapour and fluid defined by the void fraction α which results in an intensity I at the detector:

$$\frac{I}{I_1} = e^{-(\mu_L-\mu_G)\alpha L}$$

Combining the latter two expressions we have:

$$\alpha = \frac{\log_e I/I_1}{\log_e I_2/I_1} \qquad \text{(Eq. A.7.3)}$$

The measurement of void fraction therefore involves only the determination of the respective intensities and it is not necessary to have a knowledge of the attenuation coefficients (μ's) for the various materials involved. In fact only the measurement of 'I' is necessary as I_1 and I_2 are constants requiring measurement only at the beginning and end of each day if the 'half life', i.e. the time for the activity of the source to decrease by a half, is sufficiently long.

A7.4

The gamma-ray source and detection system used in the investigation is illustrated in Figs. 65 and 66 and Plates 24-27. The source of gamma-rays or photons was a radioisotope pellet contained in a removeable lead source holder (Plate 26). The radioisotope was supplied by the Radiochemical Centre where it had been produced by irradiating Thullium-169 in a nuclear reactor to produce Thullium-170. This latter isotope decays with a half life of 129 days to a stable element Ytterbium-170 with the emission of gamma-rays having a relatively low energy of .084 MeV. A low energy emitting isotope was desirable since this would result in a greaterattenuation in the two-phase mixture and thus provide a more accurate measurement of void fraction. The 129 day half life of Thullium-170 was sufficiently long to ensure an essentially constant source strength during a three-four hour data taking session. The initial activity or source strength of the isotope when supplied was about 100 millicuries which was selected so as to give reasonable counting statistics during data recording whilst not posing a significant radiological

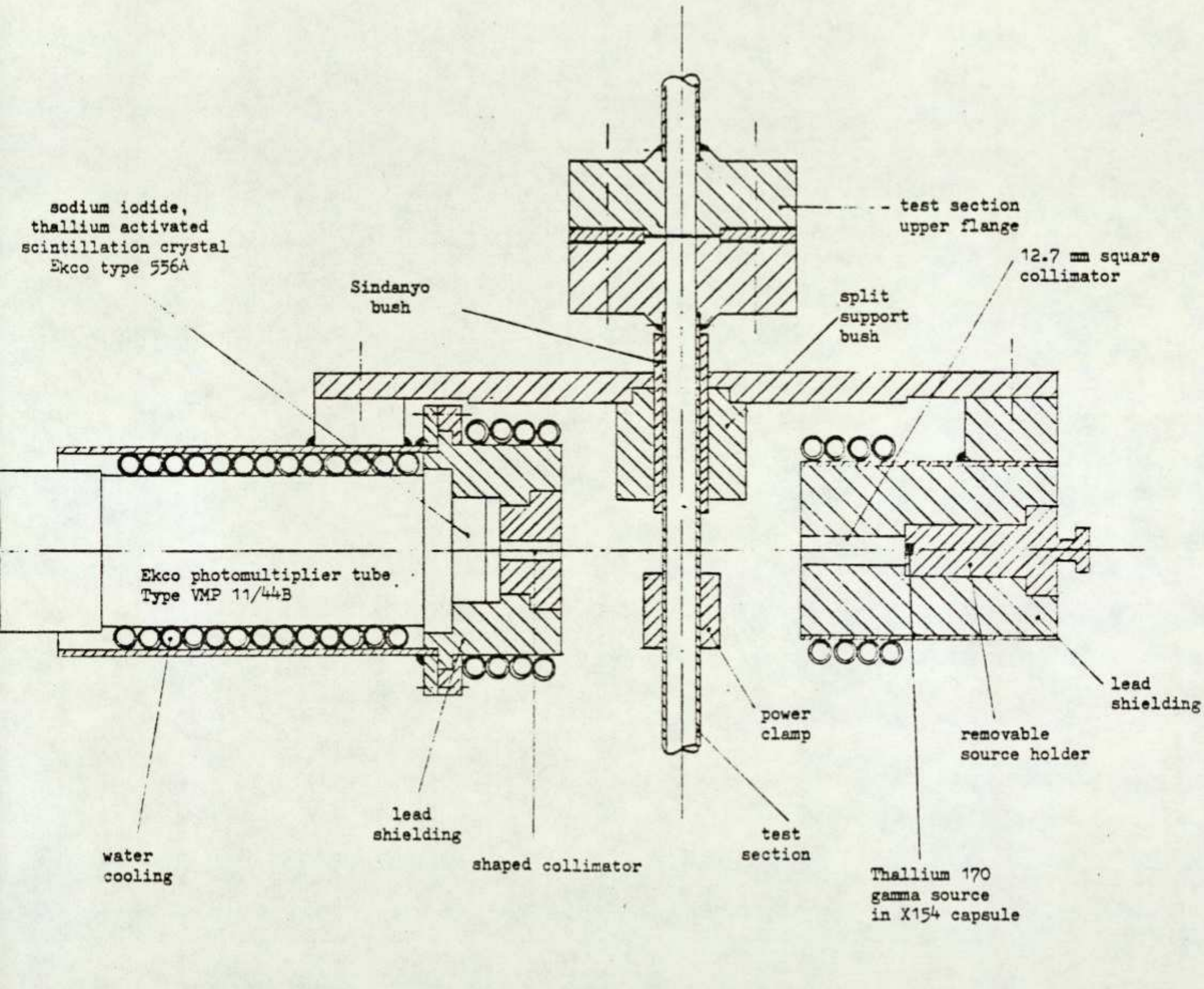


Fig. 65 Gamma-ray detection apparatus for void fraction measurement.

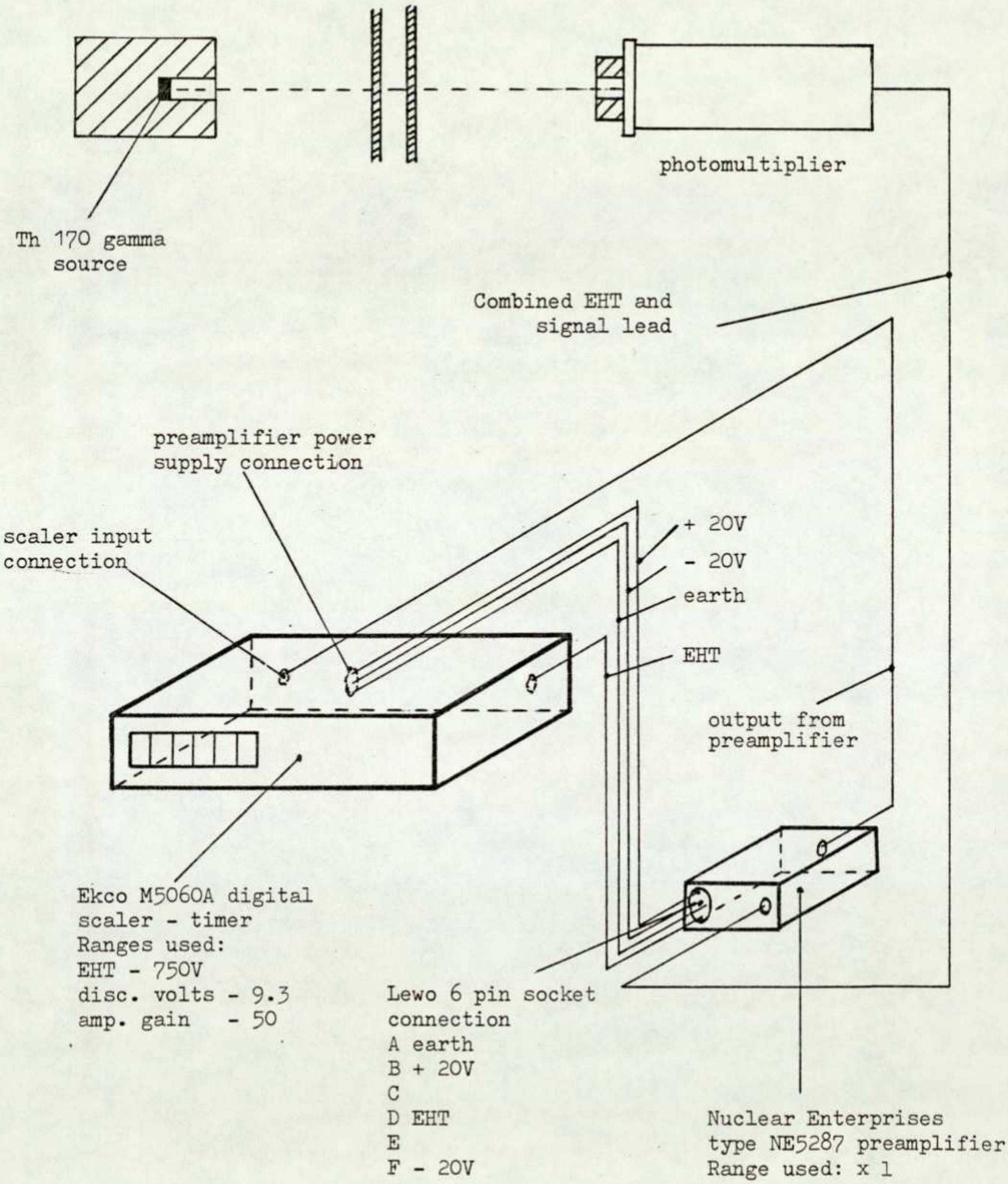


FIGURE 66 - ARRANGEMENT OF VOID FRACTION MEASURING INSTRUMENTATION

PLATE 24. Components of test section exit void measurement apparatus

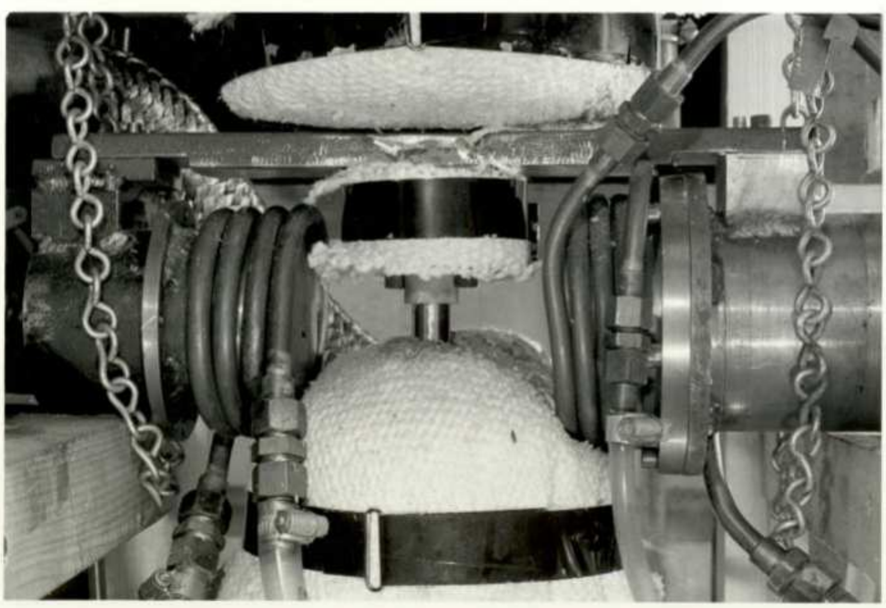


PLATE 25. Void fraction measurement system - view of gamma source and detection heads at test section exit.

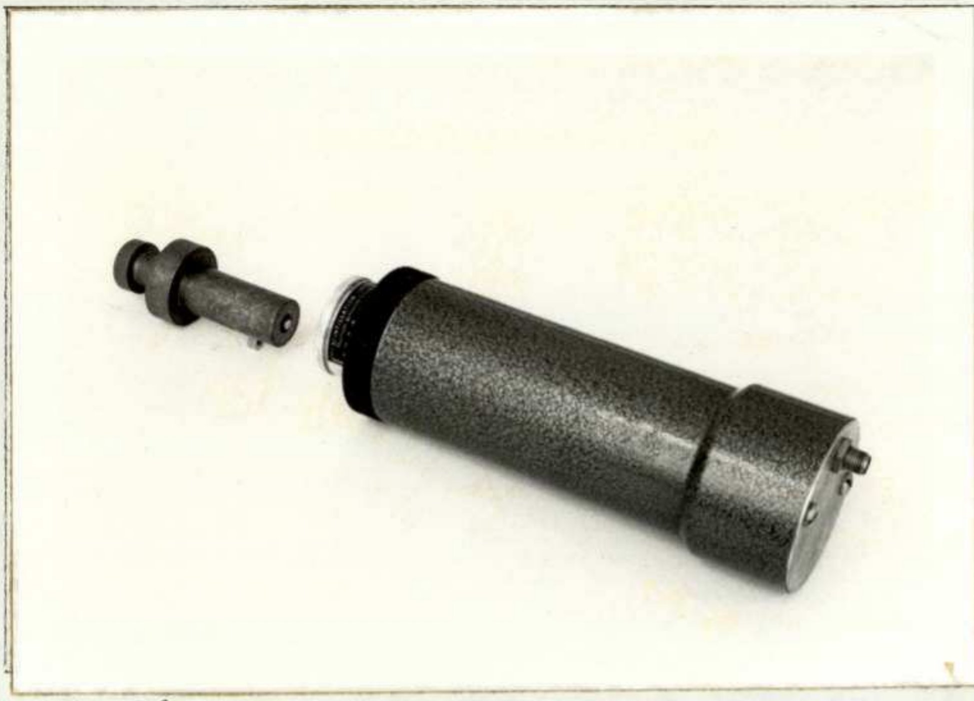


PLATE 26 Source holder showing radioisotope pellet and sodium iodide crystal - photomultipher tube.

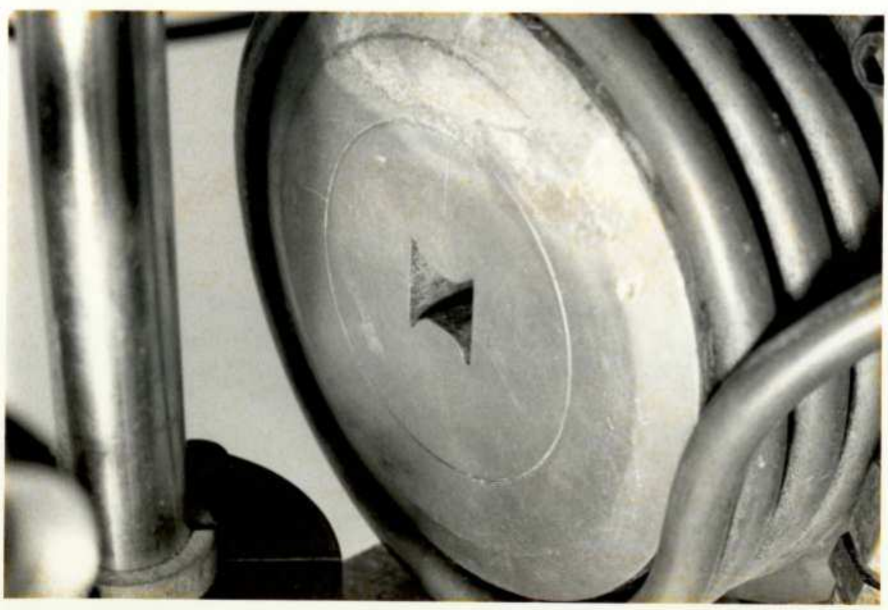


PLATE 27. View of detector head collimator

hazard to personnel in the loop area.

A7.5

A scintillation counting technique was employed to measure the intensities of the gamma-rays using a scintillation crystal and photomultiplier (Plate 26). In this method each gamma photon entering the sodium iodide crystal produces a light flash or 'scintillation' within it which is amplified by a photomultiplier to produce a current which is counted as a pulse by a scaler. The gamma-rays emanating from the source were collimated by the lead source holder to a 12.7 mm x 12.7 mm beam which traversed the complete flow area. A specially shaped detector collimator (Plate 27) was employed to reduce measurement errors with this so called 'one shot' technique which are attributable to any non-uniform distribution of voidage in the channel[110]. The discriminator pulse height setting was adjusted so that pulses below a certain level were not counted. The setting finally selected was 9.3 volts in the discriminator range 0.2 to 10 volts. The pulse amplifier voltage gain settings were x 5 for the Ekco M5050 unit and x 1 for the Nuclear Enterprises NE5287 pre-amplifier.

A7.6

For most test runs two counts each of 40 seconds duration were taken whilst data recording was in progress. These measurements are given in Table 28 of Appendix 8 along with the empty and full tube counts which had been previously obtained during the loop start-up phase and were assumed to be unchanged from test to test for the day in question. The evaluation of the void fraction using Eq.A7.3 requires that the counts are obtained at the same flow temperature. A temperature correction factor, Ft for the full tube case was determined from single phase tests at different temperatures when a count was recorded and compared to the room temperature (about 20°C) full tube count taken on the same day. Values of Ft, the ratio of these latter two counts, are shown for the single phase tests with monochlorobenzene in Fig. 67.

Since the linear mass absorption coefficient for a given material is proportional to the density of that material the temperature correction factor, Ft, can be determined from:-

$$Ft = e^{-k(\rho_L - \rho_{L20})}$$

Experimental values of Ft were used to determine the value of the constant k in the above expression as 0.1631. For the biphenyl-biphenyl oxide test series no single phase data were taken specifically for determining Ft. The temperature correction factors given in Table 28 for the biphenyl-biphenyl oxide tests were taken from the curve for this fluid given in Fig. 67 which was derived from the monochlorobenzene tests for identical values of the residual liquid density ($\rho_L - \rho_{L20}$).The empty tube temperature correction factor was assumed to be unity for all tests with both fluids since the attenuation of the tube filled with air at ambient conditions was found to be essentially the same as that of the tube filled with vapour at the operating conditions.

A7.7

The test section exit void fractions calculated using Eq.A7.3 from the values of I, I_1 and I_2 determined for each of the tests are given along with the latter in Table 28 . Also shown in Table 28 is the calculated test section exit equilibrium quality for each of the net boiling tests as abstracted from Tables 23 and 24 . The exit void fraction is plotted against the exit quality in Fig.68 for the monochlorobenzene test series conducted at a nominal reduced pressure of 0.22. Two calculated void fraction-quality relationships are included in Fig. 68 for comparison purposes with the experimental data. The theoretical curves shown were calculated using:-

(i) The homogeneous model with the liquid-vapour phase velocity ratio (or slip ratio) equal to unity.

(ii) The Martinelli-Nelson[111] correlation for steam-water systems at the same value of ρ_L/ρ_G(26.4, around 5.59 MN/m^2 with water).

A7.8

As mentioned in A7.2 it was considered that little confidence could be

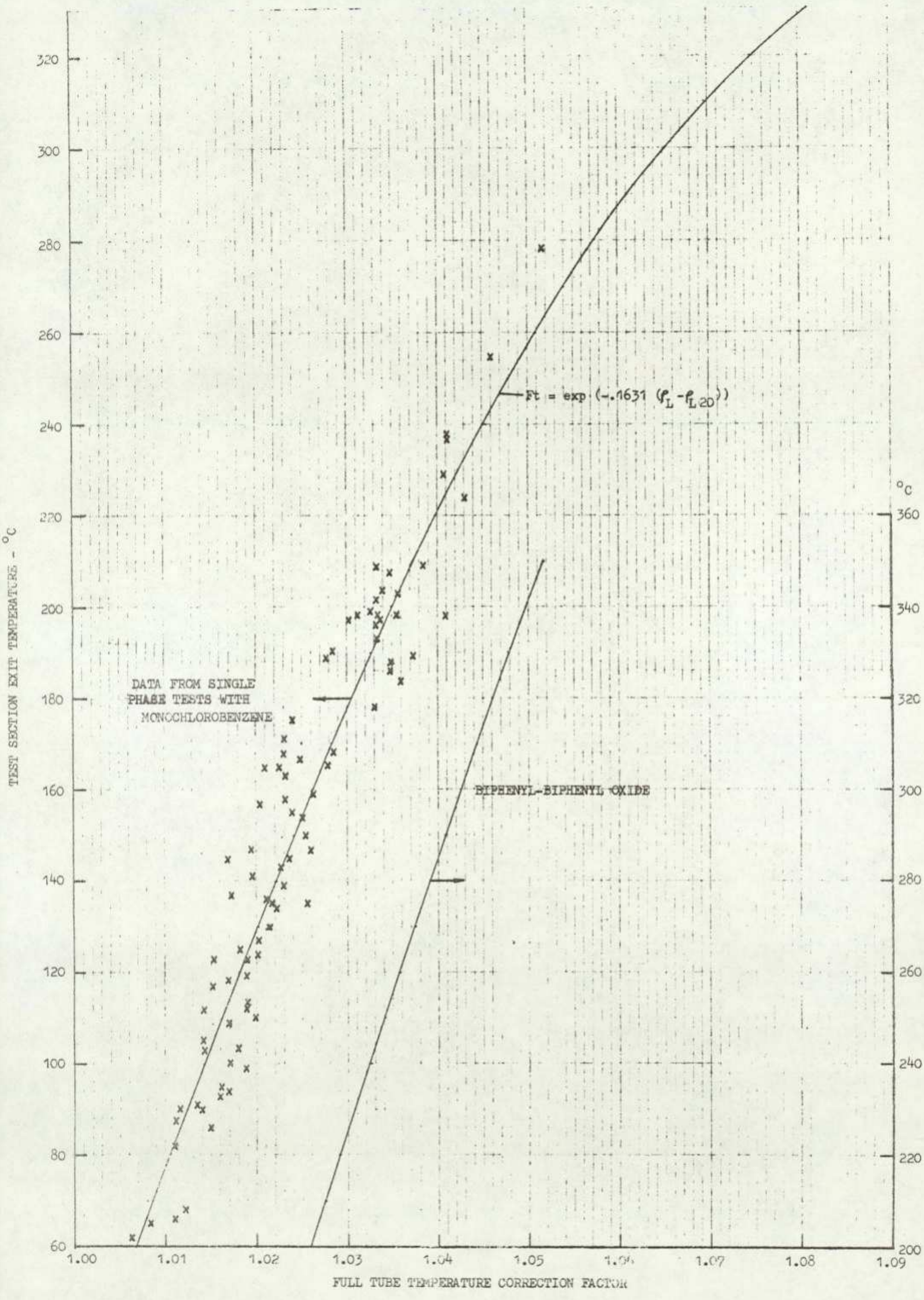


FIG. 67 TEST SECTION EXIT TEMPERATURE VERSUS FULL TUBE TEMPERATURE CORRECTION FACTOR DERIVED FROM SINGLE PHASE TESTS WITH MONOCHLOROBENZENE

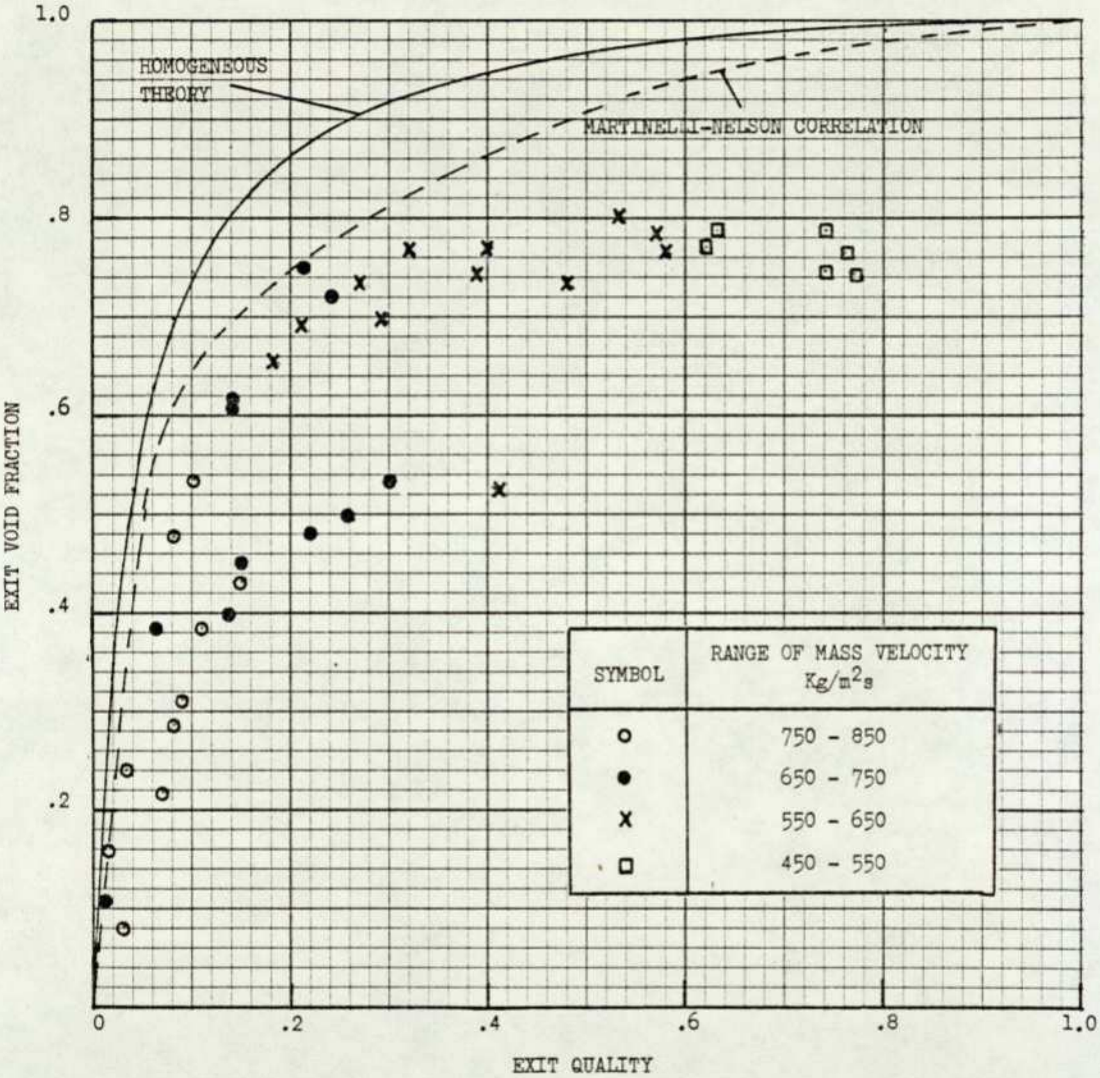


Fig. 68 Experimental and calculated exit void fraction versus exit quality for monochlorobenzene test series conducted at a nominal reduced pressure of 0.22

placed in the void fraction measurements obtained in the investigation, a view which was confirmed by the following unusual trends shown by the experimental data:-

(i) The mass velocity effect shown in Fig. 68 was opposite to that expected from the refrigerant data of Baker[112] and Zuber et al[113] as summarised by Collier[21]. In the net boiling region an increase in mass velocity increases the void fraction at a given value of exit quality, contrary to the results obtained here.

(ii) The experimentally determined void fractions are considerably less than the predicted values throughout the exit quality range when they should be expected to be near those given by the Martinelli-Nelson prediction at mass velocities less than 1,000 kg/m^2s[21][60].

(iii) No voidage was present in low exit sub-cooling tests when considerable voidage could be expected from non-equilibrium effects.

A7.9

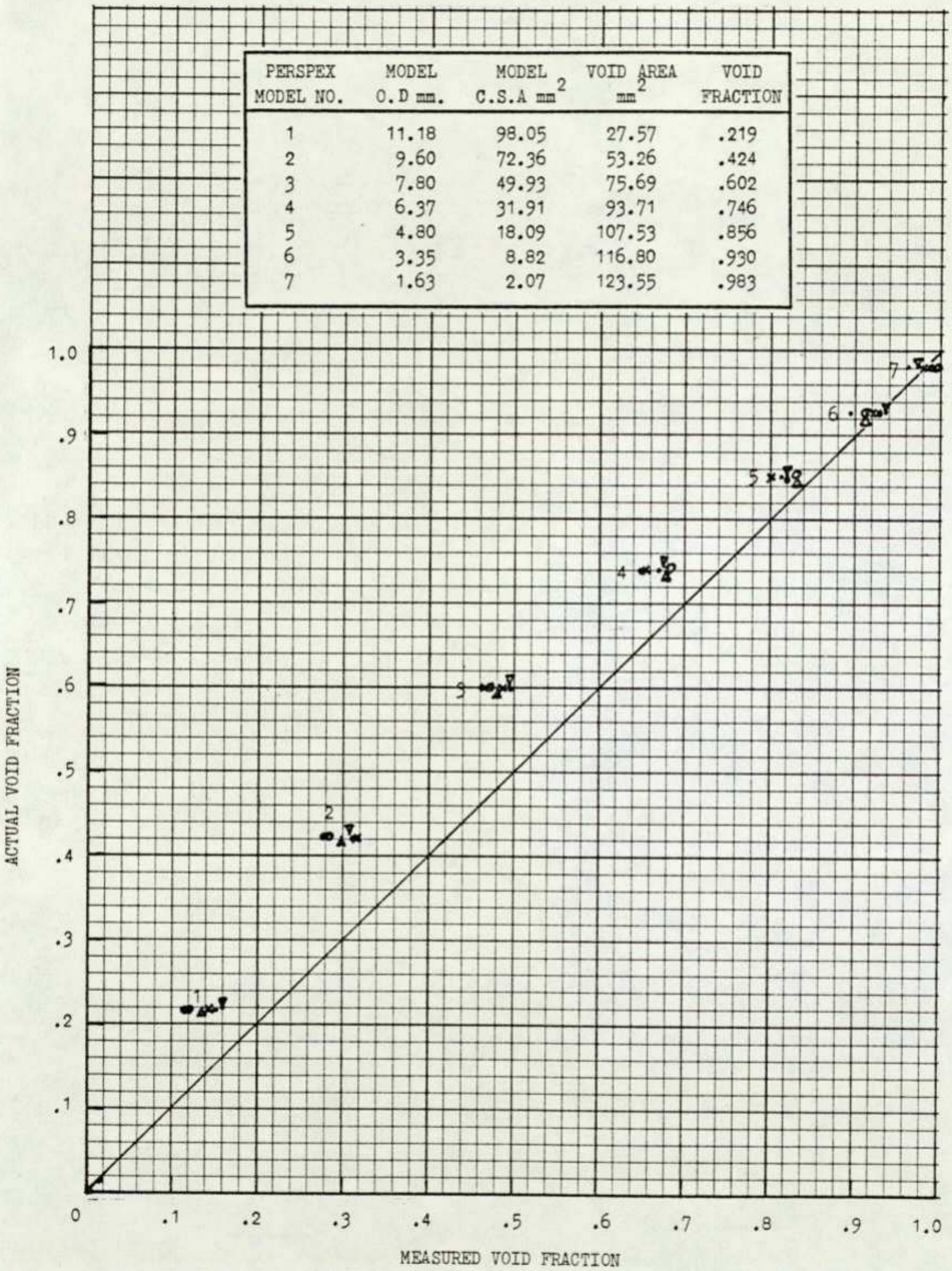
Several reasons can be advanced for the errors experienced in void fraction measurements, viz:-

(i) Preferential void fraction distribution.

(ii) Departures from the assumption of true exponential attenuation of the gamma-rays.

(iii) Errors in the full and empty tube temperature correction factors.

Of the above it is likely that (i) was the main source of error in the investigation with the 'one shot' technique employed despite the use of the specially shaped photomultiplier collimator design for minimising such errors. Prior to and at the conclusion of the experimental programme the accuracy of the gamma attenuation apparatus was evaluated using various diameter Perspex rods to create known void fractions within a sample offcut of the test section tube. The results of this exercise are presented in Fig. 69 , where it can be seen that significant differences exist between actual and measured values, particularly at low void fractions. Errors associated with (ii) would have



PERSPEX MODEL NO.	MODEL O.D mm.	MODEL C.S.A mm^2	VOID AREA mm^2	VOID FRACTION
1	11.18	98.05	27.57	.219
2	9.60	72.36	53.26	.424
3	7.80	49.93	75.69	.602
4	6.37	31.91	93.71	.746
5	4.80	18.09	107.53	.856
6	3.35	8.82	116.80	.930
7	1.63	2.07	123.55	.983

FIG.69 COMPARISON OF ACTUAL AND MEASURED VOID FRACTIONS OBTAINED USING PERSPEX MODELS WITHIN THE 12.65 mm. I.D. TEST SECTION (C.S.A = 125.62mm^2).

arisen from the use of Thullium-170 which emits, in addition to the .083 MeV gamma-rays, .053 MeV beta rays. The presence of the latter would invalidate the assumption of pure exponential attenuation to some extent.

A7.10

In retrospect it would have been preferable to employ the traversing technique to reduce errors due to preferential void distribution. With this latter system instead of traversing the complete tube diameter a narrow (~1 mm wide) collinated beam is traversed across the diameter to yield the void fraction distribution which can be integrated to give the mean value. Ideally also a pulse height analyser should have been incorporated in the detection system to create a 'window' so as to count only photons having an energy of about .083 MeV which would have followed an exponential attenuation law. This latter system would however have required a much higher activity gamma source to provide good counting statistics in a reasonable time since otherwise the count rate would be rather low.

APPENDIX 8 - LISTING OF EXPERIMENTAL & DERIVED RESULTS

A8.1

Table 21 - Listing of experimental data for monochlorobenzene (pages 264 - 281).

Table 22 - Listing of experimental data for biphenyl-biphenyl oxide (pages 282 - 284).

These Tables have an identical format and list the experimental results as inputted to the data reduction computer program, arranged in four lines of text so as to conserve space. Approximately half of the first line gives in the following order:-

Date of test, Test No. of day, Series test No., Nominal reduced pressure, Test section inlet pressure (bar), Test section exit pressure (bar), Test section inlet temperature (^{o}C), Test section exit temperature (^{o}C), flow rate (kg/s), Test section volts and amps. After a space there follows 72 recordings from the insulated test section thermocouples from the inlet to the exit end, i.e. from position No. 71 to a fictitious one required by the computer program at the end of the heated length. These latter thermocouple readings represent raw data from the tests as recorded by the datalogger teletype.

A8.2

Table 23 - Listing of derived experimental data for monochlorobenzene (pages 285 - 289).

Table 24 - Listing of derived experimental data for biphenyl-biphenyl oxide (page 290).

These Tables likewise have a similar format and give a digest of the experimental conditions for each test together with inner wall temperature values at intervals along the test section. The inner wall temperatures are listed at intervals of .127 m up the test section commencing at the first thermocouple position (location nos. 71, 66, 61, 56, 51, 46, 41, 36, 31, 26, 21, 16, 11, 6, and 1 in Fig. 24).

A8.3

Table 25- Listing of data used in multiple linear regression analysis together with a comparison of experimental and calculated net boiling heat transfer coefficients (pages 291-293).

A summary of the heat flux and liquid-vapour density ratio values used in the multiple linear regression analysis exercise together with a comparison between the experimental and calculated heat transfer coefficients and the nominal value of wall superheat present in a particular test.

A8.4

Table 26 - Comparison of measured pressure drop with that predicted by the homogeneous theory for the monochlorobenzene test series. (Pages 294-6).

Table 27 - Comparison of measured pressure drop with that predicted by the homogeneous theory for the biphenyl-biphenyl oxide test series. (Page 297).

Pressure drop components as calculated using the homogeneous theory together with the experimentally determined overall pressure drop.

A8.5

Table 28 - Summary of integral count measurements obtained with the gamma-ray attenuation apparatus for the determination of the test section exit void fraction. (Pages 298-301).

A listing of the counts recorded during the data taking phases of the monochlorobenzene and biphenyl-biphenyl oxide test seris. For each test the full and empty tube counts are given together with a full tube temperature correction factor taken from Fig. 67.

TABLE 21 EXPERIMENTAL DATA FOR MONOCHLOROBENZENE TEST SERIES

LISTING OF EXPERIMENTAL DATA OBTAINED USING MONOCHLOROBENZENE

NOTE:-

EACH DATA SET OCCUPIES 4 LINES IN THE FOLLOWING TABLE. APPROXIMATELY HALF OF THE FIRST LINE GIVES IN THE FOLLOWING ORDER :- DATE OF TEST, TEST NO. OF DAY, SERIES TEST NO., REDUCED PRESSURE, TEST SECTION INLET PRESSURE(BAR), TEST SECTION EXIT PRESSURE(BAR) TEST SECTION INLET TEMP.(DEG C), TEST SECTION EXIT TEMP.(DEG C), FLOWRATE(KG/SEC), TEST SECTION VOLTS, TEST SECTION AMPS. THERE THEN FOLLOWS A SPACE AFTER WHICH 72 TEST SECTION OUTER WALL THERMOCOUPLE READINGS(MV) FROM INLET TO EXIT COMPRISE THE REMAINDER OF THE DATA SET. THE LAST OF THESE THERMOCOUPLE READINGS IS A FICTITIOUS ONE WHICH IS REQUIRED BY THE DATA REDUCTION COMPUTER PROGRAM

21/11/74	1	1	.12	5.574	5.295	158.0	168.8	.1042	7.81	275.3						7.70	7.61	7.77	7.78	7.76	7.84
7.64	7.84	7.86	7.86	7.83	7.87	7.89	7.87	7.91	7.91	7.89	7.89	7.94	7.96	7.93	7.96	7.96	7.98	8.00	8.00	8.03	8.03
8.04	8.01	8.04	8.07	8.06	8.07	8.04	8.09	8.09	8.04	8.10	8.10	8.11	8.13	8.14	8.14	8.18	8.17	8.18	8.22	8.18	8.17
8.19	8.21	8.21	8.22	8.27	8.28	8.29	8.28	8.28	8.28	8.30	8.31	8.31	8.31	8.30	8.27	8.37	8.33	8.37	8.33	8.38	8.38
21/11/74	2	2	.12	5.549	5.286	157.6	168.6	.1041	7.79	277.2						7.69	7.62	7.76	7.77	7.75	7.85
7.82	7.84	7.84	7.86	7.82	7.86	7.88	7.87	7.89	7.89	7.89	7.87	7.93	7.94	7.96	7.95	7.94	7.97	7.98	7.99	8.03	8.00
8.03	8.00	8.03	8.04	8.04	8.06	8.04	8.08	8.07	8.04	8.09	8.08	8.09	8.12	8.13	8.13	8.16	8.16	8.17	8.18	8.16	8.16
8.18	8.19	8.18	8.20	8.25	8.25	8.29	8.27	8.28	8.27	8.29	8.30	8.30	8.30	8.30	8.27	8.37	8.33	8.38	8.32	8.38	8.38
21/11/74	3	3	.12	5.664	5.342	146.7	168.8	.1062	10.94	389.2						7.93	7.93	8.08	8.11	8.09	8.25
8.19	8.23	8.23	8.25	8.22	8.27	8.32	8.31	8.36	8.35	8.32	8.32	8.41	8.43	8.47	8.44	8.46	8.48	8.50	8.52	8.58	8.57
8.59	8.55	8.61	8.63	8.62	8.64	8.62	8.69	8.68	8.64	8.72	8.73	8.74	8.77	8.79	8.80	8.84	8.84	8.85	8.89	8.84	8.86
8.90	8.91	8.94	8.95	9.03	9.05	9.08	9.08	9.08	9.09	9.13	9.13	9.13	9.14	9.14	9.11	9.22	9.18	9.23	9.20	9.24	9.24
21/11/74	4	4	.12	5.606	5.284	146.4	168.6	.1062	10.95	389.7						7.93	7.92	8.09	8.10	8.08	8.24
8.19	8.22	8.23	8.25	8.22	8.26	8.31	8.33	8.35	8.36	8.32	8.33	8.42	8.44	8.48	8.45	8.47	8.60	8.52	8.54	8.58	8.58
8.58	8.55	8.60	8.64	8.62	8.65	8.64	8.68	8.69	8.66	8.72	8.73	8.75	8.78	8.81	8.80	8.85	8.84	8.86	8.89	8.87	8.85
8.88	8.91	8.93	8.94	9.03	9.05	9.09	9.08	9.08	9.08	9.12	9.14	9.14	9.16	9.14	9.12	9.23	9.18	9.23	9.19	9.25	9.25
21/11/74	5	5	.12	5.338	5.155	171.7	193.5	.1031	10.87	395.6						9.12	9.07	9.28	9.29	9.27	9.43
9.38	9.40	9.41	9.43	9.40	9.44	9.49	9.48	9.53	9.53	9.48	9.49	9.60	9.60	9.64	9.62	9.64	9.65	9.68	9.70	9.73	9.74
9.74	9.69	9.76	9.80	9.77	9.80	9.78	9.84	9.82	9.80	9.88	9.80	9.78	9.87	9.81	9.79	9.81	9.78	9.80	9.83	9.80	9.78
9.79	9.84	9.82	9.83	9.84	9.84	9.88	9.82	9.83	9.80	9.82	9.84	9.84	9.83	9.80	9.78	9.86	9.83	9.87	9.83	9.89	9.89
21/11/74	6	6	.12	5.183	5.102	173.0	201.7	.1029	12.57	441.7						9.73	9.70	9.93	9.94	9.89	9.93
9.96	9.89	9.89	9.91	9.87	9.89	9.91	9.89	9.91	9.92	9.91	9.91	9.95	9.93	9.92	9.89	9.89	9.89	9.92	9.89	9.93	9.92
9.95	9.92	9.97	9.93	9.89	9.94	9.89	9.93	9.89	9.86	9.92	9.91	9.90	9.95	9.94	9.92	9.96	9.93	9.95	9.97	9.94	9.93
9.95	10.01	9.97	9.99	10.00	9.99	10.04	9.96	9.98	9.96	9.96	9.98	9.98	9.98	9.98	9.91	10.00	9.96	10.01	9.95	9.99	9.99
21/11/74	7	7	.12	5.779	5.405	172.6	209.3	.0978	15.03	531.7						10.19	10.02	10.22	10.19	10.20	10.26
10.24	10.24	10.26	10.28	10.23	10.27	10.28	10.27	10.30	10.30	10.30	10.30	10.33	10.34	10.33	10.28	10.30	10.30	10.32	10.30	10.33	10.31
10.33	10.31	10.31	10.32	10.28	10.32	10.26	10.30	10.28	10.28	10.31	10.29	10.27	10.31	10.30	10.28	10.32	10.28	10.30	10.32	10.30	10.27
10.30	10.36	10.30	10.31	10.32	10.33	10.36	10.29	10.30	10.27	10.29	10.30	10.30	10.28	10.25	10.21	10.28	10.24	10.30	10.24	10.28	10.28
21/11/74	8	8	.12	5.543	5.268	173.8	208.2	.0977	15.03	530.7						10.13	9.98	10.16	10.15	10.13	10.20
10.19	10.18	10.19	10.22	10.18	10.20	10.23	10.21	10.23	10.26	10.25	10.26	10.28	10.28	10.26	10.23	10.24	10.25	10.28	10.25	10.28	10.24
10.31	10.26	10.26	10.27	10.23	10.26	10.21	10.25	10.23	10.20	10.24	10.22	10.22	10.25	10.25	10.24	10.27	10.24	10.24	10.27	10.24	10.24
10.24	10.32	10.26	10.27	10.29	10.27	10.30	10.24	10.26	10.23	10.24	10.25	10.28	10.24	10.21	10.19	10.28	10.21	10.28	10.21	10.27	10.27
21/11/74	9	9	.12	6.047	5.599	172.6	213.2	.0686	17.47	614.9						10.53	10.38	10.58	10.56	10.56	10.62
10.61	10.60	10.64	10.64	10.60	10.62	10.64	10.64	10.68	10.68	10.67	10.67	10.68	10.71	10.68	10.63	10.65	10.64	10.67	10.65	10.68	10.64
10.65	10.63	10.65	10.64	10.58	10.66	10.59	10.62	10.60	10.57	10.59	10.59	10.57	10.62	10.62	10.59	10.61	10.58	10.60	10.60	10.58	10.57
10.58	10.66	10.60	10.60	10.63	10.61	10.66	10.58	10.59	10.56	10.56	10.60	10.60	10.58	10.53	10.50	10.58	10.53	10.60	10.53	10.57	10.57
21/11/74	10	10	.12	5.793	5.454	177.0	210.2	.0771	17.60	619.6						10.47	10.33	10.52	10.50	10.50	10.56
10.55	10.56	10.57	10.59	10.54	10.56	10.58	10.57	10.60	10.61	10.59	10.62	10.63	10.64	10.62	10.57	10.58	10.57	10.61	10.58	10.62	10.58
10.63	10.56	10.58	10.59	10.54	10.58	10.52	10.56	10.54	10.49	10.53	10.53	10.50	10.53	10.54	10.50	10.54	10.52	10.52	10.51	10.51	10.49
10.51	10.58	10.52	10.53	10.54	10.53	10.58	10.49	10.52	10.48	10.50	10.52	10.52	10.50	10.45	10.44	10.51	10.46	10.52	10.46	10.49	10.49
21/11/74	11	11	.12	5.890	5.474	169.0	210.5	.0696	19.85	696.8						10.70	10.54	10.72	10.70	10.70	10.75
10.74	10.74	10.77	10.77	10.74	10.77	10.77	10.77	10.80	10.81	10.75	10.79	10.81	10.82	10.78	10.73	10.77	10.77	10.78	10.76	10.79	10.76
10.80	10.74	10.75	10.76	10.73	10.76	10.69	10.74	10.71	10.68	10.73	10.72	10.70	10.71	10.74	10.69	10.71	10.70	10.70	10.71	10.68	10.67
10.68	10.77	10.70	10.71	10.73	10.73	10.76	10.68	10.68	10.67	10.66	10.69	10.68	10.68	10.64	10.63	10.69	10.73	11.12	10.82	10.68	10.68
25/11/74	1	12	.12	5.688	5.374	192.8	209.6	.0994	10.96	397.6						10.19	10.12	10.26	10.18	10.14	10.17
10.18	10.15	10.16	10.20	10.17	10.19	10.18	10.19	10.21	10.22	10.19	10.19	10.23	10.24	10.22	10.18	10.17	10.19	10.20	10.18	10.22	10.21
10.24	10.21	10.21	10.23	10.18	10.22	10.18	10.19	10.18	10.13	10.20	10.18	10.17	10.20	10.20	10.18	10.19	10.17	10.18	10.20	10.19	10.14
10.19	10.25	10.19	10.19	10.19	10.21	10.23	10.16	10.18	10.12	10.16	10.18	10.17	10.13	10.13	10.07	10.23	10.58	10.64	10.44	10.24	10.24
25/11/74	2	13	.12	5.690	5.310	192.8	209.3	.0986	10.97	398.7						10.20	10.10	10.12	10.13	10.12	10.15

10.16	10.14	10.14	10.18	10.14	10.17	10.17	10.15	10.18	10.21	10.17	10.18	10.22	10.23	10.19	10.18	10.18	10.18	10.19	10.18	10.21	10.18
10.23	10.20	10.20	10.21	10.16	10.19	10.16	10.18	10.16	10.11	10.18	10.18	10.16	10.17	10.18	10.16	10.18	10.16	10.16	10.18	10.17	10.14
10.18	10.22	10.18	10.19	10.19	10.19	10.22	10.14	10.18	10.11	10.15	10.17	10.16	10.13	10.11	10.07	10.22	10.47	10.60	10.42	10.22	10.22
25/11/74	3	14	.12	5.676	5.359	193.6	209.6	.0986	10.97	387.9						10.27	10.12	10.14	10.14	10.14	10.16
10.18	10.15	10.15	10.19	10.16	10.17	10.18	10.18	10.18	10.20	10.18	10.17	10.22	10.23	10.18	10.17	10.17	10.19	10.18	10.16	10.18	10.18
10.22	10.20	10.19	10.21	10.16	10.18	10.16	10.18	10.16	10.11	10.18	10.16	10.16	10.18	10.18	10.17	10.18	10.17	10.17	10.18	10.16	10.14
10.18	10.22	10.18	10.18	10.15	10.19	10.22	10.15	10.17	10.11	10.16	10.16	10.15	10.13	10.10	10.06	10.22	10.46	10.58	10.41	10.23	10.23
25/11/74	4	15	.12	5.579	5.378	193.4	209.3	.0832	14.25	502.7						10.33	10.23	10.36	10.39	10.37	10.40
10.41	10.40	10.40	10.44	10.39	10.42	10.40	10.41	10.41	10.46	10.42	10.42	10.46	10.47	10.42	10.40	10.40	10.40	10.40	10.38	10.42	10.40
10.45	10.40	10.42	10.41	10.36	10.39	10.35	10.38	10.36	10.31	10.38	10.36	10.34	10.37	10.38	10.34	10.36	10.33	10.33	10.32	10.34	10.30
10.35	10.39	10.35	10.35	10.34	10.36	10.38	10.31	10.33	10.27	10.32	10.33	10.32	10.30	10.28	10.23	10.39	10.64	10.76	10.58	10.42	10.42
25/11/74	5	16	.12	5.727	5.376	192.2	211.1	.0842	14.11	497.9						10.33	10.22	10.34	10.34	10.34	10.37
10.38	10.37	10.38	10.41	10.38	10.38	10.37	10.38	10.39	10.41	10.39	10.40	10.44	10.43	10.39	10.37	10.37	10.39	10.39	10.37	10.40	10.38
10.42	10.38	10.38	10.38	10.33	10.36	10.32	10.33	10.34	10.30	10.35	10.35	10.33	10.35	10.34	10.33	10.34	10.33	10.33	10.34	10.32	10.28
10.33	10.38	10.33	10.33	10.33	10.33	10.37	10.30	10.32	10.26	10.28	10.32	10.31	10.28	10.27	10.22	10.37	10.60	10.73	10.56	10.41	10.41
25/11/74	6	17	.12	5.731	5.372	191.1	210.2	.0854	14.07	494.8						10.31	10.19	10.33	10.33	10.33	10.36
10.38	10.36	10.36	10.40	10.36	10.36	10.38	10.36	10.38	10.40	10.38	10.38	10.41	10.42	10.38	10.34	10.37	10.37	10.38	10.37	10.38	10.37
10.42	10.37	10.38	10.40	10.34	10.37	10.32	10.34	10.33	10.28	10.34	10.33	10.32	10.33	10.34	10.34	10.31	10.38	10.32	10.32	10.33	10.33
10.28	10.32	10.39	10.33	10.34	10.34	10.34	10.38	10.30	10.32	10.28	10.30	10.33	10.32	10.28	10.25	10.21	10.37	10.60	10.74	10.55	10.41
26/11/74	1	18	.12	5.608	5.390	172.8	202.6	.1037	12.78	451.3						9.78	9.81	9.98	10.04	10.02	10.14
10.13	10.14	10.14	10.15	10.10	10.14	10.20	10.14	10.16	10.17	10.13	10.14	10.19	10.20	10.18	10.16	10.15	10.17	10.18	10.17	10.20	10.18
10.22	10.18	10.19	10.19	10.14	10.17	10.12	10.18	10.14	10.09	10.17	10.16	10.15	10.18	10.18	10.14	10.19	10.16	10.17	10.18	10.17	10.16
10.20	10.25	10.21	10.22	10.23	10.22	10.26	10.18	10.20	10.23	10.19	10.22	10.23	10.19	10.16	10.13	10.32	10.58	10.69	10.54	10.42	10.42
26/11/74	2	19	.12	5.604	5.390	173.6	203.6	.1043	12.80	451.6						9.83	9.87	10.03	10.10	10.06	10.18
10.17	10.18	10.18	10.18	10.13	10.18	10.20	10.16	10.18	10.18	10.16	10.14	10.20	10.20	10.20	10.17	10.16	10.18	10.18	10.17	10.22	10.18
10.22	10.18	10.18	10.21	10.16	10.19	10.12	10.18	10.16	10.10	10.17	10.16	10.15	10.18	10.20	10.15	10.19	10.17	10.17	10.18	10.19	10.18
10.20	10.27	10.23	10.23	10.24	10.24	10.28	10.18	10.23	10.23	10.19	10.23	10.24	10.18	10.17	10.14	10.33	10.60	10.70	10.55	10.42	10.42
26/11/74	3	20	.12	5.783	5.429	173.8	208.4	.1037	14.13	498.5						10.32	10.32	10.29	10.26	10.24	10.28
10.28	10.28	10.28	10.30	10.24	10.28	10.30	10.28	10.30	10.33	10.31	10.31	10.34	10.37	10.34	10.29	10.30	10.32	10.33	10.31	10.34	10.31
10.36	10.34	10.33	10.35	10.30	10.34	10.27	10.32	10.30	10.26	10.33	10.31	10.30	10.35	10.37	10.30	10.34	10.32	10.32	10.34	10.32	10.32
10.34	10.40	10.36	10.35	10.37	10.34	10.40	10.31	10.33	10.35	10.30	10.33	10.34	10.30	10.29	10.24	10.42	10.71	10.86	10.66	10.53	10.53
26/11/74	4	21	.12	5.781	5.429	174.0	209.6	.0987	14.16	498.8						10.34	10.13	10.25	10.26	10.25	10.29
10.28	10.28	10.28	10.30	10.24	10.28	10.31	10.29	10.40	10.33	10.30	10.31	10.34	10.35	10.34	10.30	10.30	10.31	10.33	10.31	10.34	10.33
10.35	10.33	10.33	10.36	10.31	10.36	10.29	10.32	10.31	10.27	10.33	10.31	10.30	10.34	10.36	10.28	10.34	10.31	10.31	10.32	10.30	10.30
10.32	10.40	10.34	10.35	10.36	10.34	10.39	10.29	10.32	10.33	10.29	10.32	10.34	10.28	10.26	10.23	10.40	10.70	10.85	10.66	10.53	10.53
26/11/74	5	22	.12	5.719	5.390	173.2	210.8	.0889	16.89	595.5						10.41	10.33	10.46	10.45	10.45	10.51
10.51	10.50	10.54	10.53	10.49	10.53	10.54	10.54	10.54	10.58	10.54	10.55	10.58	10.58	10.55	10.50	10.53	10.53	10.54	10.51	10.54	10.52
10.59	10.55	10.53	10.55	10.49	10.53	10.47	10.52	10.49	10.46	10.49	10.49	10.48	10.50	10.52	10.47	10.50	10.48	10.47	10.49	10.48	10.46
10.47	10.56	10.50	10.49	10.52	10.50	10.54	10.46	10.48	10.50	10.45	10.49	10.49	10.47	10.44	10.40	10.57	10.89	11.09	10.83	10.70	10.70
26/11/74	6	23	.12	5.757	5.400	173.6	210.2	.0877	16.85	594.1						10.41	10.32	10.44	10.46	10.45	10.49
10.48	10.49	10.50	10.52	10.48	10.51	10.53	10.53	10.54	10.57	10.55	10.54	10.57	10.58	10.54	10.50	10.53	10.52	10.53	10.52	10.54	10.52
10.60	10.52	10.52	10.54	10.49	10.53	10.46	10.50	10.49	10.44	10.49	10.48	10.45	10.51	10.52	10.47	10.50	10.47	10.48	10.48	10.48	10.46
10.49	10.56	10.51	10.50	10.53	10.51	10.54	10.46	10.48	10.48	10.45	10.48	10.51	10.46	10.44	10.40	10.55	10.87	11.09	10.82	10.71	10.71
26/11/74	7	24	.12	5.841	5.398	176.4	211.1	.0650	19.76	693.3						10.70	10.60	10.70	10.71	10.70	10.73
10.75	10.74	10.74	10.75	10.72	10.76	10.78	10.76	10.76	10.80	10.78	10.79	10.80	10.81	10.78	10.73	10.74	10.74	10.76	10.74	10.77	10.73
10.76	10.73	10.72	10.74	10.70	10.73	10.65	10.67	10.67	10.62	10.68	10.67	10.65	10.68	10.70	10.64	10.68	10.66	10.66	10.66	10.65	10.63
10.64	10.72	10.68	10.67	10.71	10.68	10.73	10.64	10.67	10.68	10.64	10.66	10.67	10.64	10.62	10.58	10.62	10.59	11.03	10.70	10.65	10.65
26/11/74	8	25	.12	5.788	5.359	172.6	211.1	.0676	19.67	690.7						10.68	10.58	10.70	10.70	10.68	10.73
10.72	10.73	10.74	10.75	10.78	10.74	10.76	10.74	10.77	10.78	10.76	10.76	10.78	10.78	10.76	10.71	10.73	10.73	10.76	10.73	10.76	10.73
10.76	10.71	10.70	10.73	10.68	10.72	10.65	10.68	10.67	10.62	10.67	10.64	10.64	10.66	10.68	10.62	10.67	10.63	10.65	10.66	10.65	10.63
10.64	10.72	10.68	10.66	10.69	10.68	10.72	10.63	10.66	10.67	10.63	10.67	10.68	10.64	10.62	10.60	10.62	10.59	11.03	10.68	10.68	10.65
26/11/74	9	26	.12	5.765	5.366	172.4	211.1	.0613	21.74	759.9						10.84	10.69	10.86	10.86	10.82	10.87
10.88	10.89	10.89	10.89	10.87	10.90	10.92	10.90	10.93	10.97	10.97	10.94	10.96	10.94	10.91	10.86	10.89	10.88	10.92	10.88	10.92	10.87
10.91	10.86	10.86	10.87	10.80	10.85	10.78	10.81	10.80	10.74	10.80	10.78	10.75	10.77	10.79	10.72	10.78	10.74	10.73	10.77	10.75	10.71
10.77	10.84	10.78	10.81	10.86	10.91	10.96	11.00	11.26	12.28	19.66	22.06	22.74	23.53	23.84	24.18	24.98	25.14	25.65	25.18	25.25	25.25
26/11/74	10	27	.12	5.611	5.357	173.6	212.0	.0637	21.68	757.9						10.90	10.68	10.85	10.85	10.84	10.86
10.87	10.88	10.88	10.89	10.85	10.88	10.89	10.88	10.90	10.94	10.92	10.91	10.94	10.94	10.91	10.86	10.87	10.88	10.90	10.88	10.90	10.87

10.90	10.86	10.85	10.87	10.82	10.86	10.79	10.81	10.82	10.76	10.81	10.80	10.77	10.79	10.80	10.75	10.80	10.78	10.77	10.78	10.76	10.76
10.79	10.84	10.80	10.84	10.90	10.92	10.93	10.98	11.27	11.81	14.56	20.78	22.07	23.06	23.44	23.89	24.64	24.82	25.30	24.82	24.93	24.93
28/11/74	1	28	.12	5.834	5.496	194.9	208.9	.1021	9.35	324.8						9.92	9.87	10.01	10.06	10.02	10.12
10.10	10.10	10.12	10.16	10.12	10.16	10.19	10.18	10.22	10.21	10.16	10.16	10.26	10.26	10.25	10.20	10.20	10.19	10.18	10.13	10.17	10.14
10.18	10.15	10.16	10.17	10.13	10.14	10.11	10.11	10.09	10.04	10.10	10.09	10.09	10.11	10.12	10.08	10.09	10.07	10.08	10.09	10.09	10.06
10.10	10.14	10.10	10.09	10.08	10.07	10.09	10.18	10.35	10.19	10.25	9.97	9.91	9.92	9.87	9.87	10.00	10.03	10.04	10.15	10.02	10.02
28/11/74	2	29	.12	5.814	5.488	196.4	208.6	.1021	9.38	325.2						10.00	9.96	10.11	10.13	10.11	10.22
10.18	10.18	10.20	10.23	10.19	10.23	10.25	10.23	10.25	10.24	10.20	10.20	10.20	10.20	10.20	10.16	10.14	10.16	10.16	10.13	10.17	10.16
10.13	10.14	10.17	10.16	10.12	10.14	10.10	10.10	10.08	10.04	10.10	10.10	10.07	10.10	10.13	10.08	10.09	10.08	10.08	10.11	10.11	10.05
10.09	10.13	10.10	10.08	10.09	10.07	10.10	10.18	10.35	10.19	10.25	9.98	9.92	9.93	9.89	9.86	10.01	10.04	10.05	10.16	10.05	10.05
28/11/74	3	30	.12	5.811	5.495	196.7	208.6	.0985	10.93	384.9						10.37	10.09	10.18	10.18	10.18	10.20
10.23	10.21	10.21	10.26	10.19	10.23	10.24	10.22	10.24	10.26	10.23	10.25	10.27	10.28	10.25	10.22	10.23	10.24	10.24	10.22	10.26	10.24
10.30	10.23	10.23	10.26	10.20	10.24	10.18	10.22	10.20	10.14	10.22	10.19	10.18	10.21	10.23	10.17	10.20	10.18	10.18	10.20	10.19	10.15
10.18	10.23	10.19	10.18	10.19	10.18	10.21	10.31	10.49	10.30	10.45	10.07	10.01	10.03	9.98	9.98	10.12	10.15	10.14	10.26	10.13	10.13
28/11/74	4	31	.12	5.845	5.497	195.5	208.6	.0926	12.54	441.3						10.26	10.18	10.28	10.28	10.27	10.30
10.31	10.28	10.30	10.34	10.29	10.30	10.30	10.30	10.32	10.34	10.32	10.34	10.36	10.36	10.33	10.30	10.31	10.31	10.33	10.30	10.33	10.31
10.34	10.30	10.30	10.32	10.28	10.30	10.26	10.28	10.26	10.22	10.27	10.26	10.24	10.26	10.28	10.24	10.26	10.24	10.24	10.26	10.28	10.23
10.26	10.33	10.27	10.26	10.28	10.27	10.29	10.42	10.52	10.38	10.20	10.17	10.11	10.14	10.08	10.10	10.25	10.24	10.27	10.36	10.23	10.23
28/11/74	5	32	.12	5.800	5.464	195.2	209.0	.0859	14.12	496.0						10.36	10.30	10.38	10.38	10.37	10.39
10.40	10.38	10.40	10.42	10.37	10.41	10.40	10.39	10.40	10.42	10.41	10.42	10.44	10.45	10.40	10.38	10.38	10.39	10.39	10.38	10.40	10.39
10.44	10.37	10.38	10.40	10.34	10.37	10.32	10.36	10.35	10.28	10.33	10.32	10.30	10.34	10.35	10.29	10.34	10.32	10.32	10.32	10.33	10.28
10.32	10.38	10.33	10.32	10.33	10.31	10.33	10.44	10.56	10.43	10.32	10.22	10.17	10.19	10.13	10.15	10.34	10.28	10.34	10.42	10.29	10.29
28/11/74	6	33	.12	5.815	5.466	197.0	208.4	.0855	14.14	498.3						10.37	10.30	10.37	10.37	10.36	10.38
10.40	10.38	10.39	10.41	10.37	10.38	10.39	10.40	10.40	10.41	10.40	10.41	10.43	10.42	10.40	10.36	10.37	10.37	10.39	10.37	10.42	10.38
10.42	10.38	10.40	10.40	10.34	10.36	10.33	10.35	10.34	10.28	10.34	10.32	10.32	10.33	10.33	10.28	10.32	10.30	10.30	10.31	10.31	10.28
10.30	10.37	10.32	10.31	10.33	10.30	10.33	10.44	10.56	10.44	10.33	10.22	10.17	10.21	10.13	10.18	10.36	10.30	10.37	10.43	10.30	10.30
28/11/74	7	34	.12	5.828	5.455	197.0	208.8	.0747	15.54	546.3						10.47	10.39	10.47	10.46	10.43	10.46
10.49	10.47	10.46	10.49	10.44	10.48	10.48	10.47	10.48	10.51	10.48	10.50	10.52	10.52	10.49	10.44	10.46	10.45	10.48	10.44	10.47	10.45
10.49	10.43	10.44	10.46	10.42	10.44	10.38	10.41	10.41	10.36	10.40	10.39	10.39	10.40	10.41	10.37	10.39	10.38	10.38	10.40	10.38	10.36
10.38	10.46	10.41	10.40	10.43	10.39	10.43	10.56	10.68	10.54	10.43	10.32	10.26	10.30	10.22	10.29	10.47	10.40	10.47	10.53	10.42	10.42
28/11/74	8	35	.12	5.858	5.469	199.3	208.4	.0744	15.57	546.5						10.48	10.40	10.46	10.44	10.43	10.45
10.47	10.47	10.47	10.48	10.44	10.48	10.48	10.47	10.48	10.51	10.49	10.50	10.52	10.53	10.49	10.46	10.47	10.47	10.48	10.46	10.49	10.46
10.51	10.46	10.44	10.46	10.43	10.44	10.38	10.43	10.41	10.36	10.42	10.38	10.38	10.39	10.42	10.37	10.40	10.38	10.39	10.41	10.38	10.38
10.41	10.47	10.42	10.41	10.43	10.41	10.44	10.56	10.68	10.55	10.43	10.32	10.26	10.30	10.23	10.27	10.46	10.40	10.47	10.54	10.40	10.40
28/11/74	9	36	.12	5.816	5.427	194.9	208.4	.0679	16.69	584.7						10.52	10.43	10.53	10.51	10.48	10.51
10.53	10.53	10.53	10.55	10.50	10.53	10.53	10.53	10.54	10.57	10.56	10.57	10.58	10.58	10.56	10.49	10.50	10.50	10.52	10.50	10.53	10.49
10.54	10.50	10.50	10.53	10.47	10.52	10.44	10.49	10.46	10.43	10.47	10.47	10.44	10.48	10.49	10.44	10.47	10.44	10.46	10.48	10.44	10.44
10.44	10.52	10.48	10.47	10.49	10.48	10.51	10.65	10.80	10.65	10.51	10.38	10.36	10.39	10.30	10.37	10.58	10.51	10.58	10.64	10.49	10.49
28/11/74	10	37	.12	5.822	5.428	194.0	208.8	.0679	16.68	585.2						10.52	10.45	10.53	10.52	10.49	10.52
10.54	10.53	10.54	10.56	10.50	10.53	10.55	10.52	10.53	10.56	10.56	10.56	10.59	10.58	10.56	10.50	10.51	10.52	10.53	10.51	10.54	10.52
10.57	10.50	10.50	10.52	10.48	10.51	10.45	10.49	10.48	10.42	10.48	10.47	10.46	10.48	10.48	10.43	10.47	10.45	10.43	10.47	10.44	10.42
10.46	10.53	10.49	10.47	10.49	10.48	10.50	10.66	10.75	10.63	10.50	10.37	10.34	10.38	10.28	10.37	10.56	10.49	10.57	10.65	10.48	10.48
28/11/74	11	38	.12	5.839	5.428	195.8	209.3	.0598	17.91	629.2						10.58	10.53	10.60	10.60	10.56	10.59
10.60	10.60	10.60	10.63	10.58	10.60	10.60	10.60	10.61	10.64	10.62	10.62	10.64	10.66	10.62	10.58	10.60	10.58	10.60	10.58	10.60	10.57
10.68	10.57	10.58	10.59	10.54	10.58	10.50	10.55	10.54	10.48	10.56	10.53	10.52	10.55	10.55	10.50	10.54	10.52	10.52	10.55	10.54	10.51
10.53	10.60	10.56	10.55	10.58	10.58	10.60	10.78	10.90	10.76	10.62	10.48	10.45	10.49	10.38	10.45	10.67	10.61	10.70	10.76	10.58	10.58
28/11/74	12	39	.12	5.836	5.424	194.6	209.6	.0599	17.87	627.1						10.59	10.51	10.60	10.58	10.56	10.59
10.60	10.60	10.59	10.62	10.58	10.61	10.60	10.60	10.62	10.64	10.62	10.61	10.66	10.64	10.61	10.57	10.58	10.58	10.60	10.58	10.58	10.58
10.62	10.57	10.57	10.59	10.53	10.57	10.52	10.54	10.54	10.48	10.54	10.53	10.53	10.53	10.56	10.50	10.54	10.52	10.49	10.53	10.52	10.48
10.51	10.61	10.56	10.55	10.57	10.57	10.58	10.74	10.86	10.71	10.58	10.46	10.42	10.47	10.37	10.42	10.66	10.61	10.68	10.74	10.58	10.58
28/11/74	13	40	.12	5.842	5.427	196.7	209.6	.0557	18.94	664.0						10.66	10.58	10.66	10.66	10.62	10.64
10.67	10.66	10.66	10.68	10.63	10.66	10.67	10.66	10.68	10.71	10.69	10.70	10.71	10.69	10.69	10.64	10.66	10.64	10.66	10.64	10.68	10.64
10.67	10.61	10.63	10.66	10.59	10.63	10.58	10.61	10.60	10.55	10.60	10.58	10.56	10.60	10.60	10.56	10.60	10.58	10.58	10.60	10.59	10.55
10.58	10.66	10.61	10.60	10.66	10.64	10.67	10.84	10.97	10.82	10.68	10.55	10.52	10.57	10.46	10.53	10.60	10.57	10.70	10.64	10.61	10.61
28/11/74	14	41	.12	5.862	5.426	198.6	209.3	.0557	18.95	673.7						10.67	10.59	10.66	10.66	10.63	10.67
10.68	10.68	10.68	10.70	10.66	10.68	10.67	10.68	10.70	10.72	10.71	10.69	10.72	10.71	10.67	10.63	10.64	10.65	10.66	10.66	10.66	10.63
10.70	10.62	10.62	10.65	10.60	10.63	10.58	10.61	10.58	10.54	10.60	10.60	10.56	10.59	10.60	10.56	10.60	10.56	10.57	10.58	10.57	10.56

10.57	10.66	10.60	10.60	10.65	10.62	10.65	10.60	10.95	10.80	10.66	10.53	10.49	10.57	10.45	10.48	10.53	10.58	10.70	10.63	10.69	10.69
28/11/74	15	42	.12	5.845	5.422	194.0	210.2	.0569	19.19	673.7						10.65	10.58	10.66	10.66	10.63	10.67
10.69	10.68	10.68	10.70	10.65	10.68	10.68	10.68	10.69	10.73	10.70	10.70	10.74	10.72	10.70	10.80	10.66	10.65	10.67	10.64	10.67	10.64
10.69	10.63	10.65	10.66	10.61	10.65	10.58	10.62	10.61	10.55	10.62	10.60	10.60	10.60	10.62	10.56	10.62	10.58	10.57	10.60	10.58	10.56
10.59	10.68	10.62	10.61	10.65	10.64	10.67	10.60	10.83	10.72	10.63	10.54	10.54	10.56	10.48	10.43	10.86	11.02	11.09	11.26	12.97	12.97
03/12/74	1	43	.12	5.759	5.427	173.6	186.4	.0805	7.77	273.7						8.58	8.54	8.68	8.71	8.69	8.78
8.76	8.77	8.78	8.81	8.77	8.80	8.83	8.83	8.86	8.87	8.83	8.83	8.91	8.92	8.93	8.89	8.91	8.94	8.95	8.95	8.98	8.99
9.02	8.99	9.02	9.04	9.02	9.05	8.99	9.07	9.05	9.01	9.09	9.08	9.09	9.12	9.15	9.12	9.17	9.15	9.15	9.20	9.17	9.15
9.19	9.22	9.22	9.22	9.25	9.28	9.30	9.23	9.30	9.33	9.37	9.28	9.27	9.27	9.28	9.30	9.46	9.35	9.30	9.35	9.33	9.33
03/12/74	2	44	.12	5.770	5.427	174.6	187.4	.0804	7.78	274.0						8.63	8.60	8.74	8.78	8.74	8.84
8.82	8.83	8.84	8.87	8.82	8.88	8.88	8.88	8.92	8.93	8.89	8.88	8.97	8.98	8.99	8.96	8.98	8.99	9.01	9.00	9.06	9.06
9.08	9.05	9.08	9.11	9.08	9.11	9.07	9.13	9.11	9.07	9.15	9.15	9.17	9.19	9.20	9.19	9.24	9.23	9.25	9.27	9.24	9.22
9.23	9.29	9.30	9.29	9.34	9.34	9.38	9.37	9.39	9.40	9.38	9.36	9.34	9.36	9.38	9.38	9.55	9.44	9.39	9.43	9.42	9.42
03/12/74	3	45	.12	5.731	5.423	197.8	207.6	.0800	7.80	277.7						9.77	9.66	9.86	9.89	9.87	9.94
9.95	9.94	9.94	9.99	9.93	9.99	10.01	9.99	10.03	10.02	10.00	10.00	10.08	10.09	10.11	10.07	10.08	10.10	10.12	10.12	10.13	10.09
10.08	10.05	10.05	10.08	9.98	10.02	9.94	9.99	9.96	9.92	9.98	9.97	9.96	9.99	10.00	9.96	9.98	9.97	9.97	9.98	9.97	9.91
9.96	9.99	9.96	9.96	9.96	9.97	10.00	10.03	10.14	10.17	10.03	9.89	9.84	9.88	9.78	9.83	9.94	10.06	10.09	10.10	10.07	10.07
03/12/74	4	46	.12	5.700	5.417	198.2	208.2	.0800	7.88	278.1						9.81	9.73	9.93	9.96	9.93	10.01
10.02	10.01	10.03	10.07	10.03	10.08	10.10	10.08	10.11	10.08	10.04	10.05	10.06	10.05	10.05	10.01	10.01	10.05	10.05	10.01	10.05	10.01
10.05	10.02	10.03	10.06	9.98	10.02	9.96	9.99	9.98	9.93	9.98	9.97	9.97	10.01	10.02	9.97	10.00	9.98	9.98	9.99	9.97	9.93
9.96	10.01	9.96	9.97	9.97	9.97	10.00	10.03	10.16	10.14	10.14	7.28	9.84	9.87	9.73	9.81	9.94	10.03	10.07	10.06	10.03	10.03
03/12/74	5	47	.12	5.772	5.427	172.8	198.8	.0815	11.02	388.4						9.54	9.58	9.76	9.82	9.77	9.96
9.92	9.94	9.97	10.00	9.98	10.02	10.06	10.01	10.02	10.04	9.98	9.97	10.02	10.03	10.02	9.98	9.98	9.97	9.98	9.97	10.02	10.00
10.03	10.00	10.02	10.02	9.98	10.00	9.92	9.99	9.96	9.92	9.98	9.97	9.99	10.01	10.02	9.97	10.01	9.98	9.98	9.99	10.01	9.98
10.01	10.07	10.03	10.04	10.04	10.03	10.08	10.20	10.35	10.24	10.38	10.02	9.98	9.98	9.89	9.95	10.13	10.48	10.38	10.43	10.42	10.42
03/12/74	6	48	.12	5.767	5.428	173.6	201.7	.0814	11.02	389.1						9.58	9.63	9.80	9.85	9.83	10.03
9.97	9.98	10.01	10.04	9.97	10.03	10.05	9.99	9.99	10.01	9.98	9.99	10.03	10.03	10.04	9.99	9.98	9.99	10.00	9.98	10.03	10.01
10.06	10.02	10.02	10.03	9.98	10.02	9.94	10.00	9.98	9.92	9.98	9.98	9.99	10.01	10.03	9.98	10.02	9.99	9.99	10.02	10.01	9.99
10.03	10.07	10.03	10.04	10.06	10.03	10.09	10.21	10.35	10.26	10.14	10.03	9.98	10.00	9.88	9.96	10.14	10.46	10.39	10.42	10.40	10.40
03/12/74	7	49	.12	5.653	5.359	196.4	208.2	.0779	10.90	384.3						10.14	9.98	10.12	10.11	10.09	10.14
10.18	10.14	10.14	10.17	10.10	10.15	10.16	10.14	10.16	10.17	10.17	10.15	10.19	10.20	10.16	10.14	10.14	10.14	10.16	10.14	10.18	10.15
10.18	10.15	10.15	10.18	10.13	10.16	10.10	10.14	10.11	10.07	10.12	10.09	10.09	10.10	10.11	10.08	10.10	10.06	10.08	10.09	10.08	10.06
10.08	10.11	10.09	10.08	10.10	10.06	10.11	10.19	10.29	10.23	10.12	10.01	9.96	9.98	9.88	9.92	10.09	10.25	10.25	10.19	10.18	10.18
03/12/74	8	50	.12	5.662	5.357	173.4	207.6	.0785	14.17	500.0						10.28	10.04	10.20	10.19	10.18	10.23
10.24	10.23	10.25	10.27	10.21	10.26	10.28	10.26	10.28	10.31	10.30	10.31	10.33	10.34	10.33	10.30	10.30	10.30	10.33	10.31	10.36	10.31
10.38	10.32	10.31	10.35	10.28	10.33	10.26	10.30	10.26	10.23	10.27	10.26	10.28	10.29	10.29	10.24	10.28	10.27	10.26	10.29	10.28	10.26
10.26	10.34	10.28	10.28	10.30	10.27	10.33	10.40	10.52	10.45	10.34	10.23	10.18	10.19	10.08	10.17	10.42	10.71	10.70	10.61	10.56	10.56
03/12/74	9	51	.12	5.679	5.355	173.6	207.4	.0785	14.19	499.3						10.26	10.03	10.20	10.18	10.18	10.23
10.23	10.23	10.22	10.28	10.40	10.26	10.28	10.26	10.28	10.30	10.30	10.31	10.40	10.34	10.32	10.29	10.30	10.28	10.32	10.30	10.34	10.30
10.35	10.31	10.30	10.33	10.27	10.30	10.25	10.30	10.28	10.22	10.27	10.24	10.26	10.27	10.29	10.24	10.28	10.26	10.26	10.27	10.27	10.24
10.25	10.32	10.28	10.25	10.28	10.25	10.31	10.38	10.50	10.44	10.32	10.20	10.17	10.19	10.09	10.15	10.40	10.70	10.63	10.58	10.54	10.54
03/12/74	10	52	.12	5.684	5.356	200.2	208.6	.0644	14.33	505.6						10.35	10.19	10.34	10.33	10.32	10.35
10.37	10.36	10.34	10.38	10.31	10.36	10.36	10.33	10.35	10.37	10.37	10.37	10.39	10.39	10.35	10.32	10.33	10.33	10.35	10.33	10.36	10.31
10.35	10.32	10.31	10.35	10.29	10.33	10.26	10.31	10.29	10.22	10.26	10.26	10.27	10.27	10.28	10.22	10.28	10.23	10.24	10.27	10.26	10.23
10.25	10.28	10.26	10.25	10.28	10.23	10.28	10.34	10.43	10.41	10.30	10.20	10.17	10.18	10.08	10.14	10.38	10.58	10.55	10.49	10.43	10.43
03/12/74	11	53	.12	5.676	5.356	198.8	208.4	.0644	14.36	506.9						10.34	10.18	10.33	10.33	10.31	10.36
10.37	10.36	10.36	10.37	10.31	10.36	10.36	10.36	10.36	10.38	10.38	10.36	10.38	10.38	10.37	10.32	10.34	10.32	10.35	10.33	10.36	10.33
10.38	10.32	10.30	10.35	10.28	10.32	10.26	10.30	10.28	10.21	10.27	10.25	10.27	10.27	10.27	10.23	10.28	10.25	10.25	10.28	10.27	10.24
10.26	10.30	10.27	10.25	10.27	10.24	10.28	10.33	10.43	10.41	10.31	10.21	10.18	10.18	10.08	10.14	10.40	10.60	10.56	10.48	10.45	10.45
04/12/74	1	54	.22	10.114	9.910	184.6	194.9	.1043	7.89	279.3						9.02	8.93	9.08	9.12	9.08	9.17
9.17	9.17	9.18	9.20	9.15	9.20	9.22	9.19	9.23	9.23	9.22	9.20	9.29	9.30	9.30	9.25	9.26	9.28	9.30	9.30	9.35	9.35
9.35	9.33	9.38	9.40	9.36	9.39	9.36	9.41	9.39	9.34	9.42	9.40	9.44	9.46	9.48	9.44	9.48	9.48	9.48	9.51	9.47	9.47
9.48	9.52	9.52	9.52	9.56	9.56	9.59	9.57	9.60	9.64	9.67	9.54	9.54	9.55	9.56	9.57	9.73	9.64	9.60	9.58	9.56	9.58
04/12/74	2	55	.22	10.244	9.900	191.1	208.4	.1034	10.05	354.4						9.86	9.76	9.95	9.99	9.96	10.09
10.05	10.08	10.09	10.13	10.07	10.13	10.18	10.14	10.18	10.18	10.16	10.16	10.27	10.28	10.30	10.25	10.27	10.40	10.30	10.33	10.37	10.38
10.40	10.35	10.40	10.45	10.41	10.44	10.42	10.48	10.47	10.41	10.49	10.50	10.53	10.55	10.59	10.57	10.62	10.61	10.61	10.66	10.60	10.60
10.63	10.66	10.68	10.69	10.74	10.75	10.81	10.80	10.84	10.88	10.81	10.74	10.78	10.80	10.81	10.81	11.04	10.93	10.83	10.82	10.78	10.78

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04/12/74  3  56  .22 10.228  9.906 194.9 222.8 .1021 12.59 441.7  10.83 10.78 10.98 11.06 10.99 11.20
11.14 11.17 11.19 11.22 11.16 11.23 11.32 11.28 11.33 11.32 11.30 11.31 11.45 11.45 11.50 11.46 11.47 11.48 11.53 11.57 11.61 11.63
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04/12/74  4  57  .22 10.231  9.905 198.0 233.0 .1019 14.32 503.1  11.58 11.60 11.81 11.89 11.61 11.96
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18/12/74  1  58  .22 10.048  9.831 182.6 200.5 .1037 10.16 355.3   9.43  9.40  9.56  9.58  9.56  9.67
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18/12/74  2  59  .22 10.034  9.832 182.4 211.4 .1039 12.72 446.7  10.21 10.24 10.40 10.46 10.42 10.61
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19/12/74  1  60  .22 10.188  9.970 199.0 232.6 .1020 13.90 484.7  11.55 11.53 11.70 11.84 11.80 11.95
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19/12/74  2  61  .22 10.117  9.936 203.0 244.0 .1015 15.51 542.7  12.23 11.93 12.03 12.12 12.12 12.15
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19/12/74  3  62  .22 10.088  9.902 202.0 245.0 .0997 16.70 580.3  12.28 12.04 12.13 12.23 12.22 12.26
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19/12/74  4  63  .22 10.103  9.903 206.4 243.7 .0980 16.60 583.5  12.23 12.05 12.15 12.24 12.23 12.27
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19/12/74  6  65  .22 10.103  9.904 204.9 243.7 .0904 19.03 663.6  12.42 12.34 12.39 12.43 12.41 12.48
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20/12/74  2  68  .22 10.117  9.900 204.3 232.4 .1003 12.68 443.9  11.33 11.40 11.52 11.59 11.56 11.74
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20/12/74  3  69  .22 10.091  9.900 205.5 240.0 .1000 14.10 493.3  11.90 11.99 12.03 12.03 12.00 12.06
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12.26	12.20	12.21	12.23	12.16	12.21	12.13	12.17	12.16	12.11	12.18	12.15	12.15	12.16	12.17	12.13	12.18	12.14	12.16	12.14	12.16	12.12
12.16	12.26	12.19	12.18	12.19	12.18	12.23	12.35	12.46	12.40	12.30	12.20	12.16	12.20	12.12	12.16	12.51	12.79	12.68	12.69	12.56	12.56
20/12/74	5	71	.22	10.115	9.903	208.8	245.2	.0941	16.71	583.2						12.21	12.15	12.24	12.25	12.24	12.28
12.27	12.28	12.28	12.30	12.24	12.30	12.32	12.30	12.30	12.34	12.30	12.21	12.34	12.34	12.30	12.26	12.28	12.26	12.30	12.28	12.30	12.26
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12.20	12.30	12.25	12.23	12.28	12.24	12.29	12.41	12.52	12.48	12.36	12.24	12.20	12.26	12.16	12.20	12.58	12.88	12.78	12.77	12.63	12.63
20/12/74	6	72	.22	10.100	9.905	208.8	245.0	.0941	16.62	581.7						12.20	12.15	12.23	12.25	12.23	12.27
12.28	12.26	12.27	12.31	12.24	12.29	12.30	12.28	12.30	12.34	12.30	12.29	12.35	12.33	12.29	12.26	12.27	12.26	12.30	12.26	12.29	12.26
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12.20	12.29	12.23	12.22	12.26	12.22	12.28	12.40	12.53	12.45	12.34	12.24	12.21	12.26	12.16	12.20	12.57	12.87	12.76	12.76	12.63	12.63
20/12/74	7	73	.22	10.116	9.896	209.0	243.1	.0894	17.73	622.7						12.32	12.25	12.35	12.34	12.35	12.39
12.40	12.39	12.38	12.43	12.33	12.38	12.40	12.38	12.38	12.42	12.38	12.38	12.42	12.40	12.37	12.32	12.35	12.34	12.38	12.34	12.37	12.33
12.39	12.32	12.34	12.36	12.30	12.33	12.25	12.30	12.26	12.23	12.29	12.28	12.28	12.28	12.30	12.23	12.28	12.25	12.28	12.28	12.25	12.23
12.26	12.35	12.29	12.27	12.32	12.30	12.35	12.48	12.58	12.52	12.41	12.30	12.27	12.33	12.22	12.26	12.65	12.97	12.86	12.84	12.68	12.68
20/12/74	8	74	.22	10.129	9.902	208.0	245.6	.0868	19.01	664.0						12.38	12.33	12.43	12.43	12.41	12.45
12.46	12.45	12.45	12.46	12.39	12.43	12.46	12.44	12.44	12.48	12.60	12.49	12.48	12.48	12.44	12.40	12.43	12.41	12.45	12.42	12.44	12.40
12.47	12.40	12.39	12.44	12.39	12.42	12.36	12.38	12.36	12.34	12.40	12.36	12.37	12.37	12.38	12.33	12.38	12.34	12.37	12.36	12.34	12.33
12.35	12.43	12.38	12.35	12.41	12.38	12.44	12.56	12.70	12.63	12.50	12.38	12.35	12.43	12.31	12.34	12.78	13.11	12.97	12.97	12.80	12.80
20/12/74	9	75	.22	10.172	9.915	211.1	244.8	.0808	19.72	688.0						12.47	12.40	12.50	12.49	12.45	12.49
12.51	12.49	12.49	12.50	12.45	12.50	12.50	12.49	12.53	12.54	12.51	12.50	12.55	12.53	12.50	12.44	12.47	12.46	12.52	12.47	12.52	12.47
12.50	12.46	12.48	12.51	12.46	12.48	12.43	12.47	12.45	12.40	12.43	12.43	12.44	12.44	12.46	12.41	12.45	12.42	12.46	12.43	12.43	12.39
12.42	12.50	12.47	12.44	12.48	12.46	12.50	12.64	12.73	12.70	12.57	12.44	12.43	12.49	12.38	12.43	12.88	13.23	13.06	13.07	12.84	12.84
06/01/75	1	76	.22	9.885	9.693	215.2	236.0	.0931	10.82	377.9						11.37	11.37	11.51	11.58	11.55	11.67
11.66	11.67	11.69	11.72	11.69	11.75	11.80	11.79	11.82	11.84	11.78	11.77	11.85	11.83	11.82	11.78	11.78	11.80	11.80	11.75	11.80	11.75
11.78	11.72	11.76	11.79	11.72	11.76	11.76	11.80	11.79	11.73	11.80	11.78	11.78	11.81	11.83	11.78	11.81	11.79	11.80	11.80	11.80	11.77
11.82	11.89	11.83	11.83	11.84	11.84	11.88	11.96	12.06	11.98	11.78	11.58	11.77	11.78	11.77	11.80	12.04	12.19	12.15	12.20	12.16	12.16
13/01/75	1	77	.22	9.880	9.695	214.9	234.0	.0924	10.04	351.1						11.21	11.22	11.31	11.37	11.34	11.46
11.44	11.47	11.47	11.51	11.46	11.53	11.57	11.54	11.58	11.60	11.60	11.55	11.68	11.68	11.69	11.66	11.66	11.68	11.72	11.68	11.73	11.72
11.73	11.70	11.76	11.76	11.70	11.75	11.69	11.73	11.72	11.68	11.73	11.70	11.72	11.74	11.77	11.71	11.75	11.72	11.76	11.74	11.75	11.72
11.76	11.81	11.77	11.77	11.78	11.78	11.84	11.89	11.96	11.94	11.87	11.80	11.73	11.74	11.72	11.74	11.94	12.08	12.07	12.09	12.07	12.07
13/01/75	2	78	.22	9.819	9.626	219.3	240.4	.0919	10.96	381.2						11.66	11.72	11.80	11.86	11.82	11.84
11.88	11.84	11.83	11.84	11.80	11.83	11.84	11.82	11.84	11.86	11.86	11.83	11.88	11.88	11.86	11.83	11.82	11.84	11.86	11.82	11.87	11.84
11.90	11.85	11.86	11.87	11.82	11.85	11.80	11.83	11.81	11.76	11.81	11.82	11.82	11.84	11.86	11.80	11.85	11.82	11.82	11.82	11.84	11.80
11.84	11.89	11.85	11.85	11.86	11.86	11.91	11.99	12.08	12.02	11.94	11.86	11.79	11.82	11.78	11.82	12.04	12.21	12.19	12.22	12.17	12.17
13/01/75	3	79	.22	10.150	9.969	220.5	244.2	.0912	12.60	440.8						12.17	11.93	12.02	12.02	12.00	12.04
12.05	12.04	12.04	12.07	12.03	12.07	12.06	12.06	12.06	12.09	12.03	12.05	12.10	12.12	12.09	12.10	12.07	12.07	12.08	12.04	12.09	12.07
12.14	12.07	12.06	12.08	12.03	12.08	12.02	12.03	12.03	11.98	12.06	12.03	12.03	12.04	12.06	12.02	12.04	12.03	12.04	12.02	12.06	12.00
12.05	12.12	12.09	12.06	12.08	12.06	12.12	12.21	12.33	12.26	12.17	12.08	12.00	12.07	12.00	12.04	12.32	12.53	12.48	12.50	12.42	12.42
13/01/75	4	80	.22	10.066	9.900	221.4	244.6	.0879	14.12	493.3						12.10	12.02	12.09	12.09	12.08	12.12
12.14	12.13	12.13	12.18	12.11	12.17	12.14	12.14	12.16	12.19	12.16	12.15	12.18	12.19	12.17	12.12	12.13	12.13	12.14	12.13	12.16	12.13
12.19	12.13	12.14	12.15	12.08	12.14	12.08	12.10	12.08	12.04	12.09	12.09	12.08	12.09	12.10	12.07	12.10	12.08	12.08	12.08	12.10	12.05
12.08	12.18	12.11	12.11	12.13	12.11	12.16	12.28	12.40	12.33	12.22	12.12	12.06	12.14	12.04	12.08	12.39	12.62	12.56	12.57	12.46	12.46
13/01/75	5	81	.22	10.073	9.900	222.6	244.6	.0882	14.12	491.9						12.10	12.04	12.12	12.11	12.10	12.14
12.15	12.14	12.13	12.18	12.10	12.14	12.14	12.13	12.14	12.17	12.15	12.15	12.18	12.18	12.15	12.09	12.11	12.11	12.14	12.10	12.14	12.12
12.18	12.11	12.13	12.13	12.07	12.13	12.07	12.09	12.07	12.02	12.09	12.08	12.06	12.08	12.09	12.04	12.08	12.06	12.07	12.05	12.08	12.02
12.07	12.14	12.08	12.07	12.07	12.07	12.13	12.23	12.36	12.27	12.17	12.08	12.03	12.09	12.00	12.04	12.35	12.56	12.48	12.49	12.40	12.40
13/01/75	6	82	.22	10.010	9.833	223.4	244.4	.0833	15.54	541.3						12.18	12.11	12.19	12.18	12.17	12.19
12.21	12.19	12.21	12.23	12.17	12.21	12.20	12.19	12.20	12.23	12.21	12.21	12.24	12.25	12.22	12.17	12.18	12.20	12.21	12.18	12.22	12.18
12.26	12.15	12.18	12.20	12.14	12.18	12.13	12.15	12.14	12.08	12.15	12.14	12.14	12.15	12.17	12.11	12.15	12.12	12.14	12.12	12.15	12.11
12.13	12.22	12.16	12.15	12.18	12.17	12.22	12.34	12.46	12.39	12.29	12.19	12.13	12.20	12.11	12.14	12.50	12.73	12.66	12.66	12.55	12.55
13/01/75	7	83	.22	10.016	9.833	220.5	243.7	.0839	15.40	536.5						12.17	12.09	12.17	12.16	12.15	12.19
12.18	12.18	12.13	12.21	12.15	12.20	12.18	12.18	12.18	12.22	12.20	12.19	12.23	12.23	12.19	12.15	12.17	12.17	12.20	12.16	12.20	12.19
12.24	12.17	12.18	12.19	12.13	12.16	12.12	12.15	12.15	12.09	12.16	12.13	12.13	12.14	12.18	12.10	12.17	12.17	12.20	12.16	12.20	12.19
12.14	12.21	12.16	12.17	12.18	12.17	12.21	12.34	12.47	12.39	12.28	12.13	12.13	12.14	12.18	12.10	12.17	12.12	12.15	12.11	12.15	12.10
13/01/75	8	84	.22	10.022	9.834	222.4	244.6	.0794	16.74	583.6	12.18	12.18	12.20	12.09	12.14	12.49	12.73	12.66	12.65	12.54	12.54
12.27	12.27	12.27	12.30	12.24	12.28	12.27	12.26	12.28	12.32	12.29	12.28	12.33	12.31	12.29	12.23	12.28	12.19	12.27	12.30	12.24	12.26
																12.24	12.25	12.28	12.24	12.28	12.24

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13/01/75 9 85 .22 10.077 9.843 223.2 245.4 .0761 17.75 616.0 12.36 12.26 12.34 12.34 12.31 12.33

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13/01/75 10 86 .22 10.031 9.828 223.2 245.4 .0727 19.25 671.5 12.42 12.30 12.39 12.38 12.35 12.40

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13/01/74 11 87 .22 10.031 9.803 222.6 246.0 .0717 19.68 684.9 12.45 12.33 12.43 12.41 12.40 12.43

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13/01/74 12 88 .22 10.026 9.837 222.6 245.0 .0717 19.83 688.0 12.45 12.35 12.43 12.42 12.39 12.44

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14/01/75 2 90 .22 10.015 9.834 219.9 241.9 .0856 10.94 381.3 11.80 11.78 11.89 11.91 11.90 11.89

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14/01/75 7 95 .22 10.190 10.000 228.6 245.4 .0788 14.06 490.5 12.18 12.06 12.17 12.18 12.16 12.19

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14/01/75 8 96 .22 10.081 9.912 233.6 245.0 .0764 14.25 496.8 12.17 12.05 12.16 12.16 12.13 12.16

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14/01/75 9 97 .22 10.069 9.929 228.0 244.2 .0764 15.37 535.2 12.22 12.15 12.18 12.18 12.17 12.19

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14/01/75 10 98 .22 10.096 9.917 228.0 244.6 .0731 16.67 591.1 12.28 12.22 12.25 12.24 12.24 12.26

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12.22	12.31	12.26	12.28	12.28	12.27	12.31	12.44	12.60	12.49	12.38	12.28	12.22	12.32	12.18	12.23	12.64	12.89	12.77	12.60	12.66	12.66
14/01/75	11	99	.22	10.092	9.921	227.0	244.4	.0697	17.80	618.8						12.35	12.28	12.30	12.31	12.30	12.33
12.34	12.32	12.34	12.39	12.33	12.37	12.36	12.36	12.37	12.40	12.38	12.37	12.40	12.41	12.38	12.33	12.34	12.36	12.37	12.33	12.36	12.34
12.40	12.34	12.35	12.36	12.31	12.34	12.28	12.31	12.30	12.25	12.32	12.31	12.29	12.31	12.33	12.28	12.32	12.29	12.31	12.31	12.32	12.24
12.30	12.38	12.33	12.32	12.33	12.32	12.37	12.52	12.68	12.57	12.45	12.33	12.30	12.40	12.24	12.31	12.74	13.02	12.88	12.91	12.77	12.77
14/01/75	12	100	.22	10.022	9.847	229.9	244.6	.0656	19.01	660.9						12.40	12.36	12.38	12.38	12.36	12.39
12.41	12.40	12.41	12.43	12.40	12.42	12.42	12.42	12.43	12.48	12.46	12.44	12.49	12.49	12.44	12.40	12.42	12.43	12.43	12.40	12.44	12.41
12.46	12.41	12.43	12.42	12.38	12.43	12.37	12.38	12.37	12.33	12.38	12.38	12.37	12.38	12.41	12.36	12.40	12.38	12.38	12.38	12.37	12.34
12.36	12.46	12.42	12.38	12.41	12.40	12.46	12.57	12.72	12.64	12.52	12.40	12.36	12.47	12.32	12.37	12.84	13.20	12.91	12.78	12.46	12.46
14/01/75	13	101	.22	10.045	9.851	228.4	244.4	.0657	19.01	660.5						12.38	12.34	12.38	12.37	12.35	12.39
12.41	12.40	12.40	12.45	12.38	12.43	12.42	12.42	12.43	12.48	12.46	12.44	12.49	12.49	12.46	12.40	12.42	12.42	12.44	12.40	12.44	12.43
12.47	12.41	12.44	12.43	12.37	12.42	12.36	12.38	12.38	12.33	12.38	12.38	12.37	12.37	12.40	12.33	12.37	12.36	12.36	12.36	12.36	12.31
12.35	12.45	12.38	12.37	12.40	12.38	12.45	12.56	12.72	12.63	12.51	12.39	12.36	12.46	12.30	12.36	12.84	13.13	12.88	12.67	12.48	12.48
14/01/75	14	102	.22	10.034	9.862	232.0	243.7	.0629	19.78	686.0						12.44	12.38	12.41	12.43	12.42	12.44
12.46	12.45	12.50	12.49	12.45	12.48	12.46	12.47	12.50	12.52	12.49	12.50	12.53	12.54	12.49	12.44	12.46	12.46	12.48	12.46	12.60	12.47
12.52	12.47	12.48	12.49	12.43	12.47	12.41	12.44	12.43	12.36	12.43	12.44	12.41	12.42	12.44	12.38	12.43	12.41	12.41	12.41	12.40	12.36
12.40	12.48	12.44	12.42	12.46	12.44	12.48	12.59	12.73	12.66	12.55	12.45	12.38	12.37	12.48	13.22	19.18	20.04	19.46	19.43	19.40	19.40
14/01/75	15	103	.22	10.015	9.860	232.0	244.6	.0628	19.81	688.5						12.43	12.38	12.40	12.42	12.40	12.44
12.46	12.43	12.44	12.48	12.42	12.47	12.46	12.46	12.48	12.52	12.49	12.48	12.53	12.53	12.48	12.43	12.47	12.46	12.49	12.46	12.49	12.47
12.52	12.46	12.47	12.47	12.42	12.44	12.39	12.45	12.41	12.38	12.43	12.41	12.41	12.41	12.44	12.38	12.43	12.41	12.41	12.41	12.40	12.37
12.40	12.48	12.43	12.41	12.44	12.44	12.47	12.57	12.73	12.63	12.55	12.47	12.43	12.46	13.53	18.37	20.43	20.66	19.92	19.86	19.80	19.80
14/01/75	16	104	.22	10.057	9.865	233.2	245.0	.0620	19.84	689.3						12.44	12.38	12.42	12.42	12.41	12.44
12.46	12.44	12.44	12.48	12.43	12.46	12.47	12.47	12.47	12.53	12.48	12.49	12.52	12.53	12.50	12.41	12.43	12.46	12.46	12.45	12.48	12.45
12.49	12.44	12.45	12.48	12.41	12.44	12.38	12.42	12.40	12.36	12.41	12.40	12.38	12.41	12.43	12.37	12.40	12.39	12.40	12.41	12.38	12.36
12.38	12.48	12.43	12.40	12.44	12.42	12.48	12.55	12.58	12.77	12.68	12.59	12.67	16.79	19.79	20.46	21.34	21.37	20.56	20.47	20.36	20.36
14/01/75	17	105	.22	10.038	9.860	233.8	244.6	.0620	19.87	690.9						12.44	12.38	12.42	12.41	12.39	12.43
12.46	12.43	12.45	12.48	12.42	12.46	12.46	12.46	12.49	12.51	12.48	12.48	12.52	12.52	12.49	12.44	12.44	12.45	12.46	12.44	12.48	12.47
12.50	12.45	12.47	12.47	12.50	12.44	12.39	12.43	12.43	12.36	12.40	12.41	12.40	12.41	12.42	12.37	12.41	12.40	12.40	12.39	12.40	12.35
12.38	12.48	12.43	12.40	12.44	12.42	12.48	12.54	12.53	12.49	12.57	12.66	12.96	17.28	19.96	20.55	21.42	21.43	20.63	20.53	20.42	20.42
21/01/75	1	106	.39	17.057	16.935	211.7	217.2	.1000	6.34	221.7						10.01	10.10	10.14	10.15	10.12	10.18
10.19	10.18	10.19	10.21	10.17	10.21	10.23	10.20	10.22	10.22	10.19	10.21	10.26	10.27	10.26	10.23	10.24	10.26	10.27	10.25	10.30	10.31
10.53	10.29	10.31	10.34	10.31	10.34	10.28	10.34	10.31	10.27	10.33	10.34	10.36	10.38	10.38	10.34	10.39	10.38	10.38	10.41	10.39	10.36
10.39	10.40	10.42	10.40	10.42	10.43	10.47	10.44	10.43	10.48	10.47	10.41	10.40	10.41	10.45	10.45	10.53	10.48	10.44	10.43	10.47	10.47
21/01/75	2	107	.39	17.348	17.179	209.0	224.6	.0999	8.93	312.7						10.61	10.63	10.68	10.71	10.69	10.80
10.79	10.80	10.80	10.83	10.78	10.83	10.85	10.86	10.88	10.88	10.86	10.84	10.94	10.96	10.96	10.93	10.94	10.96	10.98	10.98	11.04	11.04
11.18	11.03	11.06	11.09	11.07	11.09	11.07	11.11	11.09	11.06	11.12	11.14	11.17	11.19	11.22	11.19	11.24	11.22	11.23	11.25	11.24	11.21
11.26	11.27	11.30	11.28	11.31	11.34	11.38	11.36	11.38	11.41	11.48	11.32	11.33	11.38	11.40	11.42	11.53	11.46	11.36	11.38	11.39	11.39
24/01/75	1	108	.39	17.684	17.520	218.2	227.6	.0994	7.82	273.6						10.70	10.73	10.76	10.80	10.78	10.83
10.84	10.83	10.84	10.88	10.82	10.88	10.89	10.88	10.89	10.91	10.88	10.87	10.95	10.96	10.96	10.93	10.93	10.97	10.97	10.96	11.01	11.01
11.03	10.99	11.03	11.05	11.00	11.05	11.02	11.06	11.04	10.98	11.08	11.08	11.08	11.10	11.13	11.10	11.14	11.14	11.14	11.15	11.16	11.10
11.15	11.18	11.18	11.18	11.18	11.23	11.25	11.22	11.25	11.28	11.31	11.20	11.18	11.21	11.24	11.23	11.36	11.28	11.20	11.22	11.24	11.24
24/01/75	2	109	.39	17.699	17.522	226.4	242.8	.0984	10.06	350.9						11.68	11.71	11.78	11.83	11.80	11.90
11.88	11.89	11.90	11.95	11.91	11.96	11.99	11.98	12.01	12.02	11.98	11.95	12.09	12.09	12.12	12.08	12.08	12.13	12.15	12.14	12.19	12.20
12.22	12.17	12.24	12.28	12.22	12.26	12.24	12.28	12.28	12.22	12.34	12.33	12.35	12.38	12.41	12.38	12.44	12.42	12.43	12.46	12.43	12.41
12.48	12.49	12.50	12.51	12.54	12.58	12.62	12.60	12.64	12.66	12.60	12.55	12.55	12.60	12.62	12.63	12.78	12.70	12.57	12.57	12.58	12.58
24/01/75	3	110	.39	16.969	16.805	232.2	251.2	.0978	10.89	380.3						12.19	12.23	12.30	12.37	12.36	12.47
12.44	12.46	12.48	12.54	12.48	12.54	12.58	12.57	12.60	12.61	12.56	12.57	12.70	12.70	12.72	12.70	12.70	12.74	12.76	12.76	12.81	12.82
12.85	12.79	12.87	12.90	12.86	12.87	12.87	12.93	12.92	12.85	12.96	12.97	13.00	13.02	13.06	13.04	13.09	13.08	13.09	13.12	13.09	13.06
13.14	13.13	13.19	13.18	13.23	13.27	13.31	13.31	13.34	13.35	13.28	13.22	13.23	13.30	13.32	13.33	13.50	13.42	13.26	13.26	13.27	13.27
24/01/75	4	111	.39	17.605	17.454	234.6	257.6	.0969	11.87	412.1						12.65	12.74	12.78	12.86	12.82	12.95
12.93	12.94	12.97	13.02	12.97	13.04	13.08	13.08	13.11	13.13	13.06	13.08	13.23	13.22	13.26	13.22	13.24	13.28	13.30	13.30	13.34	13.38
13.40	13.33	13.40	13.48	13.42	13.44	13.44	13.50	13.50	13.43	13.57	13.56	13.59	13.61	13.67	13.68	13.70	13.71	13.72	13.73	13.71	13.68
13.74	13.77	13.80	13.81	13.86	13.91	13.93	13.92	14.00	13.98	13.92	13.86	13.88	13.97	13.91	13.92	14.02	14.07	13.88	13.91	13.89	13.89
24/01/75	5	112	.39	17.528	17.371	237.8	264.8	.0968	12.76	440.8						13.07	13.12	13.26	13.32	13.30	13.47
13.41	13.46	13.47	13.52	13.48	13.55	13.61	13.60	13.64	13.66	13.58	13.59	13.77	13.74	13.80	13.77	13.80	13.82	13.85	13.86	13.89	13.93
13.96	13.86	13.94	13.96	13.89	13.94	13.91	13.92	13.91	13.83	13.92	13.92	13.91	13.93	13.94	13.91	13.93	13.93	13.93	13.93	13.94	13.87
13.93	13.98	13.94	13.94	13.94	13.96	13.99	14.09	14.20	14.14	14.06	13.98	13.96	14.27	14.03	14.04	14.10	14.38	14.25	14.27	14.33	14.33

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24/01/75  6 113  .39 17.533 17.379 235.2 266.0 .0972 13.34 459.9                                                 13.22 13.28 13.40 13.48 13.43 13.63
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24/01/75  7 114  .39 17.841 17.669 236.0 269.8 .0964 14.07 487.1                                                 13.50 13.58 13.71 13.78 13.75 13.94
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24/01/75  8 115  .39 17.922 17.770 239.6 280.0 .0960 15.55 539.5                                                 14.20 14.08 14.18 14.21 14.18 14.21
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24/01/75  9 116  .39 17.947 17.790 243.1 283.4 .0939 16.80 582.3                                                 14.30 14.20 14.30 14.32 14.32 14.34
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24/01/75 10 117  .39 17.957 17.817 242.8 284.2 .0945 16.69 576.9                                                 14.30 14.19 14.32 14.31 14.30 14.33
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24/01/75 11 118  .39 17.947 17.790 253.0 284.6 .0792 17.78 614.5                                                 14.39 14.28 14.40 14.40 14.38 14.41
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30/01/75  1 119  .39 18.234 18.060 219.9 236.6 .0986 10.03 349.9                                                 11.32 11.32 11.38 11.42 11.40 11.50
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30/01/75  2 120  .39 18.420 18.272 224.0 245.6 .0979 11.00 382.9                                                 11.93 11.93 11.98 12.04 12.03 12.16
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30/01/75  3 121  .39 18.597 18.403 231.7 254.2 .0976 11.83 410.9                                                 12.49 12.49 12.55 12.62 12.58 12.74
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30/01/75  4 122  .39 18.656 18.470 233.4 261.8 .0968 12.65 438.9                                                 12.90 12.90 13.00 13.08 13.03 13.21
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30/01/75  5 123  .39 18.721 18.552 234.0 267.4 .0962 13.40 463.7                                                 13.42 13.42 13.45 13.54 13.49 13.70
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30/01/75  6 124  .39 18.803 18.612 233.8 270.7 .0968 14.12 486.5                                                 13.64 13.64 13.69 13.78 13.74 13.98
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30/01/75  7 125  .39 18.784 18.613 237.2 274.2 .0974 14.78 510.5                                                 14.00 14.00 14.03 14.13 14.07 14.27
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30/01/75  8 126  .39 18.790 18.612 240.8 281.2 .0976 15.53 537.2                                                 14.43 14.43 14.38 14.40 14.38 14.42
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30/01/75  9 127  .39 18.790 18.605 235.8 284.4 .0985 15.99 553.6                                                 14.44 14.43 14.43 14.60 14.41 14.45
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14.44	14.43	14.42	14.47	14.42	14.46	14.46	14.45	14.46	14.48	14.45	14.44	14.52	14.50	14.50	14.43	14.44	14.47	14.48	14.43	14.47	14.46
14.51	14.49	14.48	14.49	14.42	14.48	14.42	14.46	14.44	14.38	14.47	14.44	14.44	14.46	14.48	14.44	14.47	14.45	14.45	14.47	14.46	14.42
14.46	14.53	14.48	14.46	14.48	14.48	14.53	14.61	14.75	14.70	14.60	14.50	14.47	14.86	14.64	14.61	14.96	15.21	14.98	15.01	14.97	14.97
30/01/75	10	128	.39	18.728	18.544	235.8	285.0	.1015	16.72	577.9						14.47	14.45	14.45	14.47	14.44	14.47
14.48	14.47	14.46	14.51	14.46	14.48	14.48	14.48	14.50	14.52	14.48	14.48	14.53	14.53	14.52	14.48	14.48	14.52	14.50	14.48	14.52	14.48
14.54	14.50	14.51	14.53	14.45	14.50	14.45	14.49	14.46	14.42	14.48	14.47	14.48	14.48	14.50	14.46	14.50	14.47	14.48	14.49	14.47	14.44
14.48	14.56	14.50	14.49	14.48	14.51	14.55	14.67	14.77	14.73	14.64	14.54	14.49	14.89	14.68	14.65	15.02	15.30	15.05	15.08	15.03	15.03
30/01/75	11	129	.39	18.639	18.471	229.0	282.4	.1047	17.30	597.7						14.43	14.46	14.46	14.46	14.44	14.48
14.48	14.46	14.46	14.50	14.45	14.49	14.50	14.48	14.51	14.52	14.49	14.49	14.56	14.55	14.52	14.48	14.50	14.53	14.52	14.49	14.53	14.51
14.57	14.53	14.53	14.54	14.48	14.54	14.47	14.49	14.48	14.42	14.49	14.48	14.47	14.49	14.52	14.48	14.51	14.48	14.48	14.52	14.48	14.43
14.49	14.58	14.52	14.51	14.51	14.52	14.56	14.64	14.76	14.72	14.63	14.53	14.52	14.89	14.69	14.66	15.04	15.34	15.09	15.10	15.06	15.06
30/01/75	12	130	.39	18.726	18.550	231.4	285.0	.1083	17.97	621.3						14.51	14.51	14.52	14.51	14.49	14.54
14.53	14.52	14.53	14.56	14.52	14.54	14.55	14.54	14.57	14.58	14.55	14.53	14.59	14.60	14.56	14.53	14.56	14.56	14.56	14.53	14.57	14.55
14.60	14.57	14.58	14.58	14.51	14.56	14.49	14.54	14.52	14.47	14.53	14.52	14.51	14.53	14.54	14.49	14.54	14.51	14.50	14.54	14.51	14.47
14.52	14.60	14.55	14.53	14.54	14.56	14.59	14.67	14.80	14.75	14.66	14.56	14.59	14.93	14.72	14.70	15.10	15.42	15.12	15.16	15.08	15.08
06/02/75	1	131	.39	18.415	18.223	223.8	250.6	.0990	12.57	440.8						12.30	12.42	12.47	12.53	12.48	12.66
12.61	12.62	12.64	12.68	12.63	12.63	12.76	12.73	12.78	12.77	12.70	12.70	12.86	12.86	12.89	13.00	12.86	12.91	12.94	12.94	12.99	13.00
13.05	12.96	13.05	13.09	13.05	13.09	13.08	13.14	13.13	13.06.	13.20	13.19	13.23	13.25	13.31	13.28	13.36	13.36	13.37	13.40	13.37	13.32
13.40	13.43	13.48	13.48	13.54	13.60	13.64	13.65	13.69	13.71	13.60	13.50	13.61	13.65	13.63	13.66	13.82	13.76	13.53	13.56	13.54	13.54
06/02/75	2	132	.39	18.374	18.201	233.8	267.0	.0982	14.08	485.9						13.34	13.49	13.54	13.62	13.59	13.60
13.73	13.77	13.80	13.85	13.80	13.80	13.96	13.94	14.01	14.03	13.95	13.95	14.12	14.09	14.12	14.06	14.06	14.08	14.08	14.05	14.11	14.09
14.14	14.10	14.11	14.13	14.06	14.11	14.06	14.09	14.08	14.00	14.08	14.08	14.07	14.10	14.12	14.08	14.10	14.08	14.08	14.11	14.10	14.04
14.10	14.17	14.12	14.11	14.10	14.13	14.18	14.28	14.40	14.37	14.26	14.16	14.21	14.46	14.26	14.27	14.55	14.74	14.58	14.58	14.60	14.60
06/02/75	3	133	.39	18.090	17.916	239.0	278.4	.0986	15.56	537.3						14.19	14.19	14.19	14.20	14.18	14.20
14.22	14.20	14.20	14.24	14.19	14.19	14.24	14.22	14.24	14.26	14.21	14.21	14.28	14.27	14.25	14.20	14.22	14.23	14.24	14.23	14.26	14.24
14.28	14.25	14.26	14.28	14.21	14.26	14.20	14.24	14.22	14.16	14.23	14.23	14.21	14.25	14.28	14.22	14.26	14.23	14.24	14.27	14.25	14.19
14.25	14.33	14.27	14.27	14.27	14.28	14.33	14.43	14.57	14.52	14.41	14.31	14.36	14.66	14.45	14.42	14.78	15.01	14.80	14.81	14.78	14.78
06/02/75	4	134	.39	18.579	18.401	232.0	276.0	.1006	16.05	554.5						14.11	14.26	14.27	14.30	14.26	14.31
14.32	14.30	14.31	14.34	14.30	14.30	14.34	14.33	14.35	14.37	14.33	14.33	14.39	14.38	14.37	14.33	14.34	14.34	14.37	14.33	14.38	14.36
14.42	14.38	14.38	14.40	14.31	14.38	14.31	14.36	14.38	14.28	14.35	14.34	14.34	14.36	14.38	14.34	14.37	14.34	14.37	14.38	14.37	14.33
14.37	14.44	14.38	14.38	14.40	14.39	14.44	14.53	14.66	14.62	14.52	14.42	14.44	14.75	14.56	14.55	14.88	15.17	14.93	14.93	14.92	14.92
06/02/75	5	135	.39	18.574	18.400	232.2	279.2	.1018	16.83	579.9						14.38	14.36	14.37	14.38	14.34	14.39
14.40	14.38	14.38	14.42	14.36	14.40	14.41	14.38	14.41	14.43	14.39	14.40	14.47	14.45	14.42	14.38	14.40	14.42	14.43	14.39	14.44	14.42
14.48	14.43	14.44	14.46	14.39	14.45	14.38	14.43	14.41	14.34	14.42	14.42	14.40	14.42	14.46	14.40	14.48	14.41	14.42	14.44	14.42	14.38
14.43	14.50	14.46	14.44	14.46	14.44	14.52	14.61	14.73	14.69	14.60	14.50	14.53	14.84	14.64	14.62	15.00	15.30	15.05	15.04	15.00	15.00
06/02/75	6	136	.39	18.521	18.341	233.2	282.7	.1028	17.39	600.4						14.41	14.39	14.42	14.42	14.40	14.44
14.43	14.42	14.42	14.46	14.40	14.46	14.46	14.44	14.46	14.49	14.44	14.46	14.49	14.49	14.47	14.43	14.44	14.46	14.47	14.44	14.48	14.46
14.53	14.48	14.49	14.51	14.43	14.49	14.42	14.48	14.44	14.38	14.45	14.44	14.44	14.46	14.49	14.44	14.47	14.44	14.46	14.48	14.47	14.44
14.47	14.54	14.48	14.48	14.48	14.48	10.53	14.63	14.77	14.72	14.63	14.53	14.54	14.87	14.67	14.66	15.04	15.36	15.09	15.08	15.03	15.03
06/02/75	7	137	.39	18.497	18.323	230.2	282.7	.1044	17.88	615.3						14.42	14.42	14.46	14.45	14.42	14.46
14.47	14.45	14.44	14.48	14.43	14.48	14.48	14.47	14.49	14.51	14.48	14.47	14.53	14.53	14.49	14.45	14.48	14.48	14.49	14.46	14.51	14.49
14.54	14.49	14.50	14.52	14.46	14.51	14.44	14.49	14.49	14.41	14.48	14.48	14.46	14.48	14.50	14.46	14.48	14.47	14.47	14.48	14.48	14.42
14.48	14.54	14.50	14.48	14.50	14.49	14.56	14.63	14.77	14.73	14.61	14.49	14.56	14.91	14.69	14.69	15.09	15.43	15.13	15.14	15.07	15.07
06/02/75	8	138	.39	18.346	18.185	224.6	281.5	.1062	18.41	635.6						14.43	14.42	14.43	14.44	14.43	14.46
14.48	14.46	14.46	14.49	14.43	14.49	14.48	14.48	14.49	14.52	14.48	14.48	14.54	14.56	14.51	14.47	14.48	14.49	14.51	14.48	14.53	14.50
14.56	14.51	14.51	14.53	14.47	14.51	14.46	14.50	14.48	14.43	14.48	14.48	14.48	14.49	14.49	14.48	14.50	14.48	14.48	14.50	14.49	14.44
14.48	14.56	14.52	14.50	14.53	14.52	14.56	14.64	14.77	14.74	14.64	14.54	14.58	14.92	14.72	14.69	15.13	15.46	15.17	15.17	15.09	15.09
06/02/75	9	139	.39	18.415	18.214	222.4	282.4	.1079	19.03	656.0						14.48	14.45	14.48	14.48	14.46	14.51
14.52	14.48	14.50	14.53	14.46	14.50	14.52	14.50	14.53	14.56	14.53	14.51	14.57	14.57	14.55	14.48	14.53	14.52	14.56	14.51	14.57	14.53
14.59	14.55	14.54	14.56	14.50	14.55	14.48	14.52	14.50	14.46	14.50	14.50	14.48	14.52	14.52	14.48	14.52	14.49	14.50	14.53	14.51	14.47
14.51	14.58	14.53	14.52	14.54	14.54	14.60	14.66	14.79	14.80	14.68	14.56	14.59	14.94	14.72	14.73	15.18	15.54	15.22	15.21	15.14	15.14
06/02/75	10	140	.39	18.338	18.156	218.8	282.7	.1089	19.44	672.4						14.48	14.48	14.50	14.50	14.48	14.52
14.53	14.49	14.50	14.54	14.49	14.54	14.53	14.53	14.56	14.59	14.54	14.52	14.60	14.60	14.58	14.52	14.54	14.55	14.57	14.54	14.58	14.55
14.61	14.56	14.57	14.58	14.53	14.56	14.50	14.55	14.52	14.48	14.54	14.54	14.53	14.54	14.56	14.51	14.54	14.52	14.53	14.56	14.54	14.49
14.54	14.63	14.58	14.54	14.57	14.56	14.60	14.67	14.82	14.78	14.68	14.58	14.64	14.98	14.77	14.74	15.21	15.58	15.24	15.23	15.16	15.16
06/02/75	11	141	.39	18.290	18.119	217.8	282.4	.1098	19.80	682.3						14.50	14.49	14.52	14.52	14.49	14.56
14.55	14.53	14.54	14.57	14.51	14.56	14.55	14.54	14.56	14.62	14.58	14.57	14.62	14.62	14.58	14.56	14.57	14.58	14.60	14.56	14.61	14.58

14.62	14.57	14.58	14.61	14.53	14.58	14.51	14.56	14.54	14.48	14.53	14.54	14.52	14.57	14.57	14.53	14.58	14.53	14.60	14.55	14.54	14.51
14.54	14.62	14.58	14.55	14.59	14.57	14.60	14.67	14.81	14.78	14.68	14.58	14.63	14.98	14.77	14.75	15.24	15.58	15.24	15.26	15.18	15.18
06/02/75	12	142	.39	18.263	18.074	213.2	283.4	.1114	20.57	710.7						14.56	14.53	14.57	14.57	14.54	14.60
14.56	14.57	14.54	14.56	14.53	14.60	14.62	14.60	14.63	14.65	14.63	14.61	14.66	14.66	14.63	14.58	14.56	14.55	14.62	14.61	14.65	14.62
14.63	14.63	14.62	14.66	14.58	14.63	14.56	14.59	14.58	14.52	14.56	14.56	14.57	14.61	14.61	14.54	14.61	14.57	14.60	14.60	14.58	14.52
14.56	14.62	14.58	14.58	14.61	14.58	14.66	14.70	14.82	14.81	14.71	14.61	14.63	14.99	14.80	14.75	15.28	15.65	15.33	15.31	15.21	15.21
07/02/75	1	143	.39	17.908	17.726	233.2	259.5	.0970	12.60	435.2						12.78	12.89	12.94	13.01	12.97	13.13
13.10	13.14	13.14	13.20	13.14	13.22	13.29	13.28	13.32	13.33	13.28	13.27	13.43	13.41	13.47	13.44	13.47	13.47	13.53	13.52	13.60	13.60
13.64	13.62	13.64	13.71	13.64	13.68	13.68	13.73	13.74	13.67	13.80	13.79	13.64	13.85	13.93	13.89	13.98	13.95	13.98	14.01	13.97	13.93
13.99	14.02	13.98	13.96	13.98	13.98	14.03	14.08	14.18	14.18	14.10	14.03	13.97	14.18	14.08	14.05	14.37	14.30	14.80	14.11	14.11	14.11
07/02/75	2	144	.39	18.046	17.864	238.4	272.6	.0966	14.07	485.9						13.62	13.66	13.83	13.91	13.87	14.05
14.00	14.03	14.06	14.08	14.03	14.11	14.18	14.12	14.13	14.14	14.08	14.09	14.17	14.16	14.17	14.12	14.11	14.13	14.15	14.13	14.18	14.14
14.19	14.16	14.16	14.18	14.11	14.17	14.09	14.14	14.12	14.05	14.13	14.12	14.12	14.15	14.16	14.12	14.17	14.13	14.15	14.17	14.16	14.09
14.14	14.22	14.17	14.16	14.18	14.16	14.23	14.38	14.45	14.42	14.31	14.20	14.18	14.51	14.33	14.33	14.69	14.84	15.32	14.61	14.60	14.60
07/02/75	3	145	.39	18.087	17.915	240.6	281.2	.0966	15.46	534.7						14.24	14.06	14.23	14.24	14.21	14.26
14.26	14.25	14.26	14.29	14.23	14.28	14.28	14.26	14.28	14.30	14.28	14.26	14.32	14.31	14.30	14.30	14.28	14.27	14.30	14.26	14.31	14.28
14.35	14.26	14.31	14.32	14.24	14.29	14.22	14.28	14.27	14.20	14.28	14.26	14.25	14.27	14.28	14.23	14.29	14.25	14.26	14.29	14.26	14.22
14.25	14.33	14.28	14.27	14.30	14.27	14.31	14.41	14.53	14.51	14.40	14.30	14.26	14.62	14.47	14.45	14.85	15.05	15.52	14.80	14.74	14.74
07/02/75	4	146	.39	18.093	17.926	234.0	278.8	.0974	16.05	553.3						14.23	14.10	14.26	14.27	14.24	14.29
14.30	14.27	14.28	14.30	14.24	14.30	14.31	14.28	14.30	14.32	14.31	14.29	14.35	14.35	14.33	14.27	14.30	14.28	14.33	14.29	14.34	14.31
14.36	14.32	14.32	14.34	14.26	14.30	14.24	14.29	14.28	14.23	14.27	14.27	14.28	14.29	14.30	14.25	14.30	14.26	14.30	14.30	14.28	14.24
14.27	14.35	14.30	14.29	14.38	14.30	14.34	14.42	14.53	14.53	14.42	14.32	14.30	14.65	14.50	14.48	14.93	15.14	14.88	14.87	14.80	14.80
07/02/75	5	147	.39	18.037	17.866	233.6	282.4	.0973	16.78	580.3						14.30	14.17	14.30	14.34	14.29	14.34
14.33	14.33	14.33	14.35	14.29	14.34	14.36	14.34	14.35	14.37	14.35	14.33	14.39	14.38	14.38	14.33	14.34	14.33	14.37	14.33	14.39	14.34
14.40	14.37	14.36	14.39	14.31	14.38	14.28	14.34	14.32	14.25	14.34	14.31	14.32	14.33	14.34	14.30	14.35	14.30	14.32	14.34	14.33	14.28
14.32	14.39	14.33	14.32	14.36	14.31	14.38	14.48	14.60	14.59	14.48	14.37	14.33	14.70	14.56	14.54	14.99	15.21	14.93	14.94	14.86	14.86
07/02/75	6	148	.39	17.950	17.783	230.2	282.1	.0987	17.31	598.9						14.34	14.20	14.34	14.33	14.31	14.37
14.36	14.36	14.36	14.39	14.33	14.39	14.39	14.36	14.38	14.40	14.38	14.36	14.42	14.43	14.40	14.36	14.37	14.37	14.40	14.38	14.43	14.38
14.44	14.39	14.39	14.42	14.34	14.40	14.32	14.36	14.35	14.28	14.35	14.34	14.33	14.36	14.38	14.31	14.38	14.33	14.33	14.37	14.36	14.31
14.35	14.42	14.38	14.35	14.36	14.35	14.39	14.49	14.61	14.60	14.50	14.40	14.36	14.76	14.58	14.57	15.03	15.27	14.98	14.98	14.90	14.90
07/02/75	7	149	.39	17.981	17.806	226.1	282.4	.0993	17.88	618.4						14.36	14.28	14.37	14.36	14.36	14.40
14.41	14.38	14.39	14.43	14.34	14.40	14.41	14.40	14.42	14.43	14.40	14.40	14.45	14.45	14.43	14.37	14.40	14.38	14.42	14.40	14.44	14.40
14.45	14.42	14.42	14.43	14.35	14.41	14.35	14.38	14.38	14.30	14.36	14.37	14.36	14.38	14.38	14.33	14.39	14.36	14.37	14.38	14.38	14.32
14.35	14.43	14.39	14.36	14.39	14.38	14.41	14.49	14.62	14.61	14.50	14.40	14.37	14.74	14.61	14.59	15.08	15.33	15.02	15.02	14.90	14.90
11/02/75	1	150	.39	18.370	18.196	240.6	261.6	.0867	10.85	376.5						12.74	12.82	12.88	12.95	12.93	13.06
13.00	13.06	13.08	13.12	13.07	13.14	13.18	13.17	13.20	13.22	13.18	13.15	13.30	13.29	13.33	13.31	13.32	13.36	13.39	13.38	13.42	13.43
13.47	13.40	13.47	13.53	13.47	13.50	13.49	13.54	13.55	13.48	13.60	13.60	13.63	13.64	13.70	13.67	13.73	13.72	13.75	13.78	13.73	13.70
13.78	13.78	13.82	13.83	13.86	13.92	13.97	13.95	13.99	14.02	13.93	13.85	13.88	13.96	13.98	13.97	14.08	14.04	13.88	13.90	13.91	13.91
11/02/75	2	151	.39	18.335	18.161	246.9	276.0	.0859	12.58	435.6						13.66	13.66	13.85	13.92	13.88	14.07
14.01	14.05	14.07	14.11	14.07	14.14	14.19	14.14	14.16	14.16	14.11	14.09	14.17	14.18	14.15	14.13	14.13	14.16	14.16	14.13	14.18	14.16
14.18	14.16	14.16	14.20	14.13	14.17	14.12	14.15	14.13	14.06	14.14	14.14	14.11	14.16	14.18	14.12	14.16	14.13	14.16	14.16	14.16	14.10
14.16	14.22	14.18	14.17	14.18	14.16	14.22	14.33	14.45	14.43	14.32	14.21	14.19	14.49	14.33	14.33	14.60	14.80	14.66	14.63	14.60	14.60
12/02/75	3	152	.39	18.281	18.114	250.4	281.5	.0855	13.43	462.4						14.18	14.06	14.20	14.19	14.18	14.20
14.18	14.18	14.19	14.24	14.18	14.23	14.22	14.24	14.22	14.25	14.22	14.20	14.26	14.26	14.23	14.19	14.20	14.30	14.24	14.20	14.24	14.22
14.28	14.25	14.23	14.27	14.19	14.24	14.18	14.22	14.20	14.14	14.20	14.19	14.19	14.24	14.23	14.19	14.23	14.19	14.21	14.22	14.21	14.17
14.21	14.28	14.23	14.21	14.23	14.23	14.28	14.38	14.49	14.48	14.37	14.26	14.25	14.55	14.41	14.39	14.67	14.90	14.72	14.72	14.66	14.66
11/02/75	4	153	.39	18.249	18.092	248.4	283.6	.0860	14.13	489.3						14.28	14.09	14.24	14.23	14.23	14.26
14.24	14.25	14.25	14.28	14.23	14.27	14.28	14.26	14.25	14.30	14.26	14.26	14.30	14.31	14.29	14.24	14.26	14.28	14.29	14.26	14.30	14.28
14.34	14.28	14.30	14.32	14.23	14.28	14.22	14.25	14.24	14.18	14.24	14.24	14.23	14.28	14.27	14.22	14.27	14.23	14.25	14.27	14.24	14.20
14.24	14.31	14.26	14.26	14.26	14.26	14.31	14.41	14.53	14.50	14.39	14.28	14.26	14.59	14.46	14.45	14.75	14.98	14.78	14.78	14.73	14.73
11/02/75	5	154	.39	18.243	18.085	248.1	285.6	.0850	15.58	537.3						14.36	14.21	14.34	14.32	14.33	14.37
14.34	14.36	14.36	14.40	14.34	14.38	14.39	14.38	14.38	14.38	14.36	14.35	14.41	14.43	14.40	14.34	14.37	14.38	14.38	14.33	14.35	14.33
14.40	14.37	14.38	14.38	14.33	14.37	14.30	14.34	14.33	14.27	14.34	14.33	14.32	14.34	14.36	14.32	14.36	14.32	14.33	14.35	14.34	14.30
14.34	14.42	14.36	14.34	14.34	14.32	14.37	14.50	14.66	14.60	14.49	14.38	14.37	14.74	14.58	14.58	14.91	15.18	14.93	14.94	14.88	14.88
11/02/75	6	155	.39	18.248	18.090	252.2	285.0	.0816	16.70	575.6						14.42	14.28	14.43	14.39	14.40	14.44
14.41	14.42	14.44	14.46	14.40	14.44	14.46	14.43	14.44	14.46	14.43	14.40	14.46	14.47	14.44	14.39	14.41	14.42	14.44	14.40	14.44	14.40
14.46	14.38	14.38	14.43	14.38	14.43	14.36	14.39	14.38	14.33	14.40	14.38	14.38	14.40	14.42	14.36	14.41	14.36	14.40	14.40	14.40	14.34

14.38 14.46 14.42 14.40 14.41 14.40 14.46 14.59 14.73 14.67 14.55 14.44 14.41 14.81 14.63 14.62 14.98 15.27 15.02 15.04 14.97 14.97
11/02/75 7 156 .39 18.212 18.059 252.6 285.9 .0802 17.74 611.6 14.46 14.40 14.48 14.44 14.43 14.47
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11/02/75 8 157 .39 18.264 18.124 254.8 286.8 .0775 18.99 655.6 14.57 14.49 14.56 14.51 14.50 14.56
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11/02/75 9 158 .39 18.228 18.094 254.8 284.2 .0785 19.04 655.5 14.55 14.48 14.56 14.51 14.50 14.55
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11/02/75 10 159 .39 18.159 18.028 256.2 287.7 .0763 19.03 656.0 14.56 14.49 14.54 14.49 14.49 14.55
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11/02/75 1 160 .39 18.299 18.117 237.5 259.8 .0832 10.94 327.3 12.67 12.67 12.82 12.88 12.85 12.98
12.96 12.97 12.98 13.03 12.98 13.06 13.11 13.09 13.13 13.13 13.08 13.08 13.23 13.24 13.27 13.22 13.24 13.28 13.30 13.30 13.37 13.38
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13.71 13.74 13.77 13.77 13.82 13.86 13.91 13.89 13.92 13.96 13.87 13.77 13.88 13.88 13.88 13.69 13.99 13.97 13.80 13.87 13.82 13.82
11/02/75 2 161 .39 18.079 17.917 248.7 278.4 .0822 12.69 436.5 13.82 13.82 14.03 14.09 14.04 14.12
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11/02/75 3 162 .39 17.945 17.812 251.6 283.4 .0819 13.46 464.1 14.24 14.24 14.18 14.18 14.16 14.20
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12/02/75 4 163 .39 17.977 17.811 250.6 283.4 .0814 13.49 464.0 14.20 14.20 14.17 14.18 14.16 14.19
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12/02/75 5 164 .39 17.962 17.806 249.4 283.6 .0815 14.00 484.4 14.20 14.20 14.19 14.21 14.18 14.22
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12/02/75 6 165 .39 17.959 17.806 251.8 284.2 .0796 15.52 536.0 14.30 14.30 14.30 14.31 14.28 14.32
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12/02/75 7 166 .39 17.970 17.826 258.6 284.2 .0748 16.72 576.7 14.38 14.38 14.38 14.38 14.34 14.37
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12/02/75 8 167 .39 17.939 17.816 263.0 285.0 .0678 17.33 598.4 14.41 14.41 14.38 14.38 14.35 14.37
14.39 14.37 14.37 14.42 14.33 14.39 14.39 14.37 14.38 14.41 14.39 14.37 14.43 14.40 14.38 14.34 14.36 14.36 14.38 14.36 14.39 14.38
14.42 14.39 14.38 14.40 14.34 14.37 14.33 14.36 14.35 14.28 14.34 14.34 14.33 14.35 14.36 14.33 14.37 14.33 14.36 14.37 14.36 14.30
14.34 14.42 14.38 14.35 14.37 14.35 14.38 14.46 14.59 14.58 14.47 14.36 14.43 14.44 14.35 14.34 14.85 14.72 14.78 14.80 15.08 15.08
12/02/75 9 168 .39 17.955 17.821 263.6 285.0 .0669 17.70 608.9 14.43 14.43 14.40 14.40 14.37 14.39
14.41 14.40 14.40 14.41 14.36 14.41 14.39 14.40 14.40 14.43 14.42 14.40 14.45 14.44 14.42 14.36 14.38 14.39 14.43 14.38 14.43 14.40
14.44 14.40 14.41 14.43 14.37 14.40 14.34 14.38 14.37 14.32 14.37 14.37 14.37 14.37 14.38 14.35 14.40 14.36 14.38 14.38 14.38 14.33
14.36 14.45 14.38 14.36 14.38 14.38 14.42 14.48 14.60 14.57 14.47 14.36 14.37 14.26 14.37 14.37 14.99 15.30 15.83 18.12 19.28 19.28
10/02/75 10 169 .39 17.945 17.822 263.0 284.6 .0668 17.69 607.6 14.42 14.42 14.40 14.40 14.37 14.39
14.40 14.38 14.38 14.42 14.36 14.40 14.40 14.40 14.40 14.43 14.42 14.40 14.45 14.45 14.44 14.36 14.38 14.38 14.41 14.38 14.43 14.40
14.44 14.41 14.40 14.43 14.38 14.41 14.36 14.39 14.38 14.31 14.37 14.37 14.38 14.38 14.41 14.34 14.40 14.36 14.38 14.39 14.38 14.32
14.35 14.43 14.38 14.37 14.38 14.37 14.42 14.47 14.58 14.58 14.47 14.36 14.38 14.36 14.40 14.38 14.96 15.18 15.30 17.78 19.12 19.12

11/02/75	11	170	.39	17.940	17.820	264.2	285.3	.0657	17.90	617.1						14.41	14.41	14.40	14.41	14.38	14.40
14.40	14.38	14.40	14.43	14.36	14.42	14.41	14.40	14.40	14.44	14.47	14.41	14.46	14.43	14.43	14.40	14.38	14.40	14.43	14.40	14.43	14.40
14.46	14.41	14.42	14.44	14.36	14.42	14.35	14.40	14.40	14.32	14.40	14.40	14.37	14.38	14.42	14.34	14.39	14.36	14.37	14.38	14.38	14.32
14.35	14.44	14.38	14.37	14.38	14.36	14.42	14.46	14.53	14.43	14.42	14.42	14.50	15.19	19.47	21.03	20.90	20.64	19.36	20.50	20.44	20.44
13/02/75	1	171	.39	18.446	18.274	240.6	264.2	.0808	11.05	380.7						12.89	13.01	13.06	13.14	13.10	13.24
13.22	13.21	13.26	13.30	13.26	13.32	13.38	13.36	13.40	13.42	13.36	13.34	13.51	13.50	13.53	13.51	13.52	13.58	13.59	13.59	13.66	13.65
13.70	13.62	13.70	13.76	13.70	13.73	13.73	13.78	13.78	13.71	13.83	13.84	13.86	13.89	13.93	13.92	13.98	13.98	13.99	14.03	13.98	13.94
14.03	14.04	14.08	14.09	14.13	14.09	14.10	14.14	14.24	14.25	14.16	14.11	14.08	14.20	14.22	14.14	14.21	14.28	14.26	14.21	14.19	14.18
13/02/75	2	172	.39	18.424	18.247	249.0	279.6	.0798	12.62	437.2						13.94	14.08	14.13	14.20	14.16	14.19
14.22	14.18	14.17	14.22	14.16	14.20	14.20	14.18	14.20	14.23	14.18	14.17	14.23	14.25	14.23	14.16	14.18	14.21	14.21	14.18	14.22	14.20
14.26	14.21	14.23	14.23	14.16	14.21	14.16	14.19	14.18	14.11	14.18	14.18	14.17	14.20	14.22	14.17	14.20	14.19	14.18	14.20	14.18	14.13
14.19	14.26	14.22	14.20	14.25	14.21	14.24	14.35	14.48	14.45	14.35	14.25	14.21	14.53	14.42	14.38	14.68	14.87	14.82	14.87	14.85	14.85
13/02/75	3	173	.39	18.336	18.170	249.6	283.8	.0799	13.47	463.9						14.23	14.19	14.24	14.25	14.22	14.24
14.26	14.24	14.23	14.28	14.23	14.26	14.25	14.23	14.26	14.28	14.24	14.24	14.30	14.31	14.28	14.23	14.24	14.28	14.28	14.24	14.28	14.26
14.32	14.27	14.28	14.28	14.22	14.27	14.22	14.25	14.23	14.16	14.24	14.23	14.20	14.23	14.25	14.21	14.24	14.21	14.21	14.24	14.23	14.17
14.24	14.28	14.23	14.23	14.37	14.24	14.26	14.38	14.50	14.46	14.36	14.26	14.23	14.55	14.48	14.43	14.77	14.94	14.91	14.95	14.90	14.90
13/02/75	4	174	.39	18.214	17.966	248.4	284.2	.0804	14.10	486.4						14.28	14.27	14.28	14.30	14.26	14.30
14.32	14.29	14.29	14.32	14.28	14.30	14.30	14.30	14.32	14.34	14.29	14.26	14.36	14.34	14.31	14.27	14.28	14.30	14.30	14.26	14.31	14.28
14.33	14.29	14.29	14.30	14.23	14.28	14.23	14.27	14.24	14.17	14.23	14.22	14.19	14.19	14.15	14.08	14.10	14.09	14.15	14.21	14.24	14.20
14.27	14.32	14.28	14.27	14.48	14.28	14.30	14.40	14.53	14.49	14.40	14.30	14.28	14.63	14.51	14.48	14.84	15.03	14.98	15.04	14.98	14.98
13/02/75	5	175	.39	18.316	18.174	246.0	283.8	.0806	14.10	486.8						14.22	14.23	14.26	14.26	14.23	14.27
14.23	14.26	14.26	14.29	14.23	14.27	14.26	14.26	14.28	14.29	14.26	14.26	14.31	14.31	14.28	14.26	14.26	14.28	14.27	14.24	14.28	14.24
14.30	14.27	14.28	14.30	14.23	14.28	14.21	14.25	14.23	14.17	14.24	14.24	14.23	14.25	14.27	14.20	14.24	14.22	14.22	14.24	14.23	14.18
14.24	14.29	14.26	14.25	14.41	14.26	14.28	14.38	14.49	14.48	14.38	14.28	14.25	14.61	14.50	14.46	14.82	15.02	14.96	15.01	14.96	14.96
13/02/75	6	176	.39	18.232	18.090	250.0	284.8	.0788	15.73	539.1						14.32	14.31	14.33	14.34	14.33	14.35
14.38	14.34	14.33	14.36	14.27	14.29	14.26	14.22	14.14	14.14	14.15	14.21	14.32	14.40	14.37	14.34	14.36	14.38	14.38	14.36	14.40	14.36
14.42	14.37	14.38	14.38	14.33	14.37	14.33	14.36	14.35	14.28	14.34	14.34	14.32	14.34	14.34	14.32	14.35	14.33	14.33	14.35	14.33	14.30
14.34	14.40	14.35	14.34	14.52	14.35	14.39	14.49	14.63	14.60	14.49	14.38	14.36	14.75	14.65	14.61	15.05	15.23	15.16	15.25	15.18	15.18
13/02/75	7	177	.39	18.319	18.136	251.8	286.6	.0777	16.77	578.7						14.40	14.36	14.38	14.34	14.28	14.34
14.36	14.36	14.40	14.44	14.38	14.43	14.43	14.43	14.43	14.45	14.43	14.40	14.46	14.46	14.44	14.38	14.40	14.40	14.43	14.38	14.44	14.40
14.45	14.42	14.43	14.44	14.38	14.42	14.37	14.40	14.37	14.28	14.33	14.33	14.26	14.25	14.28	14.26	14.32	14.34	14.37	14.39	14.38	14.34
14.38	14.46	14.41	14.38	14.41	14.40	14.44	14.56	14.70	14.67	14.55	14.43	14.40	14.83	14.73	14.68	15.17	15.36	15.26	15.36	15.28	15.28
13/02/75	8	178	.39	18.233	18.017	250.0	286.5	.0772	17.14	589.1						14.38	14.29	14.34	14.28	14.26	14.32
14.35	14.37	14.41	14.45	14.39	14.44	14.43	14.42	14.43	14.45	14.41	14.40	14.47	14.46	14.43	14.37	14.38	14.40	14.42	14.39	14.43	14.40
14.45	14.41	14.42	14.45	14.37	14.43	14.37	14.40	14.39	14.33	14.38	14.38	14.38	14.39	14.40	14.38	14.41	14.39	14.44	14.40	14.39	14.34
14.36	14.43	14.36	14.32	14.30	14.28	14.36	14.48	14.68	14.67	14.55	14.43	14.41	14.83	14.72	14.69	15.18	15.38	15.30	15.40	15.33	15.33
17/02/75	1	179	.67	30.836	30.670	227.0	246.6	.0922	10.94	375.6						11.90	12.02	12.06	12.12	12.09	12.23
12.21	12.21	12.22	12.25	12.22	12.30	12.33	12.32	12.35	12.37	12.32	12.30	12.46	12.43	12.47	12.44	12.44	12.50	12.53	12.50	12.57	12.56
12.61	12.55	12.61	12.65	12.60	12.64	12.63	12.69	12.65	12.60	12.72	12.72	12.75	12.77	12.80	12.78	12.86	12.84	12.86	12.88	12.66	12.80
12.89	12.91	12.93	12.95	13.06	13.02	13.07	13.05	13.09	13.11	13.04	12.94	12.95	13.03	13.05	13.04	13.32	13.14	12.99	13.06	13.04	13.04
17/02/75	2	180	.67	30.692	30.521	235.8	264.2	.0910	12.68	435.3						13.01	13.16	13.22	13.28	13.25	13.45
13.40	13.43	13.46	13.49	13.44	13.52	13.59	13.59	13.62	13.64	13.58	13.57	13.74	13.73	13.78	13.76	13.76	13.81	13.86	13.84	13.91	13.90
13.94	13.87	13.94	14.00	13.94	13.98	14.00	14.09	14.07	13.99	14.13	14.11	14.17	14.17	14.22	14.22	14.30	14.29	14.32	14.36	14.32	14.24
14.33	14.36	14.40	14.41	14.58	14.54	14.60	14.60	14.64	14.66	14.54	14.42	14.46	14.56	14.58	14.58	14.94	14.68	14.48	14.58	14.51	14.51
17/02/75	3	181	.67	30.468	30.314	243.1	277.6	.0900	14.07	483.1						13.88	13.93	14.13	14.20	14.19	14.45
14.35	14.41	14.43	14.46	14.43	14.52	14.60	14.60	14.65	14.65	14.58	14.57	14.78	14.76	14.83	14.81	14.81	14.87	14.92	14.92	14.96	14.99
15.02	14.94	15.02	15.10	15.05	15.08	15.11	15.20	15.20	15.11	15.27	15.26	15.31	15.31	15.38	15.38	15.46	15.46	15.50	15.52	15.47	15.40
15.50	15.54	15.58	15.60	15.71	15.78	15.90	15.86	15.89	15.89	15.74	15.59	15.66	15.83	15.82	15.81	15.96	15.96	15.68	15.78	15.71	15.71
17/02/75	4	182	.67	30.315	30.176	246.3	289.2	.0897	15.50	532.9						14.69	14.71	14.98	15.07	15.03	15.33
15.23	15.29	15.33	15.37	15.31	15.41	15.51	15.51	15.58	15.58	15.49	15.50	15.73	15.72	15.81	15.81	15.82	15.86	15.94	15.94	15.98	16.04
16.06	15.93	16.07	16.16	16.11	16.12	16.18	16.28	16.29	16.19	16.35	16.33	16.37	16.35	16.38	16.38	16.41	16.38	16.41	16.43	16.40	16.32
16.40	16.42	16.39	16.39	16.38	16.41	16.47	16.51	16.60	16.58	16.49	16.40	16.37	16.56	16.58	16.47	16.70	16.84	16.73	16.80	16.76	16.76
17/02/75	5	183	.67	30.651	30.510	249.0	297.0	.0893	16.69	571.3						15.33	15.48	15.68	15.80	15.73	16.10
15.96	16.04	16.08	16.09	16.06	16.18	16.30	16.28	16.36	16.36	16.25	16.27	16.49	16.46	16.51	16.46	16.47	16.52	16.53	16.49	16.53	16.50
16.57	16.51	16.53	16.55	16.48	16.54	16.48	16.53	16.52	16.43	16.53	16.50	16.52	16.52	16.52	16.49	16.54	16.50	16.54	16.56	16.53	16.45
16.52	16.57	16.53	16.52	16.53	16.54	16.60	16.66	16.75	16.73	16.64	16.54	16.49	16.71	16.75	16.65	16.69	17.05	16.98	17.03	17.07	17.07
17/02/75	6	184	.67	30.933	30.779	250.6	302.0	.0894	17.34	594.1						15.74	15.87	16.10	16.24	16.16	16.46

16.38	16.46	16.50	16.51	16.46	16.52	16.60	16.58	16.60	16.63	16.54	16.53	16.64	16.61	16.60	16.58	16.58	16.62	16.63	16.60	16.65	16.60
16.66	16.67	16.63	16.64	16.59	16.63	16.58	16.63	16.59	16.53	16.60	16.60	16.60	16.62	16.62	16.60	16.64	16.60	16.63	16.65	16.63	16.54
16.61	16.66	16.60	16.61	16.62	16.63	16.68	16.74	16.85	16.80	16.71	16.63	16.58	16.80	16.84	16.76	17.11	17.18	17.11	17.18	17.18	17.18
17/02/75	7	165	.67	31.048	30.910	248.4	303.8	.0895	17.88	612.8						15.96	16.08	16.32	16.45	16.37	16.59
16.56	16.61	16.63	16.63	16.58	16.64	16.66	16.64	16.67	16.68	16.63	16.60	16.70	16.69	16.68	16.64	16.66	16.68	16.69	16.64	16.70	16.67
16.72	16.68	16.68	16.70	16.63	16.69	16.65	16.68	16.67	16.60	16.68	16.65	16.66	16.66	16.67	16.70	16.69	16.67	16.68	16.70	16.69	16.60
16.66	16.71	16.67	16.67	16.68	16.68	16.74	16.78	16.91	16.88	16.78	16.69	16.64	16.86	16.92	16.81	17.18	17.26	17.18	17.26	17.26	17.26
17/02/75	8	186	.67	31.081	30.932	249.4	308.6	.0895	18.48	632.3						16.24	16.40	16.61	16.66	16.60	16.70
16.69	16.70	16.68	16.72	16.67	16.70	16.71	16.71	16.71	16.74	16.69	16.66	16.74	16.72	16.70	16.69	16.68	16.73	16.73	16.70	16.73	16.70
16.76	16.72	16.72	16.73	16.67	16.73	16.68	16.72	16.70	16.63	16.70	16.68	16.70	16.70	16.70	16.68	16.73	16.70	16.72	16.73	16.72	16.63
16.68	16.75	16.71	16.71	16.72	16.71	16.78	16.83	16.95	16.91	16.82	16.73	16.67	16.89	16.97	16.85	17.26	17.33	17.24	17.32	17.34	17.34
17/02/75	9	187	.67	30.908	30.792	249.8	312.0	.0895	18.95	649.1						16.53	16.50	16.70	16.70	16.66	16.72
16.71	16.70	16.71	16.72	16.67	16.70	16.72	16.72	16.72	16.76	16.70	16.68	16.76	16.74	16.72	16.68	16.74	16.72	16.73	16.71	16.75	16.70
16.77	16.75	16.73	16.75	16.68	16.73	16.69	16.75	16.73	16.65	16.73	16.70	16.71	16.71	16.72	16.70	16.75	16.70	16.72	16.74	16.73	16.64
16.70	16.77	16.71	16.72	16.72	16.73	16.77	16.84	16.93	16.90	16.82	16.74	16.69	16.89	16.98	16.88	17.33	17.38	17.30	17.37	17.38	17.38
17/02/75	10	168	.67	30.679	30.543	249.8	315.2	.0688	19.43	663.9						16.68	16.53	16.70	16.70	16.67	16.75
16.72	16.71	16.71	16.74	16.68	16.73	16.73	16.72	16.72	16.75	16.72	16.70	16.77	16.77	16.73	16.72	16.70	16.74	16.73	16.70	16.74	16.70
16.76	16.73	16.72	16.75	16.68	16.75	17.00	16.74	16.71	16.64	16.74	16.70	16.70	16.71	16.71	16.70	16.74	16.71	16.74	16.74	16.74	16.64
16.70	16.76	16.80	16.70	16.71	16.72	16.77	16.82	16.94	16.90	16.81	16.73	16.68	17.00	16.98	16.87	17.36	17.42	17.32	17.40	17.42	17.42
17/02/75	11	189	.67	30.501	30.393	251.0	317.0	.0899	19.73	675.9						16.67	16.52	16.71	16.70	16.66	16.73
16.71	16.69	16.68	16.72	16.68	16.70	16.70	16.70	16.72	16.75	16.70	16.68	16.76	16.73	16.73	16.70	16.69	16.73	16.73	16.70	16.74	16.70
16.74	16.72	16.71	16.73	16.67	16.74	16.67	16.73	16.69	16.63	16.70	16.70	16.68	16.70	16.70	16.67	16.73	16.70	16.71	16.72	16.73	16.62
16.70	16.73	16.70	16.69	16.71	16.70	16.77	16.80	16.92	16.88	16.83	16.78	16.68	16.87	16.97	16.86	17.38	17.43	17.33	17.41	17.43	17.43
17/02/75	12	190	.67	30.328	30.170	251.6	321.0	.0898	20.70	706.7						16.69	16.55	16.72	16.69	16.68	16.74
16.72	16.70	16.70	16.74	16.70	16.73	16.73	16.72	16.76	16.77	16.73	16.71	16.78	16.76	16.74	16.70	16.72	16.73	16.74	16.72	16.75	16.71
16.76	16.73	16.75	16.74	16.68	16.74	16.69	16.74	16.71	16.65	16.72	16.68	16.78	16.72	16.72	16.70	16.75	16.70	16.74	16.75	16.75	16.64
16.71	16.76	16.72	16.72	16.73	16.73	16.78	16.82	16.94	16.90	16.83	16.73	16.68	16.76	16.92	16.85	17.46	17.38	17.30	17.38	17.46	17.46
17/02/75	13	191	.67	30.014	29.784	253.0	325.2	.0876	21.30	728.3						16.66	16.53	16.68	16.66	16.66	16.74
16.74	16.71	16.73	16.77	16.69	16.74	16.74	16.70	16.70	16.74	16.73	16.71	16.78	16.76	16.75	16.68	16.72	16.74	16.73	16.70	16.72	16.70
16.77	16.73	16.76	16.74	16.67	16.74	16.69	16.73	16.71	16.64	16.68	16.67	16.69	16.68	16.68	16.66	16.73	16.70	16.73	16.73	16.72	16.64
16.70	16.73	16.71	16.68	16.73	16.72	16.76	16.73	16.82	16.77	16.73	16.70	16.80	16.70	16.89	16.80	17.72	18.40	20.24	25.48	27.39	27.39
17/02/75	14	192	.67	29.989	29.684	255.7	325.8	.0853	21.30	727.1						16.66	16.53	16.70	16.67	16.63	16.71
16.71	16.70	16.71	16.74	16.67	16.71	16.69	16.70	16.72	16.75	16.78	16.69	16.76	16.78	16.72	16.63	16.64	16.70	16.71	16.68	16.73	16.70
16.72	16.71	16.70	16.72	16.66	16.70	16.66	16.73	16.69	16.62	16.68	16.68	16.66	16.66	16.69	16.66	16.73.	16.69	16.73	16.72	16.71	16.59
16.64	16.71	16.70	16.70	16.70	16.73	16.76	16.72	16.81	16.77	16.73	16.72	16.65	16.78	17.15	17.24	21.15	25.09	26.34	29.08	32.12	32.12
20/02/75	1	193	.67	29.641	29.491	241.3	263.0	.0789	10.96	376.4						12.90	13.02	13.07	13.12	13.09	13.24
13.22	13.23	13.25	13.30	13.25	13.33	13.37	13.35	13.40	13.42	13.36	13.36	13.50	13.52	13.52	13.49	13.52	13.57	13.58	13.58	13.63	13.64
13.67	13.61	13.70	13.74	13.68	13.72	13.70	13.77	13.78	13.70	13.81	13.82	13.84	13.87	13.90	13.89	13.96	13.96	13.98	14.00	13.97	13.92
14.01	14.01	14.05	14.06	14.57	14.17	14.20	14.18	14.22	14.25	14.16	14.06	14.07	14.15	13.99	13.90	14.03	13.97	14.19	13.95	14.15	14.15
20/02/75	2	194	.67	29.208	29.052	249.8	280.3	.0787	12.61	433.1						13.98	14.11	14.19	14.27	14.25	14.43
14.39	14.41	14.45	14.49	14.46	14.54	14.61	14.60	14.65	14.67	14.60	14.60	14.78	14.78	14.82	14.79	14.80	14.67	14.90	14.90	14.96	14.98
15.03	15.00	15.03	15.08	15.03	15.07	15.06	15.14	15.15	15.06	15.20	15.21	15.25	12.27	15.34	15.33	15.39	15.39	15.42	15.45	15.42	15.37
15.46	15.47	15.52	15.52	15.60	15.66	15.72	15.71	15.77	15.76	15.63	15.50	15.54	15.63	15.43	15.33	15.50	15.42	15.71	15.39	15.66	15.66
20/02/75	3	195	.67	29.662	29.519	251.6	290.0	.0773	14.10	483.3						14.70	14.78	15.00	15.07	15.03	15.26
15.20	15.24	15.28	15.33	15.28	15.40	15.46	15.46	15.53	15.55	15.48	15.47	15.68	15.68	15.74	15.72	15.75	15.80	15.84	15.86	15.89	15.95
15.98	15.89	16.00	16.07	16.03	16.04	16.06	16.14	16.18	16.07	16.23	16.22	16.23	16.23	16.25	16.23	16.26	16.23	16.27	16.27	16.25	16.18
16.24	16.28	16.29	16.26	16.25	16.28	16.30	16.38	16.45	16.45	16.36	16.27	16.22	16.47	16.20	16.09	16.30	16.18	16.30	16.21	16.26	16.26
20/02/75	4	196	.67	29.945	29.793	253.9	300.4	.0763	15.45	529.2						15.46	15.56	15.81	15.90	15.88	16.15
16.07	16.11	16.16	16.19	16.16	16.24	16.33	16.31	16.37	16.37	16.29	16.29	16.42	16.40	16,38	16.33	16.36	16.38	16.38	16.37	16.41	16.38
16.43	16.41	16.41	16.43	16.34	16.41	16.34	16.39	16.38	16.29	16.38	16.38	16.37	16.40	16.40	16.38	16.41	16.39	16.39	16.40	16.38	16.32
16.40	16.44	16.40	16.39	16.40	16.41	16.46	16.52	16.63	16.61	16.53	16.45	16.39	16.61	16.43	16.38	16.51	16.37	16.48	16.43	16.41	16.41
20/02/75	5	197	.67	29.752	29.601	256.4	310.8	.0745	16.71	572.0						16.27	16.22	16.42	16.44	16.41	16.42
16.45	16.48	16.42	16.46	16.40	16.46	16.46	16.40	16.44	16.47	16.42	16.42	16.48	16.49	16.46	16.40	16.42	16.46	16.45	16.43	16.48	16.44
16.50	16.46	16.48	16.48	16.40	16.47	16.40	16.46	16.43	16.36	16.44	16.43	16.43	16.46	16.46	16.42	16.45	16.43	16.43	16.47	16.44	16.38
16.43	16.48	16.45	16.45	16.46	16.47	16.50	16.57	16.68	16.64	16.56	16.48	16.42	16.66	16.58	16.51	16.60	16.43	16.54	16.52	16.45	16.45
20/02/75	6	198	.67	29.521	29.379	256.4	317.2	.0744	17.81	608.3						16.46	16.28	16.47	16.48	16.44	16.48
16.50	16.46	16.47	16.51	16.45	16.48	16.48	16.47	16.49	16.52	16.48	16.46	16.54	16.52	16.49	16.45	16.47	16.50	16.49	16.48	16.52	16.47

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16.53 16.50 16.51 16.51 16.45 16.52 16.43 16.48 16.46 16.38 16.49 16.47 16.46 16.48 16.49 16.44 16.49 16.46 16.50 16.49 16.48 16.41
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20/02/75  7 199  .67 29.672 29.532 257.6 323.4 .0744 18.45 629.9
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20/02/75  8 200  .67 29.885 29.692 261.0 324.2 .0732 19.00 648.8
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20/02/75  9 201  .67 29.767 29.663 264.8 326.0 .0709 19.09 650.5
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24/02/75  1 202  .67 30.218 30.068 251.6 276.8 .0706 10.86 372.3
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24/02/75  2 203  .67 30.035 29.903 253.0 288.6 .0703 12.67 432.8
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14.88 14.91 14.94 14.98 14.94 15.03 15.12 15.10 15.16 15.18 15.13 15.13 15.31 15.32 15.37 15.34 15.35 15.42 15.47 15.48 15.55 15.56
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24/02/75  3 204  .67 29.959 29.828 256.0 299.1 .0701 14.05 479.2
                                                                                                 15.17 15.40 15.46 15.58 15.54 15.83
15.74 15.78 15.84 15.88 15.83 15.95 16.03 16.04 16.09 16.11 16.04 16.03 16.24 16.26 16.32 16.27 16.28 16.33 16.33 16.30 16.38 16.33
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24/02/75  4 205  .67 29.839 29.708 257.2 308.4 .0700 15.54 529.2
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24/02/75  5 206  .67 29.774 29.646 257.8 315.8 .0700 16.70 567.2
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24/02/75  6 207  .67 29.655 29.531 259.5 322.8 .0701 17.33 588.9
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24/02/75  7 208  .67 29.843 29.719 261.4 324.0 .0702 17.91 608.0
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24/02/75  8 209  .67 29.873 29.759 262.4 325.6 .0701 18.42 624.3
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16.53 16.60 16.55 16.55 16.56 16.57 16.60 16.64 16.76 16.74 16.66 16.58 16.58 16.77 16.78 16.73 16.68 16.52 16.58 16.51 16.55 16.55
24/02/75  9 210  .67 29.787 29.690 264.2 325.2 .0689 19.02 639.6
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16.56 16.60 16.57 16.56 16.56 16.58 16.59 16.66 16.78 16.77 16.69 16.61 16.59 16.68 16.82 16.70 19.32 25.67 26.74 26.18 26.73 26.73
25/02/75  1 211  .67 30.141 29.994 263.9 291.2 .0596 10.89 371.2
                                                                                                 14.43 14.60 14.66 14.75 14.72 14.88
14.86 14.89 14.90 14.97 14.93 15.01 15.07 15.06 15.11 15.16 15.06 15.07 15.26 15.26 15.29 15.27 15.27 15.35 15.35 15.35 15.79 15.44
15.50 15.42 15.51 15.56 15.49 15.56 15.54 15.62 15.62 15.52 15.68 15.68 15.70 15.73 15.80 15.77 15.83 15.84 15.86 15.91 15.84 15.80
15.89 15.90 15.97 15.98 16.01 16.11 16.15 16.11 16.17 16.18 16.03 15.93 15.96 16.03 15.77 15.69 15.93 16.14 16.19 16.13 16.11 16.11
25/02/75  2 212  .67 30.050 29.912 266.6 303.2 .0596 12.60 428.1
                                                                                                 15.32 15.56 15.63 15.73 15.70 15.95
15.88 15.90 15.94 16.00 15.96 16.06 16.14 16.15 16.23 16.23 16.15 16.13 16.30 16.29 16.32 16.26 16.27 16.30 16.29 16.27 16.27 16.30
16.35 16.30 16.34 16.36 16.26 16.33 16.27 16.31 16.28 16.18 16.30 16.30 16.28 16.32 16.33 16.30 16.33 16.30 16.33 16.32 16.31 16.26
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16.33	16.37	16.32	16.32	16.30	16.34	16.37	16.43	16.56	16.54	16.45	16.36	16.36	16.52	16.38	16.30	16.38	16.33	16.40	16.32	16.42	16.42
25/02/75	3	213	.67	29.877	29.739	267.8	313.2	.0595	14.12	480.0						16.16	16.35	16.33	16.36	16.32	16.35
16.38	16.34	16.34	16.38	16.33	16.37	16.38	16.34	16.38	16.41	16.34	16.32	16.41	16.41	16.38	16.34	16.33	16.39	16.37	16.34	16.51	16.36
16.43	16.39	16.41	16.41	14.34	16.40	16.34	16.37	16.36	16.27	16.36	16.36	16.34	16.36	16.39	16.33	16.38	16.36	16.36	16.36	16.36	16.29
16.37	16.41	16.38	16.37	16.34	16.37	16.39	16.45	16.56	16.54	16.47	16.40	16.38	16.58	16.49	16.45	16.45	16.38	16.52	16.39	16.49	16.49
25/02/75	4	214	.67	29.753	29.626	269.5	323.4	.0598	15.50	525.9						16.41	16.41	16.40	16.40	16.40	16.42
16.45	16.41	16.40	16.47	16.40	16.44	16.44	16.40	16.44	16.45	16.43	16.41	16.48	16.50	16.46	16.37	16.40	16.44	16.43	16.39	16.54	16.41
16.47	16.43	16.44	16.47	16.38	16.44	16.39	16.41	16.38	16.30	16.40	16.40	16.37	16.41	16.42	16.38	16.43	16.40	16.42	16.41	16.40	16.34
16.39	16.46	16.40	16.41	16.40	16.43	16.44	16.49	16.62	16.60	16.53	16.46	16.44	16.66	16.61	16.56	16.55	16.48	16.65	16.48	16.60	16.60
25/02/75	5	215	.67	29.550	29.506	269.5	324.4	.0598	16.03	544.0						16.43	16.43	16.44	16.45	16.41	16.42
16.43	16.42	16.42	16.48	16.40	16.46	16.46	16.43	16.46	16.48	16.43	16.42	16.51	16.48	16.46	16.40	16.40	16.45	16.44	16.41	16.53	16.43
16.48	16.45	16.44	16.47	16.38	16.44	16.38	16.42	16.40	16.31	16.38	16.39	16.37	16.42	16.44	16.39	16.43	16.40	16.43	16.44	16.40	16.35
16.40	16.44	16.41	16.40	16.41	16.44	16.47	16.52	16.61	16.62	16.54	16.47	16.46	16.68	16.64	16.58	16.56	16.50	16.70	16.49	16.62	16.62
25/02/75	6	216	.67	29.614	29.493	271.8	325.6	.0597	16.72	567.7						16.47	16.46	16.47	16.48	16.44	16.46
16.48	16.44	16.46	16.52	16.46	16.49	16.48	16.48	16.51	16.52	16.47	16.45	16.53	16.52	16.47	16.40	16.42	16.48	16.47	16.42	16.58	16.44
16.49	16.45	16.47	16.49	16.41	16.47	16.41	16.44	16.43	16.33	16.44	16.43	16.42	16.45	16.46	16.41	16.46	16.44	16.44	16.46	16.44	16.38
16.44	16.49	16.46	16.44	16.42	16.46	16.48	16.53	16.66	16.64	16.56	16.49	16.48	16.71	16.68	16.66	16.61	16.57	16.79	16.58	19.88	19.88
25/02/75	7	217	.67	29.592	29.468	272.6	325.6	.0597	16.72	567.2						16.43	16.40	16.43	16.46	16.44	16.46
16.47	16.45	16.44	16.49	16.43	16.47	16.48	16.44	16.47	16.49	16.46	16.43	16.49	16.49	16.46	16.40	16.40	16.44	16.44	16.41	16.55	16.43
16.48	16.44	16.45	16.48	16.41	16.44	16.39	16.43	16.41	16.34	16.42	16.42	16.41	16.43	16.43	16.40	16.46	16.43	16.43	16.45	16.43	16.37
16.43	16.45	16.44	16.43	16.42	16.47	16.47	16.53	16.63	16.61	16.54	16.48	16.47	16.70	16.68	16.64	16.62	16.56	16.77	16.84	21.70	21.70
26/02/75	1	218	.67	29.917	29.806	296.0	320.6	.0461	10.00	336.7						16.12	16.19	16.18	16.28	16.18	16.19
16.22	16.18	16.17	16.22	16.17	16.22	16.20	16.18	16.20	16.24	16.18	16.15	16.26	16.24	16.20	16.16	16.17	16.22	16.22	16.17	16.40	16.20
16.26	16.22	16.24	16.25	16.17	16.23	16.17	16.20	16.18	16.09	16.20	16.20	16.18	16.22	16.23	16.18	16.23	16.18	16.20	16.21	16.20	16.13
16.20	16.24	16.20	16.19	16.17	16.22	16.23	16.27	16.38	16.36	16.30	16.25	16.21	16.36	16.27	16.18	16.28	16.21	16.26	16.19	16.26	16.26
26/02/75	2	219	.67	29.805	29.686	295.6	324.0	.0463	10.92	369.6						16.23	16.23	16.25	16.26	16.22	16.23
16.27	16.22	16.23	16.30	16.22	16.24	16.26	16.24	16.25	16.28	16.24	16.21	16.30	16.28	16.26	16.19	16.19	16.24	16.25	16.20	16.38	16.24
16.28	16.24	16.28	16.28	16.19	16.25	16.19	16.22	16.21	16.13	16.23	16.23	16.22	16.24	16.26	16.20	16.26	16.23	16.23	16.25	16.21	16.17
16.23	16.27	16.22	16.23	16.21	16.24	16.27	16.33	16.45	16.41	16.34	16.27	16.27	16.44	16.33	16.25	16.33	16.26	16.33	16.26	16.31	16.31
26/02/75	3	220	.67	29.651	29.526	294.1	324.8	.0464	11.84	399.9						16.28	16.28	16.27	16.28	16.24	16.27
16.28	16.24	16.24	16.31	16.23	16.26	16.26	16.24	16.26	16.30	16.26	16.24	16.31	16.31	16.28	16.23	16.25	16.28	16.27	16.23	16.40	16.26
16.32	16.28	16.29	16.30	16.20	16.26	16.21	16.24	16.23	16.17	16.27	16.27	16.26	16.27	16.29	16.24	16.27	16.26	16.26	16.26	16.23	16.18
16.24	16.30	16.28	16.26	16.24	16.28	16.30	16.38	16.46	16.46	16.37	16.31	16.30	16.49	16.38	16.32	16.36	16.33	16.40	16.30	16.36	16.36
26/02/75	4	221	.67	29.190	29.082	295.0	324.2	.0464	12.60	425.2						16.23	16.24	16.23	16.25	16.22	16.23
16.24	16.20	16.22	16.26	16.19	16.24	16.26	16.23	16.24	16.24	16.22	16.19	16.26	16.24	16.23	16.18	16.18	16.22	16.22	16.19	16.33	16.21
16.26	16.24	16.22	16.23	16.17	16.23	16.19	16.21	16.20	16.12	16.23	16.21	16.19	16.23	16.23	16.19	16.22	16.20	16.20	16.19	16.20	16.17
16.22	16.27	16.24	16.23	16.19	16.23	16.26	16.33	16.41	16.40	16.34	16.28	16.27	16.46	16.37	16.32	16.33	16.30	16.39	16.28	16.33	16.33
26/02/75	5	222	.67	29.993	29.893	296.6	325.6	.0463	13.45	454.1						16.38	16.38	16.39	16.39	16.38	16.38
16.40	16.36	16.38	16.42	16.36	16.40	16.39	16.35	16.36	16.39	16.36	16.35	16.41	16.40	16.38	16.33	16.34	16.38	16.37	16.33	16.53	16.36
16.42	16.38	16.38	16.42	16.34	16.40	16.34	16.37	16.36	16.28	16.36	16.36	16.34	16.37	16.38	16.33	16.38	16.36	16.36	16.38	16.36	16.31
16.36	16.43	16.38	16.37	16.35	16.40	16.40	16.49	16.57	16.56	16.50	16.43	16.42	16.63	16.57	16.51	16.50	16.48	16.58	16.46	16.48	16.48
26/02/75	6	223	.67	29.886	29.799	296.6	325.8	.0462	14.12	475.3						16.41	16.39	16.39	16.42	16.38	16.40
16.41	16.37	16.39	16.43	16.36	16.41	16.40	16.37	16.39	16.42	16.38	16.37	16.43	16.42	16.39	16.34	16.35	16.39	16.39	16.34	16.52	16.39
16.44	16.40	16.40	16.41	16.36	16.38	16.33	16.39	16.36	16.28	16.36	16.37	16.34	16.37	16.38	16.33	16.38	16.36	16.36	16.38	16.35	16.31
16.36	16.40	16.36	16.36	16.35	16.37	16.41	16.48	16.58	16.57	16.50	16.42	16.42	16.64	16.58	16.53	16.52	16.51	16.67	17.18	19.80	19.80
26/02/75	7	224	.67	29.862	29.759	297.0	325.4	.0462	14.14	474.3						16.40	16.38	16.40	16.38	16.38	16.40
16.42	16.37	16.38	16.42	16.35	16.38	16.38	16.37	16.38	16.39	16.36	16.34	16.43	16.41	16.38	16.34	16.34	16.38	16.39	16.34	16.56	16.38
16.42	16.40	16.41	16.42	16.34	16.41	16.34	16.38	16.36	16.28	16.36	16.38	16.36	16.38	16.40	16.35	16.40	16.36	16.38	16.38	16.36	16.32
16.40	16.44	16.38	16.39	16.38	16.40	16.43	16.48	16.59	16.56	16.50	16.43	16.43	16.63	16.58	16.55	16.56	16.52	16.68	17.73	20.73	20.73
03/03/75	1	225	.27	11.999	11.830	222.4	241.6	.0974	10.98	368.8						11.63	11.72	11.74	11.80	11.77	11.89
11.86	11.86	11.86	11.93	11.88	11.95	11.98	11.98	12.01	12.04	11.95	11.97	12.09	12.10	12.09	12.07	12.09	12.14	12.16	12.14	12.20	12.20
12.26	12.20	12.26	12.30	12.24	12.28	12.26	12.32	12.30	12.23	12.36	12.36	12.37	12.39	12.42	12.40	12.46	12.48	12.47	12.49	12.48	12.43
12.52	12.51	12.55	12.55	12.58	12.63	12.58	12.60	12.68	12.70	12.72	12.51	12.52	12.53	12.46	12.40	12.48	12.60	12.66	12.58	12.47	12.47
03/03/75	2	226	.27	12.583	12.421	229.3	252.4	.0957	11.79	397.9						12.30	12.41	12.43	12.50	12.46	12.60
12.56	12.58	12.58	12.63	12.61	12.67	12.72	12.71	12.73	12.74	12.68	12.68	12.77	12.75	12.73	12.70	12.71	12.74	12.73	12.71	12.76	12.75
12.60	12.75	12.76	12.78	12.71	12.77	12.69	12.74	12.70	12.65	12.73	12.73	12.73	12.76	12.78	12.71	12.76	12.74	12.74	12.76	12.74	12.70
12.75	12.81	12.78	12.77	12.76	12.77	12.81	12.93	13.16	13.09	12.98	12.87	12.89	12.96	13.00	12.92	12.80	12.97	12.90	12.88	12.87	12.87

03/03/75	3	227	.27	11.869	11.705	234.8	254.8	.0899	12.50	421.2						12.78	12.63	12.64	12.64	12.63	12.66
12.66	12.65	12.63	12.71	12.64	12.69	12.69	12.68	12.68	12.72	12.66	12.67	12.73	12.73	12.68	12.65	12.67	12.67	12.67	12.64	12.70	12.67
12.73	12.68	12.68	12.70	12.63	12.68	12.61	12.66	12.63	12.58	12.63	12.64	12.63	12.66	12.68	12.61	12.67	12.63	12.64	12.66	12.65	12.61
12.66	12.72	12.68	12.68	12.67	12.68	12.73	12.87	13.06	13.00	12.89	12.78	12.80	12.89	12.96	12.87	12.73	12.92	12.86	12.79	12.78	12.78
03/03/75	4	228	.27	12.055	11.890	233.8	255.4	.0935	12.67	426.5						12.72	12.69	12.68	12.70	12.68	12.71
12.72	12.71	12.68	12.73	12.68	12.73	12.72	12.70	12.71	12.74	12.70	12.71	12.76	12.77	12.73	12.70	12.70	12.72	12.71	12.68	12.74	12.72
12.77	12.73	12.75	12.75	12.68	12.75	12.68	12.72	12.70	12.66	12.70	12.72	12.70	12.72	12.74	12.67	12.74	12.70	12.70	12.72	12.72	12.68
12.72	12.78	12.73	12.74	12.73	12.76	12.80	12.94	13.13	13.06	12.96	12.86	12.88	12.98	13.04	12.97	12.81	12.99	12.91	12.87	12.90	12.90
03/03/75	5	229	.27	12.088	11.935	235.4	255.7	.0903	13.43	450.7						12.80	12.77	12.76	12.77	12.76	12.80
12.60	12.78	12.77	12.81	12.78	12.80	12.79	12.78	12.78	12.82	12.78	12.79	12.88	12.83	12.77	12.73	12.76	12.77	12.78	12.73	12.78	12.76
12.81	12.76	12.77	12.78	12.71	12.76	12.69	12.73	12.71	12.67	12.73	12.73	12.72	12.74	12.75	12.70	12.76	12.71	12.73	12.74	12.74	12.71
12.73	12.81	12.77	12.76	12.76	12.76	12.80	12.97	13.16	13.10	12.99	12.87	12.89	13.04	13.06	13.00	12.82	13.01	12.93	12.89	12.90	12.90
03/03/75	6	230	.27	12.089	11.957	228.4	256.4	.0662	14.11	473.7						12.78	12.78	12.80	12.80	12.78	12.83
12.63	12.82	12.81	12.86	12.80	12.85	12.84	12.82	12.84	12.86	12.82	12.81	12.86	12.85	12.80	12.78	12.78	12.79	12.79	12.76	12.81	12.78
12.81	12.78	12.78	12.78	12.71	12.75	12.69	12.73	12.70	12.62	12.68	12.68	12.67	12.68	12.66	12.63	12.67	12.66	12.65	12.68	12.66	12.60
12.64	12.66	12.63	12.63	12.64	12.65	12.65	12.60	12.66	12.64	12.64	12.64	12.61	12.62	12.66	12.65	12.62	12.54	12.67	12.55	12.66	12.66
03/03/75	7	231	.27	12.096	11.950	228.8	256.8	.0627	14.62	489.7						12.82	12.82	12.83	12.85	12.83	12.87
12.68	12.84	12.84	12.90	12.83	12.87	12.86	12.84	12.84	12.86	12.82	12.80	12.84	12.83	12.80	12.76	12.78	12.79	12.78	12.74	12.80	12.77
12.82	12.78	12.78	12.79	12.73	12.77	12.70	12.73	12.72	12.64	12.72	12.70	12.70	12.70	12.68	12.64	12.70	12.69	12.68	12.70	12.68	12.63
12.66	12.66	12.66	12.66	12.64	12.67	12.68	12.62	12.69	12.68	12.67	12.66	12.63	12.63	12.68	12.68	12.67	12.56	12.70	12.58	12.68	12.68
03/03/75	8	232	.27	12.101	11.970	229.6	256.0	.0572	15.54	522.5						12.88	12.88	12.89	12.88	12.85	12.88
12.89	12.87	12.84	12.89	12.80	12.88	12.83	12.83	12.83	12.87	12.83	12.81	12.88	12.85	12.82	12.78	12.78	12.82	12.82	12.78	12.83	12.79
12.84	12.81	12.81	12.81	12.76	12.80	12.74	12.78	12.76	12.68	12.74	12.75	12.75	12.76	12.73	12.70	12.76	12.74	12.73	12.77	12.73	12.68
12.72	12.71	12.72	12.70	12.70	12.71	12.73	12.66	12.73	12.73	12.73	12.73	12.70	12.70	12.76	12.76	12.72	12.61	12.78	12.63	12.73	12.73
03/03/75	9	233	.27	12.022	11.901	229.0	256.4	.0535	16.00	539.6						12.91	12.90	12.91	12.89	12.87	12.88
12.89	12.85	12.84	12.88	12.82	12.86	12.85	12.85	12.85	12.87	12.84	12.84	12.88	12.88	12.84	12.80	12.83	12.84	12.84	12.80	12.87	12.83
12.86	12.83	12.82	12.84	12.78	12.82	12.76	12.80	12.78	12.70	12.76	12.78	12.77	12.78	12.77	12.74	12.78	12.77	12.77	12.78	12.76	12.70
12.72	12.73	12.74	12.71	12.71	12.74	12.76	12.71	12.77	12.75	12.75	12.76	12.72	12.73	12.80	12.81	12.76	12.65	12.82	12.68	12.77	12.77
03/03/75	10	234	.27	11.987	11.863	229.0	256.8	.0482	16.72	563.6						12.97	12.94	12.92	12.90	12.86	12.89
12.89	12.87	12.87	12.91	12.84	12.88	12.88	12.86	12.87	12.91	12.88	12.86	12.92	12.92	12.87	12.84	12.84	12.84	12.87	12.84	12.88	12.84
12.89	12.84	12.85	12.87	12.80	12.84	12.78	12.83	12.80	12.75	12.80	12.84	12.79	12.80	12.82	12.76	12.83	12.80	12.80	12.82	12.81	12.75
12.78	12.78	12.80	12.77	12.78	12.78	12.82	12.76	12.83	12.80	12.80	12.80	12.77	12.76	12.88	12.88	12.81	12.68	12.88	12.73	12.83	12.83
03/03/75	11	235	.27	11.938	11.834	226.7	256.4	.0458	17.33	584.8						12.98	12.93	12.95	12.90	12.88	12.89
12.90	12.88	12.88	12.92	12.87	12.88	12.88	12.88	12.90	12.93	12.90	12.90	12.93	12.93	12.90	12.85	12.86	12.89	12.89	12.85	12.90	12.88
12.92	12.87	12.88	12.88	12.83	12.86	12.82	12.84	12.84	12.76	12.83	12.83	12.83	12.84	12.83	12.78	12.84	12.82	12.84	12.84	12.84	12.78
12.82	12.82	12.83	12.80	12.80	12.82	12.84	12.77	12.86	12.84	12.84	12.84	12.97	12.80	12.94	12.96	12.85	12.74	12.96	12.79	12.88	12.88
05/03/75	1	236	.27	12.422	12.241	224.3	243.7	.0965	10.91	366.0						11.70	11.82	11.82	11.88	11.86	11.97
11.95	11.97	11.96	12.00	11.97	12.03	12.07	12.07	12.09	12.12	12.08	12.06	12.19	12.19	12.16	12.19	12.20	12.24	12.26	12.25	12.31	12.32
12.36	12.30	12.35	12.39	12.33	12.40	12.34	12.41	12.40	12.34	12.45	12.46	12.47	12.48	12.53	12.50	12.56	12.56	12.56	12.60	12.56	12.53
12.60	12.63	12.66	12.65	12.65	12.72	12.74	12.74	12.76	12.78	12.73	12.61	12.64	12.66	12.53	12.51	12.62	12.70	12.78	12.65	12.57	12.57
05/03/75	2	237	.27	12.443	12.263	232.4	256.4	.0956	12.63	421.7						12.68	12.79	12.82	12.87	12.82	12.84
12.87	12.83	12.80	12.85	12.81	12.86	12.86	12.83	12.84	12.87	12.82	12.81	12.88	12.88	12.83	12.80	12.83	12.83	12.82	12.78	12.86	12.82
12.89	12.84	12.86	12.85	12.78	12.83	12.76	12.81	12.78	12.72	12.78	12.78	12.77	12.80	12.83	12.76	12.81	12.78	12.78	12.79	12.77	12.73
12.75	12.83	12.80	12.78	12.77	12.79	12.82	12.97	13.14	13.08	13.11	12.84	12.86	13.01	13.15	13.13	12.89	13.03	13.00	12.88	12.86	12.86
05/03/75	3	238	.27	12.258	12.128	241.3	256.3	.0889	14.15	472.5						12.90	12.91	12.92	12.90	12.88	12.91
12.93	12.89	12.88	12.92	12.87	12.90	12.91	12.89	12.88	12.92	12.88	12.88	12.92	12.92	12.86	12.84	12.86	12.88	12.86	12.84	12.88	12.86
12.93	12.88	12.88	12.90	12.84	12.88	12.81	12.86	12.83	12.78	12.84	12.84	12.82	12.85	12.88	12.80	12.86	12.84	12.84	12.84	12.83	12.81
12.86	12.92	12.88	12.86	12.86	12.88	12.91	13.09	13.26	13.19	13.25	12.92	12.92	13.14	13.23	13.21	13.00	13.15	13.15	12.96	12.94	12.94
05/03/75	4	239	.27	12.114	11.896	235.4	256.5	.0880	14.21	474.0						12.84	12.85	12.86	12.83	12.82	12.84
12.85	12.82	12.82	12.86	12.78	12.83	12.82	12.82	12.82	12.84	12.81	12.81	12.86	12.86	12.81	12.79	12.80	12.81	12.82	12.78	12.83	12.79
12.87	12.84	12.82	12.84	12.77	12.83	12.75	12.80	12.78	12.72	12.78	12.79	12.77	12.80	12.81	12.77	12.82	12.79	12.80	12.80	12.79	12.76
12.81	12.88	12.83	12.83	12.83	12.85	12.89	13.20	13.22	13.17	13.22	12.90	12.93	13.08	13.22	13.18	12.97	13.09	13.09	12.91	12.92	12.92
05/03/75	5	240	.27	12.004	11.862	240.6	255.1	.0715	15.52	519.9						12.92	12.89	12.87	12.86	12.83	12.86
12.88	12.84	12.84	12.88	12.83	12.86	12.86	12.85	12.87	12.89	12.84	12.84	12.89	12.88	12.85	12.83	12.83	12.86	12.86	12.81	12.86	12.83
12.89	12.86	12.85	12.87	12.80	12.86	12.78	12.81	12.81	12.74	12.82	12.80	12.79	12.82	12.82	12.77	12.83	12.82	12.83	12.84	12.84	12.80
12.86	12.92	12.88	12.87	12.87	12.88	12.94	13.14	13.30	13.23	13.31	12.95	12.97	13.17	13.30	13.27	13.05	13.18	13.22	13.01	12.99	12.99
05/03/75	6	241	.27	12.359	12.210	236.0	257.4	.0674	15.52	518.8						12.85	12.87	12.86	12.84	12.80	12.84

12.84	12.82	12.82	12.83	12.80	12.67	12.85	12.63	12.53	12.78	12.54	12.78	12.90	12.86	12.85	12.81	12.82	12.67	12.66	12.85	12.88	12.88
12.89	12.83	12.84	12.68	12.83	12.84	12.62	12.65	12.82	12.74	12.83	12.82	12.84	12.83	12.81	12.81	12.83	12.61	12.83	12.63	12.82	12.76
12.80	12.80	12.82	12.79	12.80	12.81	12.83	12.76	12.82	12.81	12.62	12.82	12.81	12.77	12.78	12.76	12.74	12.67	12.82	12.68	12.60	12.80
05/03/75	7	242	.27	12.177	12.043	244.8	256.0	.0589	16.71	560.8						12.93	12.92	12.90	12.91	12.86	12.88
12.89	12.87	12.86	12.68	12.66	12.68	12.68	12.58	12.87	12.90	12.88	12.82	12.92	12.89	12.88	12.86	12.86	12.89	12.88	12.87	12.92	12.89
13.00	12.85	12.92	12.89	13.00	12.84	12.83	12.88	12.86	12.79	12.87	12.88	12.83	12.61	12.82	12.80	12.82	12.81	12.82	12.83	12.61	12.76
12.81	12.79	12.81	12.78	12.78	12.82	12.83	12.63	12.86	12.86	12.84	12.83	12.84	12.84	12.83	12.80	12.78	12.68	12.86	12.71	12.81	12.81
05/03/75	8	243	.27	12.263	12.190	247.2	259.0	.0541	17.86	595.6						12.93	12.93	12.93	12.96	12.93	13.06
13.10	13.04	12.98	12.94	12.88	12.92	12.94	12.93	12.96	13.02	13.25	12.99	13.04	12.95	12.93	12.90	12.92	12.98	13.05	13.19	13.97	13.43
13.16	13.03	12.98	12.97	12.91	12.98	13.03	13.58	13.80	13.09	13.09	13.16	13.36	16.36	15.73	15.56	15.18	14.80	17.66	17.58	17.02	16.74
18.44	18.82	19.74	20.72	20.92	21.53	21.52	21.52	21.57	21.51	19.88	20.18	20.60	20.91	18.94	18.68	18.69	19.21	18.95	18.77	19.76	19.76
05/03/75	9	244	.27	12.095	11.929	249.4	256.0	.0494	17.90	595.6						12.87	12.87	12.84	12.85	12.80	12.64
12.65	12.67	12.82	12.53	12.61	12.86	12.85	12.53	12.85	12.87	12.95	12.76	12.88	12.84	12.84	12.80	12.84	12.89	12.84	12.82	12.86	12.83
12.64	12.84	12.87	12.91	12.90	12.94	13.00	13.08	13.56	20.66	21.36	21.86	22.60	23.08	23.66	24.03	24.39	24.62	24.82	25.00	24.89	25.03
25.20	25.23	25.38	25.42	25.69	25.81	25.88	25.78	25.84	25.70	25.13	24.43	24.45	24.06	22.24	21.49	22.27	22.54	22.03	21.31	21.40	21.40
05/03/75	10	245	.27	11.828	11.726	247.8	254.8	.0465	17.89	601.9						12.84	12.84	12.83	12.83	12.76	12.81
12.62	12.82	12.80	12.81	12.79	12.83	12.83	12.62	12.83	12.83	12.83	12.75	12.86	12.88	12.86	12.78	12.79	12.81	12.80	12.80	12.85	12.82
12.63	12.81	12.81	12.66	12.60	12.83	12.60	12.84	12.84	12.78	12.85	12.85	12.67	12.85	12.92	12.88	12.87	12.86	12.87	12.89	12.88	12.85
12.86	12.86	12.87	12.85	12.90	12.89	12.92	12.91	12.98	13.02	13.01	13.00	12.95	12.93	13.21	13.78	17.04	18.80	19.07	19.15	19.02	19.02
05/03/75	11	246	.27	12.101	12.000	245.8	256.4	.0432	18.48	620.0						12.96	12.93	12.93	12.93	12.89	12.92
12.91	12.93	12.89	12.70	12.89	12.95	12.92	12.92	12.94	12.96	12.93	12.86	12.97	12.97	12.94	12.90	12.91	12.93	12.93	12.90	12.93	12.92
12.90	12.89	12.88	12.92	12.87	12.94	12.87	12.90	12.90	12.84	12.89	12.91	12.92	12.91	12.95	12.91	12.93	12.91	12.93	12.95	12.91	12.88
12.69	12.90	12.92	12.90	12.93	12.98	13.02	13.04	13.28	16.43	18.94	19.44	19.70	20.13	19.93	20.17	20.62	21.37	21.44	21.34	20.99	20.99
05/03/75	12	247	.27	11.977	11.862	243.7	255.7	.0421	19.06	639.2						12.93	12.93	12.93	12.91	12.88	12.91
12.89	12.93	12.89	12.91	12.68	12.92	12.92	12.89	12.91	12.94	12.93	12.84	12.98	12.96	12.94	12.89	12.90	12.91	12.92	12.89	12.94	12.91
12.92	12.89	12.68	12.92	12.65	12.90	12.84	12.58	12.90	12.82	12.88	12.68	12.90	12.89	12.94	12.68	12.90	12.88	12.90	12.91	12.89	12.84
12.88	12.92	12.89	12.91	12.97	13.02	13.21	14.25	19.26	20.63	20.65	20.60	20.78	21.18	20.93	21.13	21.56	22.35	22.34	22.22	21.80	21.80
06/03/75	1	248	.27	12.314	12.136	218.2	236.3	.0960	10.92	363.6						11.39	11.48	11.50	11.57	11.53	11.65
11.62	11.63	11.63	11.68	11.66	11.73	11.75	11.76	11.73	11.81	11.73	11.74	11.66	11.88	11.87	11.86	11.87	11.92	11.91	11.90	11.98	11.98
12.02	11.95	11.98	12.05	11.98	12.02	12.00	12.06	12.07	11.98	12.11	12.12	12.13	12.15	12.21	12.18	12.22	12.22	12.20	12.26	12.24	12.21
12.29	12.30	12.32	12.30	12.33	12.39	12.42	12.39	12.41	12.48	12.40	12.28	12.28	12.32	12.23	12.23	12.38	12.26	12.14	12.19	12.18	12.18
06/03/75	2	249	.27	12.276	12.110	230.8	256.0	.0925	12.85	425.7						12.65	12.78	12.78	12.84	12.78	12.81
12.84	12.81	12.78	12.82	12.78	12.85	12.63	12.62	12.82	12.86	12.60	12.80	12.86	12.86	12.81	12.78	12.80	12.82	12.80	12.78	12.65	12.80
12.69	12.63	12.63	12.65	12.76	12.83	12.74	12.79	12.79	12.69	12.80	12.76	12.77	12.60	12.85	12.77	12.83	12.78	12.77	12.80	12.78	12.76
12.60	12.86	12.81	12.78	12.77	12.81	12.84	12.93	12.98	12.99	12.94	12.64	12.88	12.72	13.04	12.93	12.80	12.73	12.80	12.68	12.93	12.93
06/03/75	3	250	.27	12.096	11.986	249.0	256.6	.0573	12.90	426.7						12.63	12.56	12.62	12.63	12.57	12.60
12.62	12.60	12.59	12.66	12.62	12.67	12.62	12.59	12.61	12.62	12.61	12.55	12.66	12.63	12.62	12.57	12.58	12.63	12.61	12.58	12.64	12.62
12.64	12.60	12.62	12.64	12.58	12.62	12.58	12.63	12.60	12.52	12.60	12.61	12.62	12.61	12.63	12.61	12.63	12.64	12.60	12.66	12.63	12.58
12.60	12.62	12.62	12.60	12.59	12.60	12.64	12.58	12.60	12.65	12.71	12.62	12.49	12.43	12.54	12.50	12.51	12.53	12.58	12.51	12.50	12.50
06/03/75	4	251	.27	12.059	11.948	247.2	256.0	.0538	14.08	468.3						12.73	12.63	12.65	12.68	12.63	12.66
12.67	12.65	12.65	12.70	12.67	12.74	12.68	12.65	12.66	12.70	12.66	12.61	12.72	12.68	12.65	12.64	12.65	12.68	12.68	12.65	12.70	12.66
12.70	12.66	12.68	12.70	12.65	12.69	12.63	12.68	12.66	12.56	12.66	12.64	12.66	12.66	12.67	12.64	12.68	12.69	12.66	12.69	12.67	12.63
12.66	12.66	12.66	12.65	12.63	12.67	12.70	12.64	12.66	12.70	12.69	12.67	12.55	12.47	12.60	12.55	12.54	12.55	12.63	12.53	12.56	12.56
06/03/75	5	252	.27	12.008	11.896	246.3	256.4	.0469	15.51	516.8						12.78	12.71	12.73	12.76	12.71	12.73
12.76	12.73	12.72	12.78	12.75	12.80	12.76	12.73	12.74	12.76	12.74	12.67	12.78	12.76	12.74	12.72	12.72	12.77	12.74	12.71	12.78	12.78
12.77	12.72	12.72	12.77	12.70	12.75	12.69	12.75	12.73	12.63	12.73	12.73	12.73	12.72	12.76	12.71	12.76	12.77	12.73	12.75	12.77	12.70
12.73	12.74	12.74	12.72	12.69	12.75	12.79	12.71	12.74	12.80	12.78	12.76	12.64	12.53	12.70	12.64	12.62	12.63	12.71	12.61	12.62	12.62
06/03/75	6	253	.27	11.961	11.862	245.8	256.2	.0417	16.77	560.9						12.83	12.76	12.80	12.81	12.77	12.80
12.80	12.80	12.80	12.83	12.80	12.83	12.80	12.79	12.80	12.83	12.80	12.74	12.83	12.81	12.81	12.78	12.78	12.82	12.81	12.78	12.83	12.81
12.63	12.80	12.81	12.63	12.78	12.81	12.75	12.60	12.75	12.70	12.78	12.78	12.78	12.78	12.81	12.77	12.80	12.80	12.79	12.82	12.62	12.74
12.72	12.79	12.80	12.79	12.76	12.81	12.84	12.75	12.88	12.88	12.88	12.68	12.71	12.60	12.81	12.77	12.70	12.71	12.80	12.70	12.70	12.70
06/03/75	7	254	.27	11.870	11.769	244.6	255.4	.0372	17.88	599.1						12.88	12.82	12.85	12.86	12.82	12.93
12.85	12.86	12.81	12.88	12.84	12.90	12.87	12.84	12.86	12.88	12.84	12.78	12.89	12.86	12.84	12.83	12.83	12.87	12.86	12.83	12.88	12.88
12.87	12.83	12.85	12.88	12.60	12.85	12.61	12.84	12.64	12.74	12.84	12.84	12.83	12.84	12.86	12.84	12.86	12.87	12.85	12.88	12.86	12.81
12.65	12.87	12.86	12.54	12.81	12.86	12.91	12.87	12.89	12.93	12.94	12.96	12.94	15.08	17.25	18.13	18.82	18.70	19.05	18.78	18.89	18.89

TABLE 22 EXPERIMENTAL DATA FOR BIPHENYL-BIPHENYL OXIDE TEST SERIES

LISTING OF EXPERIMENTAL DATA OBTAINED USING BIPHENYL-BIPHENYL OXIDE

NOTE:-

EACH DATA SET OCCUPIES 4 LINES IN THE FOLLOWING TABLE.APPROXIMATELY HALF OF THE FIRST LINE GIVES IN THE FOLLOWING ORDER :- DATE OF TEST,TEST NO. OF DAY,SERIES TEST NO.,REDUCED PRESSURE,TEST SECTION INLET PRESSURE(BAR),TEST SECTION EXIT PRESSURE(BAR) TEST SECTION INLET TEMP.(DEG C),TEST SECTION EXIT TEMP.(DEG C),FLOWRATE(KG/SEC),TEST SECTION VOLTS,TEST SECTION AMPS. THERE THEN FOLLOWS A SPACE AFTER WHICH 72 TEST SECTION OUTER WALL THERMOCOUPLE READINGS(MV) FROM INLET TO EXIT COMPRISE THE REMAINDER OF THE DATA SET.THE LAST OF THESE THERMOCOUPLE READINGS IS A FICTITIOUS ONE WHICH IS REQUIRED BY THE DATA REDUCTION COMPUTER PROGRAM

18/04/75	1	1	.08	2.621	2.432	232.2	246.6	.0911	10.12	340.9						12.04	12.10	12.13	12.19	12.15	12.26
12.24	12.23	12.22	12.31	12.26	12.32	12.32	12.29	12.28	12.32	12.36	12.29	12.38	12.42	12.39	12.36	12.37	12.38	12.44	12.41	12.48	12.45
12.49	12.49	12.48	12.53	12.46	12.53	12.48	12.54	12.52	12.42	12.59	12.58	12.58	12.59	12.64	12.57	12.63	12.62	12.65	12.67	12.67	12.60
12.68	12.71	12.70	12.70	12.70	12.73	12.80	12.74	12.75	12.74	12.73	12.78	12.75	12.78	12.74	12.66	12.85	12.74	12.82	12.78	12.87	12.87
18/04/75	2	2	.08	2.650	2.472	240.0	264.8	.0897	12.69	431.1						13.33	13.48	13.51	13.58	13.57	13.62
13.66	13.67	13.70	13.77	13.74	13.82	13.83	13.77	13.76	13.83	13.86	13.88	13.91	13.94	13.91	13.88	13.90	13.96	14.00	13.99	14.05	14.04
14.08	14.03	14.08	14.13	14.06	14.12	14.08	14.16	14.17	14.04	14.21	14.30	14.20	14.25	14.29	14.23	14.31	14.31	14.33	14.36	14.36	14.30
14.40	14.44	14.43	14.43	14.44	14.48	14.57	14.50	14.52	14.51	14.50	14.58	14.53	14.57	14.56	14.46	14.66	14.54	14.62	14.60	14.71	14.71
18/04/75	3	3	.08	2.681	2.503	246.6	277.8	.0891	14.11	479.9						14.30	14.48	14.54	14.60	14.60	14.66
14.73	14.75	14.77	14.87	14.82	14.91	14.92	14.88	14.87	14.93	14.97	14.99	15.05	15.08	15.07	15.05	15.08	15.11	15.17	15.18	15.26	15.24
15.29	15.28	15.28	15.34	15.26	15.33	15.29	15.39	15.22	15.02	15.26	15.12	15.16	15.26	15.32	15.09	15.09	15.10	15.05	15.08	15.12	15.12
15.19	15.23	15.22	15.23	15.16	15.18	15.26	15.24	15.32	15.30	15.27	15.38	15.35	15.32	15.22	15.22	15.41	15.27	15.34	15.26	15.38	15.38
18/04/75	4	4	.08	2.712	2.532	248.4	286.2	.0910	15.55	526.7						15.05	15.12	15.07	14.98	14.89	14.90
14.92	14.92	14.92	14.96	14.96	14.96	14.90	14.86	14.93	15.04	15.06	14.98	14.99	15.03	14.97	14.90	14.94	14.98	15.01	14.97	15.04	15.03
15.06	15.06	15.09	15.17	15.04	15.09	15.05	15.08	15.16	15.07	15.21	15.20	15.21	15.22	15.23	15.17	15.23	15.25	15.26	15.30	15.40	15.30
15.41	15.48	15.43	15.41	15.42	15.46	15.52	15.49	15.46	15.45	15.44	15.54	15.54	15.56	15.52	15.43	15.60	15.50	15.59	15.53	15.70	15.70
18/04/75	5	5	.08	2.779	2.601	250.6	295.4	.0861	16.75	572.0						15.06	15.06	15.08	15.11	15.08	15.13
15.16	15.16	15.17	15.20	15.16	15.20	15.18	15.14	15.18	15.19	15.22	15.19	15.23	15.24	15.23	15.14	15.18	15.22	15.26	15.24	15.28	15.26
15.29	15.28	15.28	15.36	15.27	15.33	15.31	15.34	15.34	15.23	15.38	15.37	15.38	15.42	15.44	15.39	15.46	15.43	15.48	15.51	15.61	15.53
15.62	15.66	15.63	15.62	15.65	15.68	15.74	15.75	15.75	15.73	15.72	15.80	15.80	15.84	15.81	15.77	15.88	15.78	15.88	15.83	15.97	15.97
22/04/75	1	6	.07	2.459	2.281	239.6	268.9	.0934	14.09	476.4						13.94	14.00	14.07	14.15	14.14	14.20
14.27	14.28	14.31	14.41	14.39	14.46	14.46	14.40	14.42	14.47	14.50	14.51	14.60	14.63	14.60	14.57	14.58	14.64	14.68	14.67	14.76	14.74
14.79	14.79	14.80	14.84	14.76	14.83	14.81	14.89	14.90	14.76	14.96	14.96	14.96	14.99	15.05	14.99	15.07	15.07	15.09	15.13	15.12	15.08
15.18	15.22	15.20	15.20	15.23	15.30	15.32	15.15	15.15	15.17	15.20	15.25	15.15	15.23	15.26	15.24	15.26	15.11	15.05	15.08	15.30	15.30
22/04/75	2	7	.07	2.436	2.257	239.8	277.6	.0927	15.44	525.3						14.58	14.78	14.88	14.96	14.96	14.97
14.94	14.82	14.88	14.94	14.90	14.95	14.92	14.82	14.68	14.73	14.78	14.78	14.78	14.72	14.68	14.61	14.60	14.65	14.68	14.68	14.68	14.66
14.65	14.68	14.66	14.74	14.66	14.70	14.66	14.68	14.69	14.57	14.77	14.74	14.74	14.77	14.82	14.74	14.79	14.78	14.84	14.91	14.96	14.80
14.92	15.01	15.07	15.02	15.03	15.04	15.13	15.14	15.09	15.09	15.10	15.21	15.24	15.26	15.22	15.14	15.28	15.18	15.28	15.26	15.41	15.41
22/04/75	3	8	.07	2.432	2.254	241.0	284.6	.0920	16.73	566.1						14.41	14.59	14.65	14.71	14.63	14.70
14.73	14.79	14.83	14.93	14.89	14.94	14.90	14.86	14.83	14.90	14.94	14.81	14.94	14.92	14.89	14.83	14.84	14.88	14.93	14.89	14.92	14.91
14.93	14.93	14.90	15.02	14.93	14.96	14.93	14.96	14.97	14.96	15.03	15.00	15.00	15.03	15.08	15.00	15.05	15.07	15.12	15.14	15.23	15.13
15.21	15.30	15.28	15.26	15.27	15.29	15.35	15.37	15.35	15.34	15.33	15.42	15.44	15.48	15.47	15.41	15.53	15.47	15.54	15.53	15.68	15.68
22/04/75	4	9	.07	2.424	2.247	244.0	291.6	.0918	17.81	605.7						14.76	14.76	14.77	14.82	14.82	14.89
14.93	14.97	14.95	15.05	14.98	15.05	14.99	14.98	14.99	15.02	15.07	15.00	15.06	15.08	15.10	14.98	15.03	15.06	15.09	15.07	15.09	15.13
15.15	15.13	15.12	15.21	15.10	15.16	15.17	15.18	15.19	15.08	15.25	15.23	15.22	15.25	15.30	15.22	15.30	15.30	15.37	15.37	15.48	15.37
15.46	15.54	15.52	15.50	15.51	15.55	15.61	15.61	15.63	15.62	15.61	15.68	15.73	15.76	15.75	15.67	15.80	15.71	15.81	15.77	15.92	15.92
22/04/75	5	10	.07	2.425	2.248	240.2	293.8	.0870	18.42	623.9						14.84	14.85	14.87	14.90	14.86	14.92
14.93	14.93	14.93	15.00	14.92	14.98	14.96	14.93	14.94	14.98	14.98	14.98	15.03	15.07	15.07	15.02	15.05	15.11	15.17	15.12	15.17	15.20
15.20	15.17	15.19	15.26	15.16	15.21	15.20	15.23	15.24	15.14	15.28	15.28	15.27	15.29	15.34	15.28	15.36	15.38	15.43	15.45	15.56	15.46
15.57	15.63	15.61	15.59	15.62	15.65	15.73	15.73	15.75	15.72	15.72	15.81	15.88	15.89	15.83	15.80	15.92	15.83	15.94	15.87	16.06	16.06
24/04/75	1	11	.11	3.801	3.673	249.0	288.6	.0818	15.54	522.3						15.30	15.53	15.61	15.70	15.71	15.77
15.65	15.68	15.93	16.03	16.02	16.09	16.10	16.03	16.06	16.10	16.11	16.13	16.16	16.14	16.10	16.06	16.09	16.11	16.11	16.10	16.14	16.12
16.16	16.13	16.14	16.18	16.09	16.16	16.12	16.14	16.20	16.02	16.17	16.18	16.16	16.16	16.20	16.13	16.19	16.18	16.19	16.20	16.26	16.16
16.25	16.32	16.29	16.26	16.25	16.31	16.35	16.28	16.29	16.29	16.29	16.37	16.42	16.42	16.43	16.37	16.48	16.40	16.48	16.44	16.62	16.62
24/04/75	2	12	.11	3.781	3.606	249.4	295.6	.0814	16.63	561.2						15.90	16.18	16.30	16.35	16.28	16.28
16.30	16.29	16.23	16.30	16.25	16.29	16.26	16.22	16.20	16.26	16.26	16.23	16.28	16.28	16.24	16.19	16.22	16.27	16.26	16.21	16.27	16.26
16.27	16.26	16.26	16.28	16.20	16.26	16.23	16.26	16.27	16.13	16.30	16.29	16.27	16.30	16.33	16.27	16.33	16.32	16.33	16.37	16.44	16.34
16.42	16.51	16.46	16.46	16.46	16.46	16.53	16.50	16.50	16.49	16.48	16.57	16.62	16.62	16.62	16.54	16.66	16.58	16.68	16.64	16.80	16.80
24/04/75	3	13	.11	3.767	3.592	251.8	306.1	.0828	17.86	601.9						16.30	16.30	16.31	16.33	16.32	16.35

16.38	16.35	16.38	16.42	16.34	16.40	16.38	16.33	16.40	16.37	16.36	16.36	16.39	16.38	16.35	16.32	16.33	16.36	16.38	16.34	16.38	16.38
16.39	16.38	16.32	16.43	16.34	16.40	16.36	16.40	16.40	16.28	16.44	16.45	16.43	16.48	16.54	16.46	16.49	16.49	16.54	16.56	16.65	16.51
16.62	16.68	16.65	16.64	16.64	16.67	16.73	16.71	16.73	16.72	16.71	16.80	16.83	16.87	16.83	16.75	16.91	16.81	16.92	16.89	17.04	17.04
24/04/75	4	14	.11	3.761	3.589	250.2	312.4	.0839	18.99	642.7						16.40	16.43	16.42	16.44	16.40	16.44
16.46	16.44	16.45	16.50	16.44	16.48	16.47	16.43	16.43	16.47	16.47	16.43	16.51	16.49	16.46	16.40	16.43	16.45	16.49	16.44	16.49	16.48
16.52	16.48	16.49	16.54	16.47	16.53	16.50	16.56	16.54	16.44	16.70	16.59	16.59	16.62	16.66	16.60	16.66	16.68	16.68	16.73	16.82	16.70
16.81	16.87	16.84	16.81	16.84	16.88	16.93	16.92	16.96	16.94	16.92	17.02	17.04	17.07	17.06	17.00	17.16	17.07	17.19	17.14	17.30	17.30
24/04/75	5	15	.11	3.760	3.586	250.4	314.6	.0847	19.48	658.5						16.42	16.42	16.43	16.43	16.40	16.44
16.48	16.44	16.47	16.50	16.46	16.48	16.48	16.43	16.43	16.48	16.48	16.41	16.51	16.51	16.48	16.43	16.45	16.48	16.52	16.50	16.54	16.54
16.55	16.53	16.54	16.60	16.52	16.58	16.57	16.58	16.60	16.49	16.68	16.66	16.66	16.69	16.74	16.67	16.76	16.76	16.79	16.80	16.89	16.78
16.88	16.98	16.93	16.95	16.94	16.96	17.04	17.04	17.06	17.05	17.05	17.14	17.15	17.20	17.18	17.11	17.27	17.18	17.28	17.24	17.40	17.40
24/04/75	6	16	.11	3.759	3.586	245.8	315.2	.0649	19.85	671.2						16.46	16.46	16.46	16.48	16.47	16.47
16.49	16.48	16.48	16.53	16.46	16.51	16.53	16.46	16.46	16.49	16.49	16.48	16.51	16.54	16.49	16.46	16.50	16.50	16.53	16.50	16.54	16.53
16.57	16.58	16.56	16.62	16.53	16.60	16.58	16.62	16.63	16.51	16.68	16.66	16.67	16.69	16.74	16.68	16.74	16.75	16.78	16.80	16.92	16.80
16.90	16.98	16.96	16.94	16.94	16.96	17.04	17.03	17.06	17.04	17.03	17.15	17.16	17.19	17.15	17.14	17.25	17.20	17.30	17.25	17.43	17.43
24/04/75	7	17	.11	3.736	3.565	247.8	320.0	.0873	20.91	706.9						16.56	16.54	16.54	16.55	16.53	16.54
16.57	16.56	16.58	16.58	16.57	16.60	16.60	16.53	16.54	16.57	16.60	16.57	16.61	16.61	16.59	16.80	16.58	16.60	16.63	16.61	16.66	16.66
16.68	16.70	16.70	16.75	16.67	16.72	16.70	16.75	16.77	16.66	16.83	16.80	16.80	16.86	16.92	16.86	16.94	16.95	17.00	17.01	17.11	17.02
17.09	17.18	17.17	17.14	17.19	17.21	17.28	17.28	17.31	17.28	17.26	17.35	17.37	17.38	17.33	17.29	17.44	17.34	17.46	17.38	17.55	17.55
24/04/75	8	18	.11	3.708	3.545	251.2	320.6	.0661	19.11	644.7						16.47	16.45	16.47	16.48	16.47	16.50
16.50	16.50	16.50	16.54	16.48	16.52	16.52	16.46	16.47	16.49	16.50	16.48	16.53	16.52	16.50	16.44	16.49	16.53	16.56	16.52	16.57	16.60
16.60	16.59	16.62	16.66	16.58	16.64	16.62	16.62	16.67	16.56	16.72	16.68	16.70	16.74	16.76	16.72	16.81	16.79	16.84	16.88	17.00	16.87
16.97	17.06	17.02	17.00	17.05	17.07	17.14	17.16	17.18	17.15	17.13	17.22	17.24	17.25	17.20	17.19	17.31	17.21	17.33	17.26	17.44	17.44
24/04/75	9	19	.11	3.748	3.593	252.4	323.1	.0662	19.68	661.3						16.50	16.50	16.51	16.51	16.50	16.50
16.53	16.50	16.52	16.56	16.51	16.54	16.54	16.48	16.49	16.54	16.55	16.52	16.57	16.58	16.57	16.52	16.54	16.60	16.62	16.60	16.65	16.63
16.65	16.64	16.66	16.72	16.63	16.70	16.67	16.72	16.72	16.62	16.79	16.80	16.78	16.84	16.88	16.82	16.90	16.88	16.94	16.95	17.08	16.94
17.04	17.14	17.11	17.09	17.11	17.13	17.22	17.22	17.24	17.22	17.19	17.28	17.28	17.28	17.23	17.22	17.34	17.26	17.37	17.30	17.47	17.47
24/04/75	10	20	.11	3.748	3.576	259.5	324.2	.0652	19.85	667.2						16.56	16.57	16.57	16.58	16.54	16.59
16.59	16.58	16.60	16.64	16.60	16.63	16.64	16.58	16.58	16.63	16.66	16.63	16.70	16.70	16.68	16.64	16.66	16.70	16.75	16.74	16.79	16.78
16.82	16.81	16.80	16.88	16.82	16.86	16.87	16.89	16.93	16.83	17.01	16.98	16.98	17.05	17.10	17.04	17.12	17.10	17.17	17.17	17.34	17.15
17.26	17.23	17.27	17.22	17.24	17.23	17.30	17.29	17.32	17.28	17.23	17.32	17.33	17.32	17.25	17.26	17.36	17.28	17.38	17.30	17.47	17.47
25/04/75	1	21	.14	4.766	4.601	270.4	318.6	.0723	15.64	524.5						16.93	17.22	17.30	17.14	17.08	17.12
17.14	17.12	17.14	17.19	17.12	17.19	17.17	17.10	17.12	17.15	17.15	17.13	17.20	17.17	17.14	17.08	17.11	17.15	17.18	17.13	17.17	17.16
17.16	17.17	17.17	17.17	17.12	17.16	17.13	17.16	17.17	17.00	17.18	17.16	17.14	17.19	17.21	17.14	17.22	17.19	17.23	17.25	17.33	17.20
17.30	17.36	17.33	17.29	17.30	17.35	17.40	17.37	17.38	17.35	17.33	17.43	17.48	17.46	17.43	17.39	17.54	17.45	17.55	17.49	17.67	17.67
25/04/75	2	22	.14	4.759	4.597	269.2	326.0	.0736	16.70	561.1						17.22	17.23	17.23	17.22	17.21	17.24
17.22	17.23	17.25	17.28	17.24	17.28	17.26	17.19	17.22	17.23	17.24	17.22	17.27	17.27	17.23	17.17	17.21	17.23	17.24	17.23	17.27	17.25
17.27	17.28	17.27	17.27	17.20	17.27	17.23	17.28	17.28	17.14	17.32	17.31	17.29	17.32	17.37	17.31	17.38	17.38	17.38	17.42	17.51	17.38
17.47	17.55	17.52	17.49	17.49	17.55	17.62	17.57	17.60	17.58	17.56	17.66	17.68	17.68	17.65	17.63	17.78	17.68	17.79	17.74	17.90	17.90
25/04/75	3	23	.14	4.755	4.596	267.4	332.4	.0736	17.85	598.4						17.30	17.30	17.29	17.30	17.27	17.31
17.34	17.31	17.31	17.38	17.28	17.35	17.32	17.25	17.28	17.30	17.31	17.29	17.35	17.36	17.30	17.26	17.27	17.31	17.33	17.30	17.35	17.35
17.38	17.37	17.36	17.38	17.40	17.38	17.35	17.38	17.40	17.24	17.42	17.41	17.40	17.46	17.51	17.44	17.52	17.52	17.56	17.58	17.68	17.55
17.67	17.73	17.71	17.69	17.68	17.73	17.80	17.76	17.81	17.79	17.78	17.88	17.87	17.87	17.85	17.81	17.96	17.88	18.00	17.92	18.10	18.10
25/04/75	4	24	.14	4.734	4.583	269.2	339.2	.0735	19.12	641.2						17.40	17.41	17.42	17.40	17.38	17.42
17.43	17.41	17.41	17.46	17.39	17.46	17.42	17.36	17.38	17.40	17.41	17.38	17.48	17.44	17.40	17.38	17.41	17.43	17.46	17.45	17.50	17.50
17.52	17.51	17.53	17.51	17.49	17.56	17.52	17.58	17.60	17.47	17.67	17.65	17.65	17.71	17.76	17.70	17.78	17.78	17.83	17.86	17.97	17.82
17.93	18.03	17.98	17.95	17.96	17.98	18.03	18.00	18.01	17.92	17.92	18.01	18.00	18.01	17.93	17.92	18.06	17.94	18.07	17.98	18.16	18.16
25/04/75	5	25	.14	4.755	4.592	278.0	341.0	.0724	19.80	667.5						17.52	17.52	17.53	17.52	17.49	17.53
17.56	17.51	17.54	17.60	17.54	17.62	17.57	17.53	17.55	17.58	17.59	17.58	17.66	17.68	17.67	17.63	17.65	17.69	18.00	17.71	17.78	17.80
17.64	17.84	17.61	17.81	17.81	17.88	17.83	17.89	17.92	17.78	17.98	17.93	17.92	17.96	18.02	17.95	17.99	17.98	18.03	18.05	18.18	18.00
18.09	18.16	18.12	18.07	18.08	18.09	18.13	18.09	18.13	17.93	18.03	18.14	18.10	18.11	18.03	18.06	18.17	18.06	18.18	18.09	18.28	18.28
25/04/75	6	26	.14	4.752	4.549	308.6	341.0	.0525	19.85	666.5						17.81	17.83	17.84	17.89	17.85	17.83
17.94	17.93	17.96	18.01	17.93	17.98	17.96	17.87	17.90	17.89	17.91	17.89	17.93	17.97	17.94	17.89	17.88	17.93	17.95	17.94	17.97	17.96
17.98	17.96	17.94	17.94	17.91	17.97	17.91	17.93	17.97	17.82	17.99	17.94	17.94	17.96	18.02	17.92	18.00	17.98	18.00	18.04	18.17	18.00
18.09	18.16	18.12	18.07	18.08	18.09	18.14	18.10	18.12	17.93	18.03	18.14	18.20	18.13	18.08	18.05	18.18	18.09	18.18	18.12	18.31	18.31
25/04/75	7	27	.14	4.760	4.597	318.8	341.0	.0523	19.84	667.6						17.97	17.97	17.96	17.96	17.93	17.93
18.00	17.98	17.98	18.02	17.93	17.99	17.97	17.88	17.89	17.90	17.92	17.90	17.93	17.98	17.94	17.90	17.89	17.93	17.96	17.94	17.96	17.95

17.98	17.96	17.92	18.02	17.90	17.96	17.89	17.95	17.97	17.82	17.98	17.93	17.94	17.96	18.10	17.90	17.93	17.94	18.01	18.00	18.13	17.98
18.06	18.15	18.10	18.05	18.06	18.09	18.19	18.39	18.70	21.29	24.19	25.08	25.42	25.82	26.13	26.18	26.69	26.71	27.00	27.15	27.46	27.46
29/04/75	1	28	.15	5.091	4.924	266.6	313.2	.0730	15.61	522.4						16.60	16.91	17.06	17.17	17.19	17.27
17.38	17.36	17.38	17.44	17.38	17.42	17.36	17.27	17.28	17.31	17.33	17.30	17.38	17.38	17.33	17.28	17.27	17.34	17.35	17.32	17.36	17.34
17.35	17.37	17.36	17.40	17.30	17.36	17.33	17.34	17.34	17.18	17.38	17.37	17.35	17.37	17.42	17.40	17.42	17.40	17.42	17.46	17.56	17.39
17.49	17.55	17.53	17.50	17.49	17.60	17.73	17.63	17.85	17.80	17.76	17.76	17.68	17.66	17.77	17.60	17.67	17.63	17.64	17.60	17.60	17.60
29/04/75	2	29	.15	4.858	4.689	267.8	324.2	.0723	16.74	560.5						17.40	17.53	17.26	17.24	17.20	17.22
17.26	17.26	17.26	17.33	17.26	17.32	17.31	17.24	17.28	17.28	17.28	17.26	17.32	17.32	17.29	17.23	17.25	17.30	17.31	17.28	17.32	17.31
17.33	17.34	17.33	17.40	17.29	17.33	17.32	17.34	17.35	17.20	17.39	17.36	17.36	17.36	17.42	17.36	17.42	17.42	17.46	17.46	17.58	17.45
17.56	17.62	17.60	17.57	17.60	17.67	17.80	17.90	18.02	17.98	17.95	17.94	17.88	17.85	18.03	17.84	17.89	17.86	17.86	17.82	17.85	17.85
29/04/75	3	30	.16	5.236	5.072	269.2	332.2	.0732	17.83	597.9						17.60	17.60	17.62	17.62	17.64	17.63
17.63	17.60	17.63	17.67	17.61	17.64	17.65	17.60	17.62	17.62	17.63	17.61	17.67	17.67	17.64	17.58	17.60	17.63	17.64	17.63	17.66	17.64
17.67	17.67	17.63	17.71	17.62	17.68	17.67	17.69	17.69	17.55	17.72	17.71	17.68	17.70	17.77	17.72	17.77	17.78	17.80	17.83	17.94	17.80
17.90	17.97	17.96	17.90	17.96	18.02	18.16	18.25	18.48	18.43	18.38	18.36	18.36	18.28	18.49	18.28	18.30	18.28	18.27	18.22	18.26	18.26
29/04/75	4	31	.16	5.271	5.109	271.0	342.2	.0755	19.11	638.9						17.73	17.74	17.74	17.73	17.70	17.72
17.74	17.73	17.74	17.78	17.74	17.78	17.77	17.69	17.74	17.80	17.75	17.73	17.80	17.80	17.77	17.73	17.76	17.80	17.83	17.79	17.84	17.84
17.85	17.83	17.82	17.89	17.78	17.84	17.82	17.86	17.87	17.73	17.90	17.89	17.89	17.93	17.97	17.93	18.00	18.01	18.04	18.08	18.18	18.06
18.16	18.26	18.23	18.21	18.24	18.33	18.45	18.48	18.66	18.60	18.55	18.57	18.59	18.47	18.70	18.46	18.46	18.43	18.42	18.36	18.42	18.42
29/04/75	5	32	.16	5.325	5.168	268.6	343.6	.0766	19.47	652.4						17.78	17.78	17.77	17.77	17.74	17.79
17.79	17.78	17.80	17.84	17.78	17.81	17.81	17.75	17.77	17.79	17.80	17.78	17.84	17.86	17.82	17.76	17.79	17.83	17.86	17.81	17.86	17.90
17.86	17.85	17.85	17.93	17.83	17.90	17.86	17.90	17.91	17.78	17.98	17.95	17.95	18.00	18.07	18.01	18.08	18.08	18.11	18.14	18.26	18.14
18.26	18.33	18.32	18.29	18.31	18.40	18.49	18.48	18.68	18.62	18.57	18.57	18.64	18.48	18.73	18.49	18.48	18.46	18.46	18.38	18.49	18.49
29/04/75	6	33	.15	5.367	5.207	298.5	343.0	.0600	19.82	664.0						17.76	17.80	17.80	17.83	17.80	17.82
17.87	17.89	17.92	17.97	17.90	17.98	17.98	17.89	17.93	17.96	18.00	17.96	18.05	18.08	18.05	18.01	18.04	18.08	18.12	18.09	18.14	18.14
18.18	18.15	18.12	18.22	18.11	18.18	18.13	18.15	18.18	18.04	18.20	18.16	18.20	18.20	18.23	18.16	18.18	18.19	18.23	18.23	18.38	18.22
18.30	18.40	18.35	18.30	18.34	18.38	18.44	18.33	18.51	18.32	18.39	18.40	18.44	18.33	18.49	18.30	18.29	18.26	18.28	18.19	18.30	18.30
29/04/75	7	34	.16	4.800	4.645	320.8	341.8	.0517	19.84	659.6						18.04	18.03	18.04	18.07	18.01	18.05
18.07	18.07	18.08	18.10	18.04	18.08	18.06	17.97	18.00	18.00	18.00	17.98	18.02	18.06	18.00	17.96	17.98	18.02	18.03	18.03	18.06	18.02
18.07	18.08	18.00	18.13	18.01	18.07	18.03	18.03	18.07	17.94	18.08	18.04	18.03	18.05	18.09	18.01	18.06	18.07	18.09	18.11	18.25	18.09
18.18	18.29	18.23	18.18	18.24	18.32	18.51	18.70	20.98	22.85	24.64	25.32	25.60	25.84	26.20	26.12	26.70	26.70	26.98	27.13	27.43	27.43
02/05/75	1	35	.15	4.885	4.723	284.4	333.6	.0531	14.23	472.4						17.36	17.70	17.80	17.68	17.52	17.54
17.55	17.51	17.55	17.58	17.52	17.60	17.57	17.49	17.53	17.54	17.55	17.51	17.58	17.58	17.58	17.50	17.52	17.54	17.57	17.55	17.58	17.58
17.59	17.57	17.57	17.63	17.53	17.58	17.53	17.58	17.57	17.40	17.60	17.60	17.58	17.62	17.66	17.58	17.66	17.64	17.68	17.78	17.80	17.63
17.74	17.81	17.76	17.77	17.76	17.80	17.88	18.00	18.28	18.24	18.20	18.13	18.15	18.07	18.02	17.85	18.00	17.95	17.88	17.88	17.86	17.86
02/05/75	2	36	.15	4.812	4.699	324.0	343.0	.0328	14.80	488.5						17.81	17.80	17.82	17.80	17.76	17.79
17.82	17.79	17.82	17.85	17.78	17.87	17.82	17.74	17.77	17.76	17.79	17.71	17.61	17.83	17.80	17.73	17.80	17.80	17.81	17.80	17.82	17.80
17.83	17.82	17.80	17.90	17.78	17.84	17.80	17.82	17.93	17.68	17.83	17.81	17.78	17.82	17.86	17.78	17.86	17.84	17.88	17.89	18.02	17.87
17.96	18.03	18.00	17.97	18.01	18.06	18.04	18.02	18.24	18.22	18.20	18.10	18.13	18.03	18.05	17.89	18.01	17.92	17.94	17.94	17.97	17.97
02/05/75	3	37	.15	4.814	4.688	330.0	342.8	.0255	15.66	520.0						17.93	17.89	17.90	17.87	17.82	17.86
17.88	17.84	17.88	17.90	17.83	17.90	17.88	17.80	17.84	17.81	17.84	17.82	17.85	17.89	17.87	17.80	17.82	17.87	17.88	17.86	17.88	17.88
17.88	17.86	17.84	17.95	17.82	17.88	17.84	17.84	17.87	17.73	17.87	17.86	17.83	17.86	17.89	17.83	17.89	17.89	17.92	17.94	18.06	17.91
17.98	18.08	18.07	18.00	18.06	18.12	18.10	18.09	18.30	18.28	18.27	18.15	18.18	18.13	18.14	17.98	18.08	18.03	18.04	18.02	18.06	18.06
02/05/75	4	38	.15	4.780	4.639	331.6	342.2	.0245	16.11	535.5						17.98	17.93	17.92	17.91	17.88	17.92
17.93	17.90	17.93	17.95	17.87	17.93	17.92	17.83	17.86	17.83	17.86	17.83	17.83	17.90	17.88	17.80	17.82	17.88	17.89	17.87	17.91	17.91
17.92	17.91	17.89	18.00	17.66	17.93	17.89	17.90	17.92	17.77	17.93	17.90	17.87	17.91	17.93	17.86	17.91	17.90	17.95	17.97	18.09	17.93
18.04	18.10	18.08	18.02	18.08	18.14	18.13	18.11	18.35	18.32	18.30	18.20	18.23	18.18	18.20	18.05	18.13	18.11	18.06	17.63	17.76	17.76

TABLE 23 DERIVED EXPERIMENTAL DATA FOR MONOCHLOROBENZENE TEST SERIES

TEST NO.	MASS VEL. KG/S M**2	HEAT FLUX KW/M**2	SUB-COOL KJ/KG	EXIT PRESS MN/M**2	PRESS DROP KN/M**2	EXIT QUAL	AXIAL DISTANCE FROM START OF HEATING - M. / INNER WALL TEMPERATURE - C														
							.025	.152	.279	.406	.533	.660	.787	.914	1.041	1.167	1.294	1.421	1.548	1.675	1.802
1	829.1	23.5	86.7	.529	27.9		170.3	177.0	172.8	174.4	175.8	176.2	176.9	177.9	178.3	179.5	179.9	181.6	182.0	181.4	183.6
2	828.3	23.3	87.0	.529	26.2		170.1	173.2	172.7	174.0	175.4	176.0	176.8	177.7	177.9	179.3	179.7	181.0	181.8	181.4	183.6
3	845.0	51.0	108.7	.534	32.2		173.4	179.7	179.1	181.6	183.9	184.9	186.6	188.2	189.1	191.1	192.2	195.1	196.6	196.2	198.7
4	845.0	51.1	108.3	.528	32.2		173.4	179.5	179.1	181.8	184.1	185.3	186.4	188.0	189.3	191.1	191.8	195.1	196.4	196.4	198.9
5	820.3	50.1	58.7	.515	18.3		196.5	202.4	201.8	204.3	206.4	207.5	208.6	210.1	209.0	209.0	209.2	210.1	209.8	209.0	211.1
6	818.7	68.1	53.9	.510	8.1		207.2	211.0	209.8	210.8	210.8	210.2	211.0	211.0	210.4	211.0	211.3	212.1	211.5	210.6	212.1
7	778.2	100.2	64.4	.540	37.4	.06	214.3	215.6	215.1	216.4	216.9	216.4	216.6	216.4	215.8	216.0	216.4	216.9	216.0	214.7	216.9
8	774.2	100.0	58.5	.527	27.5	.08	213.2	214.5	214.1	215.6	215.6	215.4	215.6	215.4	214.9	215.3	215.3	215.8	215.3	214.3	215.8
9	705.0	136.5	68.7	.560	44.8	.19	218.9	220.6	220.2	221.7	221.7	221.2	221.2	220.6	219.7	219.9	219.9	220.4	219.5	218.4	219.7
10	613.5	135.6	57.1	.545	33.9	.29	217.7	219.4	219.0	220.3	220.5	219.8	219.8	219.4	218.3	218.7	218.5	218.8	218.3	217.2	218.1
11	553.8	177.7	72.4	.547	41.6	.45	220.2	221.1	220.9	222.2	221.7	221.3	221.1	220.9	220.2	220.2	219.8	220.7	219.4	218.9	219.8
12	790.9	50.9	28.7	.537	31.4	.05	216.7	216.3	216.3	217.2	217.2	216.5	217.0	216.7	216.3	216.3	216.7	217.0	216.1	214.4	217.6
13	784.5	51.1	28.6	.531	38.0	.05	216.8	215.9	215.7	217.0	216.7	216.5	216.8	216.5	216.1	216.1	216.5	216.7	215.9	214.4	217.2
14	784.5	51.0	27.1	.536	31.7	.06	218.2	216.1	216.1	216.8	216.5	216.1	216.7	216.5	216.1	216.3	216.5	216.7	216.1	214.2	217.4
15	662.0	89.3	26.0	.538	20.1	.21	217.4	218.8	218.6	219.9	219.1	218.4	219.1	218.4	217.6	217.4	217.8	218.0	217.3	215.6	219.1
16	669.9	87.5	30.3	.538	35.1	.19	217.5	218.3	218.5	219.0	218.7	218.3	218.5	217.5	217.5	217.5	217.5	217.5	216.6	215.5	219.0
17	679.5	86.6	32.2	.537	35.9	.17	217.2	218.1	218.1	218.9	218.5	218.3	218.5	217.8	217.4	218.5	216.6	217.8	216.6	216.1	221.7
18	825.1	70.9	61.4	.539	21.8		208.0	214.8	214.0	215.3	215.5	215.3	215.7	215.5	215.0	215.1	215.9	216.3	215.7	214.6	220.0
19	829.9	71.1	60.0	.539	21.4		208.9	215.5	214.6	215.5	215.9	215.3	215.5	215.5	214.9	215.3	215.9	216.6	215.7	214.8	220.0
20	825.1	87.7	62.4	.543	35.4	.02	217.3	216.6	215.8	217.5	217.7	217.1	217.5	217.3	217.0	217.3	217.7	217.7	217.0	215.8	221.3
21	785.3	88.0	62.1	.543	35.2	.03	217.7	216.8	215.8	217.5	217.7	217.1	217.5	217.3	216.9	217.1	217.3	217.7	216.8	215.6	221.2
22	707.3	127.5	62.4	.539	32.9	.17	217.1	219.0	218.6	220.3	219.7	219.0	219.4	219.2	218.4	218.4	218.2	218.8	217.9	216.9	222.5
23	697.8	126.8	62.3	.540	35.7	.18	217.2	218.7	218.5	220.1	219.6	219.2	219.2	218.8	217.9	218.3	218.5	219.0	217.9	217.0	222.8
24	517.2	175.5	58.8	.540	44.3	.54	220.3	220.8	220.6	222.1	221.8	221.0	220.6	219.7	219.3	219.5	219.1	219.9	219.1	218.0	219.3
25	537.9	174.0	64.5	.536	42.0	.48	220.0	220.9	221.8	221.8	221.5	220.9	220.3	220.0	219.2	219.0	219.2	220.0	219.0	218.5	220.0
26	487.7	212.6	64.5	.537	39.9	.72	221.1	221.7	221.7	223.5	222.4	221.9	221.5	220.6	219.4	219.3	219.8	222.4	376.3	448.6	465.8
27	506.8	211.5	60.0	.536	25.4	.69	222.3	221.6	221.4	223.0	222.5	221.9	221.4	220.6	219.9	220.1	220.2	222.7	288.7	444.0	460.7
28	812.4	34.9	27.5	.550	33.8	.01	212.4	216.1	216.1	217.8	218.5	216.3	216.9	215.9	215.4	215.2	215.7	215.2	218.5	211.4	214.2
29	812.4	35.1	24.7	.549	32.6	.02	213.9	218.0	217.4	218.4	217.6	216.3	217.0	215.7	215.2	215.4	215.5	215.2	218.5	211.6	214.8
30	783.7	50.3	24.2	.549	31.6	.07	220.1	216.9	216.7	219.0	217.8	217.2	217.4	217.2	216.5	216.5	216.5	216.5	221.5	212.8	215.6
31	736.8	67.8	26.7	.550	34.8	.12	217.2	217.9	217.7	218.7	218.5	217.9	217.9	217.5	216.8	216.8	217.2	217.3	216.0	214.2	216.6
32	693.5	87.2	26.5	.546	33.6	.20	218.1	219.7	218.3	219.2	218.9	218.5	218.5	218.1	217.0	217.4	217.4	217.2	217.4	214.2	216.8
33	680.3	87.8	23.7	.547	34.9	.21	218.3	218.5	219.3	219.0	218.8	218.3	218.8	217.9	217.3	217.0	217.0	217.0	217.5	214.7	217.0
34	594.4	106.9	23.9	.545	37.3	.32	219.2	219.0	218.7	220.0	219.6	218.7	218.7	218.1	217.7	217.5	217.5	217.7	218.5	215.9	218.3
35	592.0	107.0	20.5	.547	38.9	.34	219.4	218.8	218.7	220.0	219.6	219.0	218.7	218.5	217.5	217.5	218.1	218.1	218.5	215.5	217.9
36	540.3	123.5	27.2	.543	38.9	.41	219.4	219.2	219.0	220.3	220.1	219.0	219.0	218.8	217.9	217.9	217.9	218.6	219.2	216.6	218.8
37	540.3	123.5	28.8	.543	39.4	.41	219.4	219.4	219.0	220.1	220.1	219.2	219.0	218.8	218.2	218.1	218.2	218.6	219.0	216.6	218.6
38	475.8	143.4	26.0	.543	41.1	.58	219.5	219.7	219.5	220.7	220.3	219.5	219.5	219.0	218.4	218.4	218.6	219.5	220.3	217.1	219.5
39	476.6	142.6	28.0	.542	41.2	.57	219.8	219.8	219.6	220.7	220.1	219.6	219.4	218.8	218.7	218.5	218.3	219.4	219.6	216.6	219.6
40	443.2	160.7	24.5	.543	41.5	.72	220.2	219.8	219.7	221.2	220.8	219.8	219.7	219.3	218.4	218.7	218.7	219.8	220.6	217.8	219.3
41	443.2	163.2	21.6	.543	43.6	.74	220.3	220.3	220.1	221.2	220.3	220.1	219.4	219.2	218.2	218.2	218.4	219.4	220.1	216.7	220.7
42	452.7	165.3	29.1	.542	42.3	.70	219.8	220.2	219.8	221.3	220.7	219.6	219.8	219.3	218.9	218.5	218.7	219.6	219.4	215.7	262.4
43	640.5	22.9	62.4	.543	33.2		187.5	191.3	191.1	193.0	194.2	194.6	195.9	196.9	197.2	198.4	199.1	200.6	202.6	201.2	201.8
44	639.7	23.0	60.9	.543	34.3		189.4	192.4	192.1	194.2	195.3	195.5	197.0	198.0	198.8	199.9	200.8	202.0	202.7	202.7	203.5
45	636.5	23.4	21.0	.542	30.8	.02	210.1	213.3	213.1	214.8	216.5	216.7	215.4	214.2	213.7	213.9	213.7	213.9	215.0	211.2	215.7
46	636.5	23.8	19.9	.542	28.3	.02	210.8	214.6	215.0	215.9	215.3	214.6	215.0	214.2	213.8	214.0	213.6	213.8	217.0	210.8	215.0
47	646.5	51.3	64.0	.543	34.5		204.4	212.3	212.7	213.8	213.5	212.5	213.5	212.9	212.9	212.7	213.3	213.6	220.2	212.1	220.9
48	647.7	51.4	62.5	.543	33.9		205.2	213.6	212.5	213.3	213.8	212.7	213.4	213.1	212.9	212.9	213.6	213.6	215.7	212.3	220.6
49	619.8	50.1	22.1	.536	29.4	.11	215.8	215.8	215.0	216.3	216.1	215.8	215.9	215.8	214.8	214.6	214.6	214.3	215.4	211.6	216.5
50	624.6	88.3	61.2	.536	30.5	.09	216.6	215.6	215.2	217.1	217.5	217.1	217.1	216.9	216.6	216.4	216.2	216.4	217.7	214.5	221.8
51	624.6	88.3	61.1	.535	32.4	.09	216.2	215.6	218.8	216.9	217.3	216.9	216.9	216.9	216.2	216.2	216.0	216.0	217.3	214.1	221.4
52	512.4	90.4	16.2	.536	32.8	.34	217.8	217.8	217.0	218.1	218.3	217.4	217.0	217.0	216.3	215.5	215.9	215.5	216.8	213.8	219.3

53	512.4	90.8	16.4	.536	32.0	.33	217.6	217.9	217.0	218.3	218.1	217.4	216.8	216.8	216.3	215.9	216.1	215.7	217.0	213.8	219.6
54	829.9	23.9	101.9	.991	20.4		195.8	198.7	198.3	199.8	201.2	201.2	202.7	203.3	203.8	204.6	204.6	206.1	208.2	206.3	206.5
55	822.7	41.8	92.2	.990	34.4		210.9	215.2	214.8	216.9	219.1	219.7	221.0	222.5	223.4	224.9	225.3	227.5	228.6	228.6	228.1
56	812.4	66.2	85.7	.991	32.2		227.8	234.6	233.9	236.8	240.1	241.4	243.2	245.2	247.1	246.1	246.5	247.1	248.5	245.8	251.2
57	810.8	89.8	80.5	.990	32.6		240.6	247.5	246.8	247.9	248.6	247.9	248.2	247.9	247.7	247.5	247.3	248.8	250.2	247.3	255.3
58	825.1	42.5	104.6	.983	21.7		202.7	207.3	207.5	209.4	211.4	212.0	213.3	214.6	215.9	217.1	217.6	219.9	220.8	220.2	219.7
59	826.7	69.8	104.8	.983	20.2		216.1	223.6	223.0	226.6	229.7	230.8	232.5	235.1	236.9	238.6	239.7	243.7	244.8	243.9	243.0
60	811.6	83.7	78.5	.997	21.8		240.3	247.6	247.2	249.1	249.1	248.2	249.1	248.2	248.2	248.3	249.6	249.8	251.4	248.9	256.5
61	807.6	105.8	71.0	.994	18.1	.03	251.7	250.2	249.9	251.3	250.8	250.4	251.0	250.0	249.9	249.9	250.0	251.1	252.6	249.9	257.7
62	793.3	122.6	72.4	.990	18.6	.08	251.8	251.5	250.9	252.7	252.2	251.5	252.2	251.5	252.2	250.4	250.6	251.5	252.9	250.2	258.2
63	779.7	122.6	65.2	.990	20.0	.11	250.9	251.6	250.9	252.4	252.2	251.5	252.0	251.3	250.4	250.0	250.2	251.1	252.7	250.0	257.6
64	795.7	142.2	82.2	.997	19.9	.09	251.1	252.2	251.8	253.1	252.6	251.8	252.4	251.7	251.1	250.9	251.3	252.2	253.5	250.9	259.1
65	719.3	161.3	67.7	.990	19.9	.26	252.6	253.7	253.0	254.0	253.5	252.4	253.0	252.2	251.7	251.7	251.5	252.4	253.9	251.1	259.1
66	775.8	156.9	82.5	.990	25.9	.15	251.7	252.6	252.1	253.0	252.8	252.1	252.4	252.1	251.5	251.3	251.5	252.4	254.1	251.3	259.3
67	798.8	40.8	71.4	.990	18.6		221.6	226.5	225.7	228.3	230.0	230.5	232.2	233.3	234.6	235.7	236.8	238.6	239.4	239.4	238.8
68	798.0	69.1	68.8	.990	21.7		236.9	244.5	244.3	247.4	248.5	247.7	248.3	247.9	247.9	247.9	248.1	248.8	250.7	248.3	255.2
69	795.7	86.6	66.6	.990	19.1		246.6	249.5	248.8	250.2	250.0	249.5	249.8	249.5	249.1	248.9	249.1	249.7	251.5	248.9	255.8
70	779.0	106.2	64.2	.987	19.1	.07	250.4	250.8	250.2	251.9	251.3	250.8	251.3	250.6	250.2	250.0	250.4	250.8	252.9	250.4	257.7
71	748.7	123.3	61.3	.990	21.2	.15	250.5	251.8	251.1	252.9	252.2	251.8	251.4	251.1	250.5	250.3	250.3	251.1	253.2	250.3	258.1
72	748.7	122.3	61.1	.990	19.5	.14	250.4	251.7	251.1	252.9	252.0	251.5	251.5	251.1	250.7	250.4	250.4	250.7	252.9	250.4	258.2
73	711.3	140.4	60.9	.990	22.0	.22	251.7	253.0	251.9	253.5	252.6	252.1	252.1	251.4	251.0	250.5	250.6	251.4	253.4	250.6	258.3
74	690.6	161.3	62.7	.990	22.7	.30	251.9	253.1	252.0	253.7	253.0	252.6	252.0	251.9	251.7	251.1	251.3	251.9	254.0	251.1	259.5
75	642.9	173.7	58.0	.991	25.7	.41	252.9	253.3	252.6	254.2	253.5	252.9	253.1	252.9	252.4	252.0	252.0	252.7	254.7	252.2	259.6
76	740.8	48.8	48.0	.969	19.2		238.6	244.1	244.5	247.2	246.9	245.6	245.8	246.5	246.1	246.3	246.9	247.2	246.1	246.5	253.0
77	735.2	41.3	48.4	.969	18.5		236.0	240.6	240.6	243.2	244.8	244.6	246.1	245.6	245.4	245.4	246.1	246.5	248.1	245.7	251.8
78	731.2	50.0	40.3	.963	19.3	.01	243.9	247.2	246.4	247.5	247.5	246.8	247.5	247.0	246.8	246.8	247.2	247.5	249.0	246.8	253.2
79	725.6	66.1	41.9	.997	18.1	.06	252.3	250.0	249.8	250.9	250.9	250.0	250.3	249.8	249.8	249.8	250.2	250.3	252.3	250.0	256.9
80	699.4	86.7	39.5	.990	16.6	.14	250.2	250.6	250.4	251.8	251.5	250.7	250.9	250.2	249.8	249.8	249.8	250.4	252.4	249.8	256.7
81	701.8	86.4	37.5	.990	17.3	.14	250.2	250.9	250.2	251.5	251.1	250.2	250.8	250.0	249.5	249.5	249.7	249.7	251.5	249.1	255.7
82	662.8	105.8	35.5	.983	17.7	.24	250.8	251.0	250.6	251.7	251.5	250.8	250.8	250.2	250.1	249.7	249.9	250.6	252.8	250.1	257.5
83	667.6	103.8	40.5	.983	18.3	.21	250.7	251.1	250.3	251.6	251.1	250.5	250.9	250.3	250.0	249.8	250.1	250.7	252.7	250.1	257.4
84	631.8	123.7	37.3	.983	18.8	.32	251.8	251.4	251.0	252.5	252.0	251.0	251.4	250.9	250.3	250.3	250.5	250.9	253.2	250.3	257.9
85	605.5	139.0	36.5	.984	23.4	.40	252.5	252.0	251.6	253.1	252.9	251.8	252.2	251.4	251.3	250.9	251.4	251.6	254.0	251.1	259.0
86	578.4	165.3	36.0	.983	20.3	.53	252.4	252.0	251.7	253.5	253.0	252.2	252.4	252.0	251.7	251.7	251.7	252.0	254.2	251.3	258.9
87	570.5	172.5	37.0	.980	22.8	.57	252.6	252.3	251.9	253.3	253.2	252.4	252.8	252.3	252.1	251.7	251.7	252.3	254.3	251.2	254.8
88	570.5	174.7	36.7	.984	18.9	.58	252.5	252.3	252.0	253.4	253.1	252.2	252.7	252.5	252.2	251.8	251.8	252.2	254.5	251.1	254.7
89	682.7	41.4	42.7	.985	17.8		240.6	245.6	245.9	247.2	247.6	246.8	247.6	247.2	246.8	247.2	247.6	248.1	249.6	246.8	253.0
90	681.1	49.9	41.5	.983	18.1	.01	246.4	248.1	247.9	248.6	248.3	247.9	248.8	248.3	247.9	248.1	248.1	248.3	250.1	247.7	254.1
91	679.5	49.8	35.7	.977	16.4	.03	248.4	247.9	247.9	248.8	248.6	248.3	249.0	248.3	247.9	248.1	248.1	248.4	250.1	247.7	254.1
92	675.5	68.0	39.2	.999	17.1	.08	250.7	250.5	250.5	251.4	251.3	250.3	250.9	250.3	249.8	250.2	250.3	250.7	251.8	249.4	256.5
93	669.2	68.5	35.9	.993	18.4	.10	250.3	250.3	250.3	251.6	251.0	250.3	250.7	250.3	250.0	249.8	250.0	250.7	252.1	250.0	256.7
94	643.7	85.7	35.4	.993	16.7	.18	250.8	251.2	251.0	251.9	251.7	250.6	251.2	250.6	249.7	249.7	249.9	250.1	252.1	249.9	256.8
95	627.0	85.8	28.5	1.000	19.0	.21	251.7	251.9	251.3	252.4	251.9	251.2	251.7	251.2	250.8	250.4	250.6	251.0	253.0	250.4	257.5
96	607.9	88.2	18.7	.991	16.9	.27	251.4	251.2	251.0	252.1	251.8	251.0	252.0	251.2	250.5	250.9	250.7	251.4	253.2	250.7	257.4
97	607.9	103.3	28.3	.993	14.0	.29	251.6	251.1	250.9	252.3	252.0	250.9	251.3	251.1	250.3	250.3	250.2	250.9	253.1	250.7	257.8
98	581.6	122.6	28.5	.992	17.9	.39	251.8	251.5	251.1	252.7	251.8	251.3	251.6	251.1	250.6	250.9	250.7	251.6	253.6	250.9	258.7
99	554.6	140.1	30.2	.992	17.1	.48	252.3	251.9	251.9	253.2	252.8	251.9	252.3	251.6	251.2	251.2	251.4	251.7	254.1	251.6	259.9
100	522.0	160.5	24.5	.985	17.5	.63	252.3	252.1	252.3	253.7	253.0	252.3	252.8	251.9	251.7	251.9	251.5	252.3	254.4	251.7	253.4
101	522.7	160.4	27.3	.985	19.4	.62	251.9	252.1	251.9	253.7	253.4	252.3	253.0	251.9	251.7	251.5	251.4	251.9	254.3	251.5	253.7
102	500.5	174.3	21.0	.986	17.2	.74	252.4	252.4	252.5	253.8	253.3	252.7	253.1	252.4	251.8	251.8	251.6	252.4	254.4	266.5	373.6
103	499.7	174.7	20.8	.986	15.5	.74	252.2	252.3	252.0	253.8	253.1	252.7	252.9	252.5	251.8	251.8	251.6	252.3	254.3	356.3	360.2
104	493.3	175.1	19.1	.986	19.2	.76	252.3	252.3	252.1	254.0	253.4	252.5	252.5	252.0	251.2	251.4	251.2	252.0	256.7	391.0	369.4
105	493.3	175.8	17.9	.986	17.8	.77	252.3	252.1	251.9	253.6	253.2	252.3	252.8	252.1	251.6	251.6	251.2	251.9	254.7	392.4	390.3
106	795.7	13.4	122.5	1.693	12.2		215.1	218.3	218.1	219.0	219.8	219.6	220.7	221.2	221.6	222.0	222.2	222.9	223.7	223.3	223.7
107	794.9	31.7	129.5	1.718	16.9		225.4	228.9	228.6	230.4	231.9	232.2	233.7	234.6	235.8	236.7	237.4	238.9	241.4	240.3	239.8
108	790.9	23.1	116.9	1.752	16.4		227.5	229.9	229.7	231.4	232.3	232.3	233.6	234.1	234.5	235.6	236.0	237.3	238.7	237.3	237.4
109	782.9	41.4	103.1	1.752	17.7		244.6	248.7	248.8	250.8	252.7	253.0	254.8	255.6	256.8	258.1	259.2	261.0	261.3	261.9	261.0

110	778.2	49.5	86.8	1.680	16.4	
111	771.0	59.4	88.1	1.745	15.1	
112	770.2	69.0	81.9	1.737	15.7	
113	773.4	75.7	86.5	1.738	15.4	
114	767.0	85.2	87.7	1.767	17.2	
115	763.8	105.5	82.1	1.777	15.2	
116	747.1	123.8	76.1	1.779	15.7	
117	751.9	121.8	76.7	1.782	14.0	
118	630.2	136.9	58.2	1.779	15.7	.10
119	784.5	41.1	118.7	1.806	17.4	.09
120	779.0	50.4	113.4	1.827	14.8	.33
121	776.6	59.0	101.6	1.840	19.4	
122	770.2	68.1	99.1	1.847	18.6	
123	765.4	76.8	98.7	1.855	16.9	
124	770.2	85.4	99.7	1.861	19.1	
125	775.0	94.3	93.6	1.861	17.1	
126	776.6	104.8	87.3	1.861	17.8	
127	783.7	111.6	96.1	1.860	18.5	
128	807.6	122.2	95.6	1.854	18.4	
129	833.1	131.2	106.6	1.847	16.8	
130	861.7	142.0	103.2	1.855	17.6	
131	787.7	67.9	113.6	1.822	19.2	
132	781.3	85.1	96.1	1.820	17.3	
133	784.5	105.1	84.6	1.792	17.4	
134	800.4	112.2	100.9	1.840	17.8	
135	810.0	123.5	100.5	1.840	17.4	
136	817.9	132.5	98.4	1.834	18.0	
137	830.7	139.9	103.3	1.832	17.4	
138	845.0	149.1	111.7	1.818	16.1	
139	858.5	159.4	116.0	1.821	20.1	
140	866.5	167.2	121.5	1.816	18.2	
141	873.6	173.0	122.8	1.812	17.1	
142	886.4	187.6	130.4	1.807	20.9	
143	771.8	67.2	93.1	1.773	18.2	
144	768.6	85.0	85.2	1.786	18.2	
145	768.6	103.8	81.7	1.791	17.2	
146	775.0	111.9	93.3	1.793	16.7	
147	774.2	123.2	93.6	1.787	17.1	
148	785.3	131.5	98.7	1.778	16.7	
149	790.1	140.6	106.0	1.781	17.5	
150	689.8	48.7	84.1	1.820	17.4	
151	683.5	67.1	72.6	1.816	17.4	
152	690.3	76.7	65.8	1.811	16.7	.01
153	684.3	86.0	69.2	1.809	15.6	.02
154	676.3	105.2	69.7	1.808	15.8	.10
155	649.3	121.6	62.3	1.809	15.8	.22
156	638.1	137.9	61.2	1.806	15.3	.31
157	616.6	159.0	57.6	1.812	14.0	.44
158	624.6	159.4	57.3	1.809	13.4	.43
159	607.1	159.4	54.2	1.803	13.1	.47
160	662.0	49.3	89.0	1.812	12.2	
161	654.0	67.9	67.2	1.792	16.2	
162	651.6	77.2	60.8	1.781	13.3	.04
163	647.7	77.4	62.9	1.781	16.6	.04
164	648.5	84.3	64.9	1.781	15.6	.05
165	633.3	104.5	60.5	1.781	15.3	.17
166	595.2	122.0	48.1	1.783	14.4	.34

253.6	258.6	258.8	261.2	263.1	263.9	265.8	266.9	268.2	269.6	270.7	273.0	273.2	274.1	273.0
261.4	266.8	267.2	270.0	272.4	273.1	274.9	276.7	278.3	280.4	280.9	284.0	284.1	284.1	283.6
268.5	275.7	275.9	279.1	281.6	282.6	284.1	283.7	283.5	283.9	283.9	284.4	286.2	285.8	291.0
270.9	278.2	278.4	281.8	283.8	283.9	284.6	284.5	284.1	284.3	284.5	285.0	287.1	286.1	292.1
275.5	283.3	283.5	285.8	286.0	285.5	286.5	285.8	285.6	285.6	285.8	286.5	288.7	287.9	294.7
287.0	287.2	287.0	288.1	287.9	287.0	288.5	287.6	287.4	287.4	287.8	288.1	290.2	289.7	296.8
288.0	288.7	288.7	289.8	289.4	288.7	289.2	288.5	287.7	288.4	287.7	289.1	290.3	290.7	298.1
288.1	288.6	288.4	289.5	289.3	288.6	289.3	288.6	287.7	288.3	288.1	288.8	291.1	290.6	297.6
288.9	289.3	288.8	289.8	289.5	288.6	289.3	289.1	288.8	288.4	288.8	289.1	291.2	290.9	297.2
238.1	241.4	241.5	243.7	245.4	245.6	247.6	248.3	249.6	250.9	251.6	253.8	254.1	254.7	253.9
248.8	253.0	253.0	255.7	257.3	258.2	260.2	261.5	262.7	264.4	264.7	267.6	267.8	268.7	267.2
258.6	263.1	263.2	265.8	268.3	269.0	271.0	272.6	274.2	276.1	277.2	280.2	280.2	281.5	279.7
265.5	271.1	271.6	274.5	277.3	278.6	280.2	282.3	283.9	287.5	287.5	288.4	289.6	289.1	289.9
274.5	279.4	280.0	283.2	286.0	287.3	289.0	289.2	288.5	289.0	289.0	289.7	291.9	291.5	296.8
278.0	284.0	284.0	287.8	289.9	289.2	289.7	289.7	289.4	289.7	290.1	290.4	292.5	292.4	298.2
284.0	288.8	288.8	290.4	290.6	289.8	290.7	290.4	290.0	290.4	290.7	291.1	293.7	293.6	299.7
291.1	291.0	290.3	291.5	291.5	291.0	291.9	291.1	290.8	291.1	291.1	291.9	294.0	294.0	300.1
291.0	291.2	290.7	291.7	292.1	290.8	291.7	291.4	291.0	291.2	291.4	291.7	293.9	294.0	300.4
291.1	291.1	290.9	292.0	292.0	291.3	291.8	291.4	291.3	291.1	291.3	291.8	294.1	294.3	301.0
290.0	290.9	290.3	291.6	291.6	291.0	291.7	291.0	290.7	290.9	291.0	291.6	293.5	294.0	301.1
290.9	291.4	291.1	292.2	291.8	291.3	292.2	291.4	290.9	290.9	291.1	291.8	293.6	294.3	301.0
254.7	261.2	260.7	263.2	265.4	266.3	268.2	269.8	271.5	273.8	274.5	278.1	278.1	279.1	277.0
272.6	280.9	280.9	284.9	286.5	285.3	286.4	286.0	285.7	285.8	286.2	286.7	289.0	289.2	295.0
286.9	287.1	286.9	288.1	288.0	287.6	288.1	287.8	287.2	287.6	288.0	288.5	290.8	291.0	297.3
285.2	288.7	288.5	289.8	289.8	289.1	289.9	289.6	289.2	289.2	289.8	290.1	292.4	292.9	299.5
289.4	289.6	289.1	290.3	290.1	289.6	290.5	290.3	289.8	290.0	290.3	290.5	293.3	293.7	300.4
289.6	290.1	289.4	291.0	290.6	290.1	291.0	290.8	290.1	290.1	290.6	290.8	293.5	294.0	300.5
289.4	290.1	289.6	291.0	290.7	290.1	290.8	290.7	290.1	290.3	290.5	290.7	292.8	294.2	300.9
289.2	289.7	289.2	290.8	290.6	290.1	290.6	290.4	290.1	290.1	290.1	290.8	292.9	293.8	300.8
289.6	290.1	289.3	291.0	290.9	290.1	290.7	290.3	289.6	289.8	290.1	290.7	293.2	294.0	301.3
289.3	290.0	289.4	291.2	291.0	290.3	290.9	290.5	290.2	290.0	290.3	290.7	292.8	293.9	301.3
289.4	290.4	289.5	291.5	290.8	290.4	290.8	290.4	289.7	289.9	290.1	290.6	292.6	293.8	301.4
289.8	290.5	289.3	291.4	291.0	290.7	290.8	290.3	290.0	290.0	289.8	290.1	292.4	293.1	301.3
263.4	269.7	269.9	273.3	275.8	276.7	278.8	280.4	282.4	284.3	285.0	284.9	287.0	286.1	287.2
277.7	285.3	284.9	286.9	287.4	286.7	287.3	286.9	286.5	286.7	286.9	287.3	289.9	290.3	295.0
287.8	288.2	287.7	288.9	288.9	288.2	289.1	288.5	288.0	288.0	288.0	288.4	290.7	291.5	296.7
287.3	288.4	287.5	288.9	289.1	288.4	288.9	288.4	288.2	287.8	288.0	288.5	290.7	291.7	297.4
288.0	288.7	287.9	289.3	289.4	288.6	289.1	288.7	288.4	288.0	288.4	288.2	291.2	292.3	297.9
288.4	288.9	288.2	289.4	289.4	289.1	289.1	288.7	288.2	288.2	288.5	288.5	291.2	292.4	298.3
288.3	289.0	288.0	289.6	289.6	289.0	289.4	288.7	288.3	288.3	288.1	288.7	290.8	292.4	297.9
263.5	269.3	269.5	272.1	274.1	275.0	276.6	277.9	279.5	281.1	282.1	284.6	284.8	285.5	284.4
279.2	286.5	286.5	288.0	287.9	287.5	288.0	287.9	287.2	287.5	288.0	288.0	290.9	291.1	295.8
288.0	288.3	288.0	289.2	288.9	288.3	288.9	288.7	288.1	288.1	288.5	288.9	291.3	291.7	296.4
289.3	289.0	288.4	289.7	289.5	289.0	289.7	288.8	288.4	288.4	288.6	289.0	291.3	292.3	297.3
289.9	290.1	289.5	290.2	290.6	289.4	290.2	289.5	289.2	289.2	289.5	289.2	292.2	293.8	299.1
290.2	290.6	289.9	290.9	290.6	289.9	289.5	289.7	289.5	289.2	289.5	289.9	292.5	293.8	299.9
290.2	290.4	289.9	290.7	290.7	289.9	290.4	290.4	288.4	289.3	290.0	290.6	292.9	293.6	299.2
291.2	291.1	290.0	291.4	291.1	290.7	291.1	290.7	288.6	289.6	289.8	290.7	291.1	291.8	393.8
290.9	290.9	290.1	291.4	291.0	290.3	290.7	290.7	289.6	290.0	290.0	290.7	291.0	290.9	393.4
291.0	290.9	290.0	291.0	291.0	290.3	290.7	290.5	289.8	290.0	290.0	290.5	290.7	291.9	398.9
262.2	267.8	267.8	270.5	273.0	273.5	275.5	276.8	278.2	280.0	280.9	283.5	283.7	284.1	282.8
282.0	287.3	286.8	288.0	287.7	287.1	288.0	287.7	286.9	286.9	287.5	287.3	289.1	290.0	293.7
289.0	288.3	287.4	288.7	288.7	287.8	288.5	288.0	287.2	287.4	287.6	287.8	290.1	290.8	294.7
288.3	288.1	287.4	288.8	288.7	287.6	288.1	287.8	287.2	287.2	287.2	287.6	290.1	290.8	294.5
288.0	288.3	287.6	288.5	288.7	287.8	288.3	287.8	287.3	287.6	287.6	287.6	290.1	291.0	295.2
288.9	289.2	288.5	289.6	289.0	288.3	288.7	288.3	287.6	287.8	287.8	288.3	290.8	292.0	296.6
289.5	289.3	288.6	289.5	289.5	288.1	288.4	288.6	288.1	288.4	288.6	288.6	291.4	293.0	298.3

167	539.5	131.6	39.5	1.782	12.3	.48	289.6	288.9	288.2	289.6	289.1	288.7	289.1	288.7	288.2	289.2	288.4	288.5	290.7	288.4	301.4
168	532.3	136.9	38.5	1.782	13.4	.52	289.7	289.0	288.5	289.7	289.5	288.8	289.4	288.8	288.7	288.5	288.5	288.8	290.4	288.7	373.1
169	531.5	136.6	39.6	1.782	12.3	.52	289.6	289.0	288.5	289.7	289.9	288.9	289.2	289.0	288.9	288.5	288.3	288.7	290.5	288.9	370.4
170	522.7	140.5	37.3	1.782	12.0	.56	289.2	289.0	288.3	289.7	289.6	289.0	289.4	289.0	288.5	288.3	288.2	288.3	289.4	401.1	392.1
171	642.9	50.3	84.8	1.827	17.2		266.2	272.4	272.8	275.6	277.6	278.7	280.6	282.1	283.5	285.6	286.5	287.6	289.1	288.4	289.1
172	634.9	67.6	69.6	1.825	17.7		284.1	288.6	288.0	289.3	289.3	288.4	289.3	288.6	288.2	288.6	288.6	288.9	291.4	291.9	300.2
173	635.7	77.2	67.7	1.817	16.6	.02	288.9	289.0	288.8	289.7	289.7	289.0	289.7	289.2	288.3	288.5	289.0	289.0	291.1	292.4	300.6
174	639.7	85.3	66.8	1.797	24.8	.05	289.4	289.7	289.4	290.4	289.9	289.0	289.5	289.2	287.8	286.0	289.2	289.4	291.5	292.9	301.7
175	641.3	85.4	74.1	1.817	14.2	.02	288.3	289.2	288.5	289.5	289.4	288.7	289.4	288.8	288.5	288.3	288.7	289.0	291.1	292.5	301.3
176	627.0	106.7	66.1	1.809	14.2	.16	289.1	289.7	288.2	285.9	290.0	289.8	290.2	289.8	289.1	289.3	289.5	289.7	292.1	294.2	304.3
177	618.2	122.8	63.6	1.814	18.3	.25	289.8	288.8	289.5	290.7	290.5	289.5	290.4	289.8	287.3	288.8	289.5	289.8	292.5	294.8	305.3
178	614.3	126.0	66.1	1.802	21.6	.27	289.2	288.2	289.4	290.5	290.1	289.4	289.9	289.6	289.2	289.4	289.2	287.5	292.2	294.7	306.0
179	733.6	49.0	201.4	3.067	16.6		248.3	254.3	254.1	256.8	258.6	259.2	261.2	262.6	263.7	265.3	266.0	268.5	268.9	268.9	268.9
180	724.1	67.6	185.2	3.052	17.1		267.5	275.4	275.2	278.8	281.3	282.3	284.1	286.6	288.2	290.3	291.0	294.7	294.7	295.4	294.2
181	716.1	84.5	170.8	3.031	15.4		282.3	292.4	292.0	295.9	299.1	300.7	302.4	305.6	307.5	310.1	310.8	315.7	315.0	316.2	314.5
182	713.7	103.6	164.1	3.018	13.9		295.8	307.0	306.7	311.4	315.4	317.6	319.9	323.5	325.1	325.3	325.6	325.8	327.2	326.8	331.8
183	710.5	120.6	161.5	3.051	14.1		306.3	319.7	319.0	324.2	326.8	326.4	327.1	327.1	327.0	326.6	327.0	327.3	329.0	329.2	336.4
184	711.3	130.7	160.5	3.078	15.4		313.0	325.5	325.5	328.4	327.9	327.9	328.4	328.4	327.9	327.9	328.1	328.4	329.8	330.7	337.9
185	712.1	139.3	165.3	3.091	13.8		316.5	327.4	327.2	328.9	328.9	328.2	328.9	328.9	328.6	328.8	328.6	328.9	330.6	331.2	338.9
186	712.1	148.9	163.7	3.093	14.9		320.9	328.9	328.3	329.5	328.9	328.9	329.2	329.2	328.9	328.9	328.5	329.0	330.9	331.4	339.8
187	712.1	157.0	161.9	3.079	11.6		325.6	328.9	328.0	329.5	328.9	328.7	329.0	329.4	328.7	328.5	328.5	329.0	330.6	331.6	340.2
188	706.5	164.9	160.3	3.054	13.6		327.8	329.0	327.8	329.0	328.7	328.2	328.5	328.9	328.2	328.3	328.2	328.5	330.1	331.1	340.5
189	715.3	170.7	156.9	3.039	10.8		327.4	328.4	327.6	328.8	328.4	327.9	328.1	328.4	327.6	327.9	327.9	327.9	330.2	330.7	340.5
190	714.5	187.7	154.6	3.017	15.8		327.0	327.9	327.2	328.4	327.9	327.5	328.1	327.9	328.6	327.2	327.4	327.7	329.4	329.8	340.3
191	697.0	199.4	149.8	2.978	23.0	.11	326.0	327.4	326.5	327.4	327.6	326.7	327.7	327.2	326.5	326.7	326.7	327.0	327.2	328.4	500.4
192	678.7	199.0	144.6	2.968	30.5	.17	326.0	326.9	326.2	327.6	327.1	326.4	326.7	327.2	326.0	326.5	325.7	327.2	327.2	336.0	574.5
193	627.8	49.3	168.4	2.949	15.0		266.4	272.5	272.7	275.7	277.5	278.5	280.7	281.9	283.2	285.3	286.2	289.0	288.8	284.2	268.7
194	626.2	66.9	150.2	2.905	15.6		284.9	292.8	293.4	297.1	299.7	301.1	303.4	305.3	307.2	309.7	310.9	314.4	313.9	308.6	314.4
195	615.0	84.7	150.0	2.952	14.7		296.8	306.6	307.0	311.7	315.0	317.1	319.5	321.9	323.5	323.5	323.7	324.4	325.7	321.1	324.0
196	607.1	102.7	147.7	2.979	15.2		309.3	321.3	321.5	325.1	325.3	325.1	325.6	325.5	325.1	325.5	325.7	325.8	327.9	325.3	325.8
197	592.8	120.9	141.6	2.960	15.1		322.6	325.2	324.9	326.1	325.9	325.4	326.3	325.9	325.4	325.4	325.4	326.1	327.6	326.8	325.7
198	592.0	137.7	140.2	2.938	14.2		325.2	325.5	325.0	326.2	325.7	325.5	326.1	325.5	325.2	325.2	325.4	325.7	326.9	327.8	325.7
199	592.0	148.1	139.0	2.953	14.0	.04	325.8	326.1	325.4	326.7	326.5	325.6	326.5	326.0	325.4	325.6	325.8	326.0	328.2	328.4	326.0
200	582.4	157.4	134.1	2.969	19.3	.15	326.4	326.4	326.3	326.8	327.1	326.1	327.3	326.8	325.7	326.3	326.4	326.8	328.3	328.5	326.8
201	564.1	158.6	126.1	2.966	10.4	.24	326.2	326.7	326.2	327.2	326.4	326.2	326.7	326.2	325.9	326.0	326.0	326.5	327.9	327.8	516.1
202	561.7	48.2	153.6	3.007	15.0		278.4	285.0	285.2	288.2	290.3	291.4	293.7	295.1	296.7	298.8	299.8	303.0	302.3	297.4	299.6
203	559.3	67.2	150.0	2.990	13.2		292.5	301.8	301.8	306.0	309.3	311.2	313.5	315.9	318.0	320.8	321.7	324.9	324.6	318.9	321.5
204	557.8	83.6	144.0	2.983	13.1		305.1	316.6	316.6	321.5	325.1	324.7	325.6	325.3	324.7	325.3	325.3	325.8	327.7	324.7	325.8
205	557.0	103.3	140.9	2.971	13.1		318.0	325.5	325.1	326.0	326.2	325.3	326.3	325.8	325.3	325.3	325.6	326.0	327.9	326.8	326.5
206	557.0	119.7	139.4	2.965	12.8		325.6	326.0	325.3	326.3	326.3	325.4	326.3	326.0	325.4	325.4	325.6	326.0	327.5	328.0	326.7
207	557.8	129.4	135.4	2.953	12.4	.07	325.5	325.9	325.5	326.6	326.1	325.4	326.2	325.7	325.0	325.2	325.4	325.7	327.4	328.5	327.1
208	556.6	138.4	133.1	2.972	12.4	.14	326.4	326.5	325.9	327.2	326.7	326.0	326.7	325.9	325.5	325.7	325.7	326.0	328.1	329.0	327.2
209	557.8	146.5	131.4	2.976	11.4	.24	326.7	326.9	326.2	327.4	327.2	325.9	326.9	325.9	325.9	325.3	326.0	326.7	328.3	329.5	326.4
210	548.2	155.2	127.4	2.969	9.7		326.5	326.9	324.3	327.4	327.0	326.0	326.5	326.2	325.5	325.7	326.2	326.5	328.4	328.6	491.5
211	474.2	48.2	130.4	2.999	14.7		293.7	301.6	302.4	306.5	308.7	309.8	312.6	314.5	315.9	318.3	319.2	323.0	321.6	315.7	323.0
212	474.2	66.0	124.6	2.991	13.8		308.5	319.5	319.6	324.3	325.9	325.0	326.2	325.7	325.2	325.5	326.0	326.2	328.1	325.5	327.6
213	473.4	84.2	121.1	2.974	13.8		322.3	325.6	325.2	326.6	326.1	325.4	326.6	325.9	325.4	325.8	325.9	325.9	327.7	327.3	328.0
214	475.8	102.3	116.9	2.963	12.7	.05	325.8	326.0	325.7	326.5	326.7	325.5	326.4	325.8	325.2	325.7	325.5	326.2	327.9	328.4	329.1
215	475.8	109.8	115.6	2.951	4.4	.12	325.9	325.7	325.4	326.7	326.4	325.5	326.0	325.7	324.8	325.4	325.4	326.0	327.8	328.5	329.1
216	475.0	120.0	111.4	2.949	12.1	.23	326.1	326.0	326.0	327.0	326.1	325.3	326.1	325.6	325.3	325.6	325.6	326.0	327.7	329.4	363.7
217	475.0	119.9	109.7	2.947	12.4	.24	325.4	326.0	325.4	326.5	326.0	325.1	325.8	325.4	325.1	325.4	325.4	326.1	327.3	329.1	412.6
218	366.8	39.5	63.1	2.981	11.1		323.5	324.7	324.4	325.6	324.9	324.4	325.6	324.9	324.6	324.6	324.9	325.3	326.6	324.6	326.0
219	368.4	48.1	62.8	2.969	11.9	.09	325.1	325.1	324.9	325.9	325.6	324.5	325.9	324.9	324.9	325.1	325.1	325.2	327.0	325.4	326.4
220	369.2	57.3	65.5	2.953	12.5	.16	325.5	325.4	324.7	325.9	325.5	324.7	325.7	324.8	325.2	325.2	324.8	325.5	327.1	326.2	326.9
221	369.2	65.5	60.4	2.908	10.8	.27	324.3	324.3	323.6	324.5	324.3	323.6	324.1	324.0	323.6	323.8	324.1	324.3	326.2	325.9	326.0
222	366.4	75.4	62.3	2.989	10.0	.37	326.5	326.5	326.1	326.7	326.5	325.6	326.5	326.3	325.8	326.1	326.1	326.8	328.6	328.7	328.2
223	367.6	83.3	61.6	2.980	8.7	.46	326.7	326.5	325.8	326.8	326.3	325.5	326.5	326.1	325.5	325.8	325.8	326.0	328.2	328.7	383.9

224	367.6	83.3	60.6	2.976	10.3	.46	326.5	326.5	325.6	326.3	326.1	325.5	326.7	326.1	325.8	325.8	326.5	326.5	328.2	329.1	398.6
225	775.0	47.8	57.9	1.183	16.9		243.4	248.2	248.0	250.9	251.8	252.7	254.9	256.0	256.9	258.9	259.6	261.6	263.2	257.4	258.7
226	761.4	56.7	51.9	1.242	16.2		255.2	260.6	260.8	263.2	263.0	262.6	263.5	263.2	263.0	263.2	263.3	263.7	267.5	266.4	265.5
227	715.3	64.3	35.3	1.170	16.4	.08	263.5	261.4	261.0	262.5	261.7	261.0	261.7	261.4	260.6	260.8	261.4	261.7	265.5	265.2	263.5
228	743.9	66.1	36.9	1.189	16.5	.06	262.4	262.2	261.7	262.7	262.6	261.7	262.9	262.4	262.0	262.0	262.4	263.1	266.7	266.9	265.6
229	718.5	74.7	36.5	1.193	15.3	.10	263.4	263.4	263.1	263.8	262.9	262.2	262.9	262.2	262.0	261.8	262.2	262.7	266.8	267.0	265.2
230	526.7	83.0	48.6	1.196	13.1	.18	262.7	263.6	263.0	264.1	263.0	262.3	262.7	261.8	260.7	260.5	260.2	260.3	260.2	260.3	260.5
231	498.9	89.3	48.0	1.195	14.6	.24	263.1	264.0	263.3	263.8	262.8	261.7	262.4	261.5	261.0	260.8	260.2	260.4	260.4	260.6	260.6
232	455.1	101.9	46.7	1.197	13.1	.35	263.6	263.6	262.2	263.4	262.5	261.8	262.4	261.8	261.3	261.1	260.7	260.6	260.9	261.5	260.9
233	425.7	108.7	46.9	1.190	12.1	.43	263.9	263.3	262.2	263.1	262.6	261.9	262.2	261.9	261.3	261.3	260.4	260.8	261.0	262.1	261.3
234	383.5	119.1	46.6	1.186	12.4	.56	264.5	263.0	262.1	263.4	262.7	262.1	262.3	261.9	261.2	261.4	261.0	261.0	261.4	262.8	261.9
235	364.4	128.5	50.1	1.183	10.4	.65	264.2	262.6	262.2	263.3	262.8	261.9	262.4	261.7	261.5	261.3	261.3	261.3	261.7	263.9	262.4
236	767.8	47.5	58.9	1.224	18.1		244.7	249.6	249.6	252.4	253.5	254.7	256.5	257.6	258.7	260.3	261.1	263.2	263.4	259.4	260.5
237	760.7	65.1	45.1	1.226	16.0	.03	261.7	264.6	264.0	265.1	264.4	263.5	264.9	264.0	263.3	263.5	263.5	263.7	269.4	269.8	264.9
238	706.5	83.0	27.8	1.213	13.0	.17	264.8	265.0	264.3	265.2	264.1	263.8	264.5	264.1	263.4	263.8	264.1	264.5	271.1	270.4	265.6
239	700.2	83.7	36.6	1.189	22.8	.14	263.7	263.7	262.7	263.7	263.2	262.7	263.4	263.0	262.5	262.8	263.2	263.9	270.6	269.8	265.2
240	568.9	101.2	26.5	1.186	14.2	.33	264.4	263.3	262.8	263.8	263.1	262.4	263.1	262.4	262.0	262.6	263.3	263.7	271.4	270.7	265.6
241	536.3	101.0	38.1	1.221	14.9	.31	263.1	262.9	262.2	263.7	263.1	263.1	262.9	263.1	262.9	262.4	262.2	262.4	262.6	261.5	262.2
242	468.6	118.4	20.8	1.204	13.4	.53	263.8	262.9	262.5	263.2	262.9	262.7	263.6	262.9	262.0	261.6	261.6	261.8	262.2	261.4	261.6
243	430.5	135.1	17.4	1.219	7.3	.70	263.0	265.7	262.1	264.6	263.0	267.7	263.9	274.7	271.1	296.3	359.1	409.3	383.1	363.1	361.1
244	393.1	135.4	11.6	1.193	16.4	.80	261.9	261.4	260.8	261.9	261.4	261.0	261.9	265.7	426.4	458.6	467.9	477.6	466.8	408.7	407.2
245	370.0	136.8	11.9	1.173	10.2	.85	261.3	260.8	260.4	261.1	261.7	260.6	260.8	261.3	261.9	261.7	261.7	262.2	264.4	278.2	368.8
246	343.7	145.9	18.3	1.200	10.1	.96	263.1	262.3	261.8	263.1	262.7	262.0	261.6	262.0	262.3	262.2	261.8	263.4	367.0	387.4	400.3
247	335.0	155.5	20.8	1.186	11.5	1.0	262.1	261.7	261.2	262.3	262.3	261.4	261.2	261.2	261.6	261.2	261.2	263.7	394.5	402.1	412.8
248	763.8	47.2	68.2	1.214	17.8		239.1	243.8	244.0	246.7	247.6	248.4	249.8	251.3	252.6	254.2	255.3	257.3	257.5	254.4	253.5
249	736.0	67.0	46.3	1.211	16.6	.03	261.1	264.0	263.4	264.9	264.0	263.4	264.3	263.4	263.2	263.4	263.8	264.0	266.3	266.1	266.1
250	455.9	67.4	12.4	1.199	11.0	.31	260.7	260.1	260.5	260.5	260.5	259.8	260.5	260.7	260.5	260.9	260.1	260.1	262.1	258.3	258.3
251	428.1	81.8	15.3	1.195	11.1	.40	261.8	260.6	260.8	261.3	260.9	260.4	260.9	260.9	260.6	261.1	260.6	260.8	261.1	258.6	258.8
252	373.2	100.5	16.4	1.190	11.2	.59	261.9	261.0	261.3	261.5	261.2	260.6	260.8	261.3	261.0	261.7	261.0	261.3	261.9	259.4	259.0
253	331.8	118.9	16.9	1.186	9.9	.80	262.0	261.4	261.4	262.0	261.6	261.1	261.6	261.4	261.1	261.4	261.2	261.6	262.9	260.9	259.6
254	296.0	136.1	18.1	1.177	10.1	1.0	262.1	263.0	261.4	262.1	261.4	261.2	261.5	261.4	261.2	261.9	261.5	261.7	263.2	353.8	366.6

TABLE 24 DERIVED EXPERIMENTAL DATA FOR BIPHENYL-BIPHENYL OXIDE TEST SERIES

AXIAL DISTANCE FROM START OF HEATING - M.
INNER WALL TEMPERATURE - C

TEST NO.	MASS VEL. KG/S M**2	HEAT FLUX KW/ M**2	SUB-COOL KJ/ KG	EXIT PRESS MN/ M**2	PRESS DROP KN/ M**2	EXIT QUAL	.025	.152	.279	.406	.533	.660	.787	.914	1.041	1.167	1.294	1.421	1.548	1.675	1.802
1	724.8	40.4	165.0	.243	18.9		251.3	255.2	255.2	256.3	257.6	258.0	259.2	260.3	261.0	261.7	262.8	263.7	263.7	262.5	266.2
2	713.7	67.0	149.6	.247	17.8		273.3	278.5	280.6	282.2	283.6	285.0	286.6	288.1	288.8	290.7	292.3	293.7	294.1	293.4	297.8
3	708.9	84.1	136.6	.250	17.8		289.8	296.1	298.9	300.9	303.3	305.2	307.0	306.7	304.9	303.8	305.2	305.2	306.8	305.9	308.7
4	724.1	103.2	134.2	.253	18.0		302.1	299.5	300.6	302.0	300.7	300.7	302.8	302.7	304.9	305.6	308.4	309.3	309.0	308.8	313.5
5	685.1	121.2	132.7	.260	17.8		301.5	302.8	303.3	303.8	304.5	304.7	305.4	306.4	307.1	308.0	311.3	312.4	313.1	313.9	317.4
6	743.1	83.4	140.5	.226	17.8		281.6	288.0	291.4	292.8	295.1	296.3	298.6	300.2	301.4	303.4	305.3	307.4	305.6	306.3	307.4
7	737.6	101.8	138.9	.226	17.9		293.9	300.8	299.6	296.6	295.7	295.7	295.3	295.7	296.9	297.5	299.9	302.0	303.1	303.8	308.5
8	732.0	119.7	136.0	.225	17.8		290.1	295.3	298.6	298.8	298.6	298.6	298.8	299.8	300.5	301.8	304.2	305.6	306.3	307.7	312.4
9	730.4	137.1	129.0	.225	17.7		295.5	297.8	299.4	300.1	301.5	301.0	301.9	302.9	303.6	305.0	307.8	309.4	310.5	311.5	315.9
10	692.2	146.4	137.4	.225	17.7		296.5	298.0	298.0	299.0	300.6	301.5	302.7	303.4	304.1	306.0	309.4	310.8	312.0	313.4	317.9
11	650.9	101.9	182.1	.362	17.9		306.6	314.8	319.1	320.5	320.5	320.5	321.2	321.2	321.5	321.9	323.3	324.1	323.8	325.2	329.5
12	647.7	117.9	180.4	.361	17.5		316.3	322.9	322.4	322.6	322.2	321.7	322.6	322.6	322.8	323.6	325.4	326.0	326.4	327.4	331.9
13	658.8	136.6	174.5	.359	17.5		322.5	323.3	323.2	323.7	323.3	323.2	323.9	324.2	324.7	325.8	328.0	328.9	329.6	330.2	335.2
14	667.6	155.9	177.9	.359	17.2		323.4	324.1	324.1	324.6	324.4	324.1	324.9	326.1	326.7	328.2	330.5	331.7	332.4	333.7	338.9
15	673.9	164.0	177.4	.359	17.4		323.4	323.7	324.1	324.4	324.4	324.8	325.5	326.1	327.5	329.2	331.3	332.7	334.2	335.3	340.2
16	675.5	170.5	187.5	.359	17.3		323.8	324.0	323.8	324.3	324.3	324.5	325.5	326.6	327.4	328.8	331.4	332.4	333.6	335.5	340.5
17	694.6	159.7	182.2	.356	17.1		324.7	324.4	324.9	324.9	325.2	325.6	327.1	328.0	328.8	331.4	333.8	335.9	336.8	337.3	341.7
18	535.9	157.3	173.5	.354	16.7	.02	324.5	325.0	324.7	324.9	325.0	325.4	327.1	327.1	328.5	330.1	333.1	334.9	335.9	336.9	341.2
19	526.7	166.4	172.5	.359	15.5	.06	324.7	324.7	324.8	325.3	325.9	326.4	327.4	328.5	329.5	331.2	334.0	335.5	336.5	337.1	341.3
20	518.8	169.5	156.5	.358	17.2	.14	325.6	326.1	326.3	326.8	327.6	328.7	329.7	331.3	332.8	334.9	337.6	337.1	337.1	337.6	341.2
21	575.3	103.0	169.6	.460	16.5		334.8	338.0	338.0	338.5	338.4	338.2	338.9	338.7	338.4	339.2	341.1	342.0	341.6	342.6	347.4
22	585.6	118.4	172.1	.460	16.2		339.1	339.4	339.4	339.3	339.3	339.3	339.9	340.1	340.3	341.8	343.4	344.7	344.9	346.1	350.7
23	585.6	135.7	176.1	.460	15.9		339.7	339.9	339.4	339.7	339.7	339.7	340.7	341.1	341.4	343.5	346.0	347.1	347.9	348.4	353.3
24	594.8	156.5	171.3	.458	15.1		340.6	340.9	340.4	340.6	340.6	341.4	342.8	343.6	344.2	347.0	349.6	350.4	349.4	349.4	353.5
25	576.1	169.1	151.6	.459	16.3	.09	342.1	342.2	342.4	343.1	344.6	345.3	347.0	348.4	348.9	349.9	351.8	351.8	350.8	351.3	355.0
26	417.7	169.3	79.5	.455	20.3	.62	347.0	347.3	349.0	348.4	349.2	349.2	349.2	349.0	349.2	349.9	351.6	351.6	350.7	351.1	355.5
27	416.1	169.5	55.2	.460	16.3	.72	349.7	349.0	349.0	348.5	349.2	349.2	348.9	349.4	349.2	349.2	351.2	351.8	450.3	482.2	502.6
28	580.8	102.4	188.7	.492	16.7		329.1	340.6	342.5	341.3	341.6	341.5	342.2	341.8	342.0	342.2	344.4	346.2	349.0	346.2	346.2
29	575.3	118.6	175.5	.469	16.9		342.2	339.1	339.8	340.1	340.3	340.1	341.0	341.1	341.5	342.5	344.9	346.8	351.5	349.6	349.8
30	582.4	135.4	187.3	.507	16.4		344.9	345.4	345.0	345.2	345.5	345.4	345.4	346.4	346.2	347.9	350.0	352.0	358.1	356.4	356.1
31	600.7	155.8	194.3	.511	16.2		346.2	346.0	346.4	347.4	346.9	347.2	347.7	348.4	348.9	351.0	353.5	356.4	360.1	358.6	357.9
32	609.5	162.3	191.4	.517	15.7		346.9	347.0	346.8	347.0	347.5	347.3	348.0	348.8	349.7	351.9	354.9	357.3	360.2	358.8	358.8
33	477.4	168.4	123.2	.521	16.0	.34	346.2	347.2	348.6	349.6	351.1	351.8	352.3	352.8	353.7	353.5	355.4	356.7	356.9	355.4	355.4
34	411.4	167.4	51.7	.464	15.5	.73	351.0	351.2	351.0	350.3	350.3	350.8	350.3	350.8	350.8	351.5	353.4	355.7	457.7	481.4	502.2
35	422.5	83.5	141.2	.472	16.2		343.0	346.0	345.7	346.0	346.7	346.2	346.5	346.7	346.7	347.7	349.4	350.4	357.2	351.3	351.5
36	261.0	90.2	44.4	.470	11.7	.68	350.3	350.0	349.8	349.5	350.2	350.2	350.2	350.5	349.8	350.8	352.9	354.6	356.9	351.7	353.0
37	202.9	102.2	29.7	.469	12.6	1.0	351.9	350.7	350.2	349.8	350.5	350.7	350.3	350.3	350.2	351.2	352.7	355.1	357.6	352.7	354.1
38	194.9	108.6	24.6	.464	14.1	1.0	352.4	351.4	350.6	349.9	350.7	350.6	350.9	351.1	350.6	351.1	353.4	355.1	357.8	353.6	348.7

TEST NO.	HEAT FLUX kW/m^2C	NOMINAL AVERAGE $T_w - T_{sat}$ C	LIQUID VAPOUR DENSITY RATIO	EXP.HEAT TRANSFER COEFF. kW/m^2C	CAL.HEAT TRANSFER COEFF. kW/m^2C	% ERROR*
8	100.0	9.2	49.68	10.83	10.83	0
9	136.5	9.6	46.18	14.34	13.90	-3.1
10	138.6	9.7	47.49	14.35	13.91	-3.1
11	177.7	10.8	47.01	16.54	16.67	.8
12	50.9	8.8	48.56	5.80	6.75	16.3
13	51.1	9.0	48.92	5.70	6.75	18.4
14	51.0	8.7	48.64	5.91	6.75	14.2
15	89.3	10.2	48.55	8.79	10.08	14.7
16	87.5	9.3	48.07	9.47	9.97	5.2
17	86.6	9.3	48.11	9.36	9.89	5.6
22	127.5	10.4	48.25	12.26	13.03	6.3
23	126.8	10.2	48.06	12.44	12.99	4.4
24	175.5	10.9	47.41	16.18	16.47	1.8
25	174.0	11.2	47.87	15.54	16.31	4.9
30	50.3	7.5	47.39	6.73	6.75	.3
31	67.8	7.8	47.15	8.84	8.37	-5.3
32	87.2	8.5	47.32	10.37	10.00	-3.6
33	87.8	8.2	47.21	10.70	10.06	-6.0
34	106.8	8.9	47.11	12.13	11.58	-4.5
35	107.0	8.8	46.89	12.30	11.62	-5.5
36	123.5	9.5	47.26	13.09	12.83	-2.0
37	123.5	9.5	47.25	13.07	12.83	-1.8
38	143.4	9.8	47.08	14.76	14.30	-3.1
39	142.6	9.8	47.13	14.71	14.23	-3.3
40	160.7	10.0	47.03	16.15	15.51	-4.0
41	163.2	9.8	46.93	16.79	15.70	-6.5
42	165.3	10.1	47.06	16.56	15.83	-4.4
46	23.8	6.2	48.35	3.84	3.93	2.3
49	50.1	7.0	48.48	7.15	6.68	-6.6
50	88.3	9.5	48.76	9.34	9.98	6.8
51	88.3	9.0	48.72	9.88	9.98	1.0
52	90.4	8.4	48.05	10.83	10.21	-5.7
53	90.8	8.5	48.11	10.80	10.23	-5.3
63	112.6	7.9	26.44	15.78	15.91	.8
64	142.2	9.6	26.27	14.91	17.73	18.9
65	161.3	8.3	26.40	19.58	19.36	-1.1
66	156.9	8.7	26.39	18.22	18.99	4.2
71	123.3	7.6	20.42	16.58	15.98	-3.6
72	122.3	7.5	26.43	16.61	15.89	-4.3
73	140.4	7.5	26.40	19.00	17.53	-7.7
74	161.3	8.1	26.36	20.11	19.37	-3.7

*% Error = ((Calculated-Experimental)/Experimental) x 100

Table 25: Data used in multiple linear regression analysis together with a comparison of experimental and calculated net boiling heat transfer coefficients and values of wall superheat.

TEST NO.	HEAT FLUX kW/m^2C	NOMINAL AVERAGE $T_w - T_{sat}$ C	LIQUID-VAPOUR DENSITY RATIO	EXP. HEAT TRANSFER COEFF. kW/m^2C	CAL. HEAT TRANSFER COEFF. kW/m^2C	% ERROR*
75	173.7	8.8	26.26	19.94	20.46	2.6
79	68.1	7.7	26.28	9.32	10.48	12.4
80	86.7	6.8	26.45	12.97	12.43	-4.2
81	86.4	6.3	26.44	14.02	12.39	-11.6
82	105.8	7.2	26.60	14.86	14.29	-3.8
83	103.8	7.2	26.60	14.59	14.10	-3.3
84	123.7	7.7	26.57	16.17	15.98	-1.2
85	139.0	8.3	26.47	16.89	17.39	2.9
86	165.3	9.0	26.54	18.43	19.66	6.6
87	172.5	9.2	26.58	18.82	20.26	7.6
88	174.7	9.3	26.53	18.98	20.46	7.8
92	68.0	6.5	26.61	10.53	10.48	-.5
93	68.5	6.7	26.35	10.39	10.52	1.2
94	85.7	6.4	26.35	13.61	12.34	-9.3
95	85.8	6.8	26.10	12.77	12.39	-2.9
96	88.2	7.5	26.35	11.85	12.60	6.3
97	103.3	7.2	26.35	14.49	14.10	-2.7
98	122.6	7.7	26.32	16.17	15.94	-1.4
99	140.1	8.2	26.31	17.20	17.53	1.9
100	160.5	9.1	26.51	17.83	19.26	8.0
101	160.4	8.9	26.47	18.22	19.27	5.8
102	174.3	9.2	26.46	19.17	20.45	6.7
103	174.7	9.0	26.49	19.45	20.47	5.2
104	175.1	8.7	26.42	20.28	20.52	1.2
105	175.8	8.8	26.46	20.12	20.57	2.2
116	123.8	7.9	12.88	15.87	21.05	32.6
118	138.9	6.3	12.85	22.37	22.87	2.2
154	105.2	6.8	12.58	16.11	18.91	17.4
155	121.6	6.2	12.56	19.91	20.98	5.3
156	137.9	6.0	12.58	23.60	22.94	-2.8
157	159.0	6.3	12.52	25.79	25.43	-1.4
158	159.4	6.6	12.55	24.50	25.46	3.9
159	159.4	6.8	12.62	23.48	25.40	8.2
165	104.5	5.9	12.85	18.23	18.67	2.4
166	122.0	5.9	12.82	21.02	20.86	-.8
167	131.6	6.0	12.83	21.97	22.02	.2
168	136.9	6.2	12.82	22.12	22.65	2.4
169	136.6	6.3	12.83	21.94	22.61	3.0
170	140.5	6.2	12.83	22.80	23.10	1.3
176	106.7	6.4	12.57	17.27	19.10	10.6
177	122.8	5.2	12.50	25.59	21.17	-17.3

*% Error = ((Calculated - Experimental)/Experimental) x 100

TEST NO.	HEAT FLUX kW/m^2C	NOMINAL AVERAGE T_w-T_{sat} C	LIQUID-VAPOUR DENSITY RATIO	EXP.HEAT TRANSFER COEFF. kW/m^2C	CAL.HEAT TRANSFER COEFF. kW/m^2C	% ERROR*
178	128.0	5.6	12.61	23.35	21.73	-6.9
201	158.6	5.1	5.84	31.39	33.90	8.0
210	155.2	4.9	5.83	32.15	33.40	3.9
216	120.0	4.5	5.89	26.99	27.69	2.6
217	119.9	4.5	5.90	27.39	27.66	1.0
220	57.3	4.0	5.88	14.82	16.41	10.7
221	65.5	3.7	6.03	18.25	17.82	-2.3
222	75.4	3.6	5.76	21.92	20.05	-8.5
223	83.3	3.4	5.79	25.19	21.48	-14.7
224	83.3	3.8	5.80	22.72	21.47	-5.5
227	64.3	7.9	21.98	8.24	10.77	30.7
228	66.1	8.7	21.59	7.74	11.06	42.9
229	74.7	7.5	21.49	10.14	12.09	19.2
230	83.0	5.0	21.45	16.79	13.04	-22.3
231	89.3	5.3	21.44	17.18	13.74	-20.0
232	101.9	5.8	21.40	17.94	15.11	-15.8
233	108.7	6.4	21.55	17.30	15.78	-8.8
234	119.1	6.9	21.62	17.55	16.82	-4.2
235	128.5	7.1	21.70	18.26	17.73	-2.9
238	83.0	7.9	21.08	10.66	13.13	23.0
239	83.7	8.3	21.52	10.37	13.10	26.3
240	101.2	8.1	21.61	12.65	14.98	18.4
241	101.0	5.9	20.89	17.34	15.15	-12.6
242	118.4	6.5	21.22	18.55	16.87	-9.1
245	136.8	7.1	21.92	19.37	18.47	-4.6
246	145.9	6.7	21.34	21.95	19.54	-11.0
250	67.4	4.8	21.37	14.27	11.26	-21.0
251	81.8	5.3	21.44	15.50	12.91	-16.7
252	100.5	6.0	21.55	16.81	14.92	-11.2
253	118.9	6.5	21.63	18.49	16.80	-9.1
254	136.1	7.1	21.83	19.18	18.43	-3.9
BIPHENYL-BIPHENYL OXIDE TESTS						
20	169.5	14.0	60.29	12.09	14.64	21.0
26	169.3	10.4	46.18	16.61	16.20	-2.5
27	169.5	9.7	45.58	18.04	16.27	-9.8
33	168.4	7.4	40.30	23.80	17.00	-28.6
34	167.4	11.1	45.55	15.78	16.19	2.6
36	90.2	9.7	44.98	9.59	10.45	9.0
37	102.2	9.9	44.99	10.59	11.42	7.8
38	108.6	10.7	45.57	10.40	11.88	14.2

*% Error = ((Calculated-Experimental)/Experimental) x 100

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp	TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp
1	1.24	.01	18.89	20.14					20.14	27.9	43	.79	.00	18.32	19.11					19.11	33.2
2	1.24	.01	18.91	20.15					20.15	26.2	44	.79	.00	18.29	19.08					19.08	34.3
3	1.28	.01	19.41	20.43					20.43	32.2	45	.66	.00	14.75	15.41	.29	.38	3.30	3.97	19.37	30.8
4	1.28	.02	19.15	20.44					20.44	32.2	46	.62	.00	13.86	14.48	.37	.47	3.72	4.56	19.04	28.3
5	1.23	.01	18.26	19.50					19.50	18.3	47	.81	.01	18.14	18.96					18.96	34.5
6	1.23	.02	18.11	19.36					19.36	8.1	48	.81	.01	18.11	18.93					18.93	33.9
7	.93	.02	14.86	15.80	.72	1.88	2.28	4.88	20.68	37.4	49	.36	.00	8.55	8.91	1.62	2.26	3.75	7.63	16.54	29.4
8	.85	.02	13.72	14.59	1.05	2.50	2.45	6.00	20.59	27.5	50	.56	.01	13.26	13.83	.87	1.98	2.39	5.24	19.07	30.5
9	.57	.02	10.98	11.58	2.23	4.83	2.23	9.39	20.97	44.8	51	.55	.01	13.04	13.60	.91	2.01	2.45	5.37	18.97	32.4
10	.35	.01	8.46	8.82	3.43	5.93	2.12	11.47	20.30	33.9	52	.12	.00	3.87	3.99	3.97	4.85	2.68	11.49	15.48	32.8
11	.26	.01	7.84	8.12	4.20	7.31	1.70	13.21	21.32	41.6	53	.13	.00	4.32	4.45	3.79	4.75	2.63	11.18	15.63	32.0
12	.83	.01	12.59	13.42	.96	1.65	3.47	6.08	19.50	31.4	54	1.26	.01	18.02	19.29					19.29	20.4
13	.79	.01	12.14	12.94	1.08	1.83	3.52	6.42	19.36	38.0	55	1.25	.01	17.74	18.99					18.99	34.4
14	.77	.01	11.91	12.69	1.12	1.88	3.58	6.59	19.27	31.7	56	1.22	.02	17.49	18.73					18.73	32.2
15	.32	.01	6.79	7.12	3.43	4.90	3.01	11.34	18.46	20.1	57	1.22	.02	17.28	18.53					18.53	32.6
16	.37	.01	7.68	8.06	3.03	4.59	2.95	10.57	18.63	35.1	58	1.25	.01	17.98	19.24					19.24	21.7
17	.41	.01	8.14	8.55	2.83	4.38	2.97	10.18	18.73	35.9	59	1.26	.02	17.84	19.12					19.12	20.2
18	1.25	.02	18.11	19.37					19.37	21.8	60	1.22	.02	17.29	18.53					18.53	21.8
19	1.26	.02	18.08	19.36					19.36	21.4	61	1.13	.02	15.81	16.96	.28	.52	2.16	2.95	19.91	18.1
20	1.17	.02	16.89	18.08	.27	.55	2.09	2.90	20.98	35.4	62	.96	.02	13.89	14.87	.65	1.47	2.60	4.72	19.59	18.6
21	1.03	.02	16.2	17.24	.38	.95	2.16	3.49	20.73	35.2	63	.83	.02	12.33	13.18	1.02	2.09	2.89	6.01	19.18	20.0
22	.58	.02	10.99	11.59	2.30	4.72	2.28	9.30	20.88	32.9	64	.95	.03	13.73	14.71	.76	1.81	2.50	5.07	19.77	19.9
23	.55	.01	10.76	11.33	2.35	4.72	2.30	9.37	20.70	35.7	65	.55	.02	9.55	10.12	2.18	4.13	2.70	9.01	19.13	19.9
24	.19	.01	6.21	6.41	4.9	7.78	1.67	14.36	20.76	44.3	66	.80	.02	12.28	13.06	1.24	2.76	2.61	6.6	19.67	25.9
25	.23	.01	7.14	7.38	4.55	7.59	1.68	13.81	21.19	42.9	67	1.19	.01	17.41	18.61					18.61	18.6
26	.16	.01	5.78	5.94	5.56	9.37	1.37	16.32	22.27	39.9	68	1.19	.02	17.21	18.42					18.42	21.7
27	.16	.01	5.55	5.72	5.93	9.71	1.46	17.09	22.82	25.4	69	1.19	.02	17.08	18.28					18.28	19.1
28	1.14	.01	16.56	17.71	.23	.26	2.37	2.85	20.56	33.8	70	.93	.02	13.83	14.78	.60	1.24	2.73	4.57	19.35	19.1
29	1.04	.01	14.98	16.02	.43	.63	3.11	4.17	20.2	32.6	71	.70	.02	11.23	11.95	1.29	2.52	2.98	6.79	18.75	21.2
30	.70	.01	10.76	11.46	1.39	2.13	3.88	7.40	18.86	31.6	72	.70	.02	11.24	11.96	1.28	2.46	3.02	6.75	18.71	19.5
31	.52	.01	8.99	9.52	2.21	3.40	3.47	9.08	18.60	34.8	73	.54	.02	9.52	10.08	1.93	3.49	2.93	8.36	18.44	18.4
32	.35	.01	6.99	7.35	3.37	4.88	3.08	11.33	18.69	33.6	74	.46	.01	8.46	8.93	2.52	4.43	2.76	9.72	18.65	22.7
33	.32	.01	6.32	6.64	3.72	5.18	3.11	12.02	18.66	34.9	75	.34	.01	7.15	7.50	3.10	5.19	2.59	10.88	18.39	25.7
34	.20	.00	4.99	5.19	4.51	6.06	2.61	13.18	18.37	37.3	76	1.04	.01	17.00	18.05					18.05	19.2
35	.18	.00	4.53	4.71	4.79	6.29	2.61	13.70	18.41	38.9	77	1.03	.01	17.05	18.09					18.09	18.5
36	.16	.00	4.77	4.93	4.76	6.51	2.22	13.49	18.43	38.9	78	.99	.01	16.45	17.46	.13	.07	1.89	2.09	19.55	19.3
37	.17	.00	5.00	5.17	4.64	6.42	2.21	13.27	18.43	39.4	79	.78	.01	13.02	13.81	.55	.91	3.28	4.74	18.55	18.1
38	.10	.00	3.88	3.99	5.16	7.04	1.87	14.06	18.05	41.1	80	.54	.01	9.63	10.18	1.32	2.06	3.70	7.09	17.26	16.6
39	.11	.00	4.11	4.22	5.02	6.92	1.87	13.81	18.03	41.2	81	.53	.01	9.40	9.94	1.40	2.17	3.71	7.28	17.22	17.3
40	.08	.00	3.43	3.52	5.35	7.57	1.65	14.57	18.08	41.5	82	.37	.01	7.29	7.67	2.19	3.23	3.50	8.92	16.59	17.7
41	.07	.00	3.21	3.28	5.52	7.82	1.63	14.98	18.26	43.6	83	.42	.01	8.16	8.58	1.87	2.86	3.48	8.22	16.80	18.3
42	.09	.00	3.67	3.76	5.44	7.78	1.64	14.86	18.62	42.3	84	.30	.01	6.45	6.76	2.65	3.89	3.19	9.74	16.50	18.8

Note: All pressure drop components have the units of kN/m^2

TABLE 26 COMPARISON OF MEASURED PRESSURE DROP WITH THAT PREDICTED BY THE HOMOGENEOUS THEORY FOR THE MONOCHLOROBENZENE TEST SERIES

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp
85	.24	.01	5.60	5.85	3.12	4.53	2.96	10.61	14.46	23.4
86	.19	.01	4.75	4.95	3.76	5.52	2.62	11.90	16.85	20.3
87	.18	.01	4.75	4.95	3.84	5.74	2.51	12.09	17.04	22.8
88	.18	.01	4.55	4.73	3.93	5.82	2.53	12.28	17.00	18.9
89	.90	.01	16.91	17.81					17.81	17.8
90	.84	.01	15.79	16.64	.16	.15	2.31	2.62	19.27	18.1
91	.74	.01	13.85	14.60	.35	.48	3.23	4.05	18.65	16.4
92	.61	.01	11.52	12.13	.74	1.16	3.62	5.52	17.65	17.1
93	.54	.01	10.45	11.00	.93	1.39	3.84	6.16	17.16	18.4
94	.40	.01	8.34	8.75	1.52	2.23	3.74	7.50	16.24	16.7
95	.32	.01	6.83	7.15	1.89	2.55	3.89	8.32	15.47	19.0
96	.21	.00	4.71	4.92	2.52	3.08	4.00	9.60	14.51	16.9
97	.25	.01	5.78	6.04	2.43	3.29	3.55	9.27	15.31	14.0
98	.20	.01	4.94	5.15	2.95	4.01	3.19	10.15	15.30	17.9
99	.17	.00	4.53	4.70	3.25	4.51	2.88	10.63	15.33	17.1
100	.12	.00	3.47	3.59	3.81	5.30	2.57	11.68	15.27	17.5
101	.12	.00	3.68	3.81	3.72	5.21	2.57	11.50	15.31	19.4
102	.09	.00	3.04	3.14	3.98	5.72	2.37	12.70	15.20	17.2
103	.09	.00	3.04	3.14	3.98	5.73	2.37	12.70	15.20	15.5
104	.09	.00	2.83	2.91	3.99	5.73	2.35	12.08	14.99	19.2
105	.09	.00	2.82	2.91	4.01	5.80	2.34	12.14	15.05	17.8
106	1.19	.00	17.31	18.50					18.50	12.2
107	1.17	.00	17.31	18.48					18.48	16.9
108	1.17	.00	17.09	18.26					18.26	16.4
109	1.15	.01	16.76	17.92					17.92	17.7
110	1.15	.01	16.54	17.69					17.69	16.4
111	1.14	.01	16.40	17.55					17.55	15.1
112	1.13	.02	16.24	17.39					17.39	15.7
113	1.14	.02	16.28	17.44					17.44	15.4
114	1.13	.02	16.19	17.34					17.34	17.2
115	1.13	.03	15.91	17.07					17.07	15.2
116	.87	.03	12.65	13.55	.51	.86	2.96	4.33	17.87	15.7
117	.90	.03	13.50	13.99	.45	.75	2.85	4.02	18.01	14.0
118	.40	.02	7.78	8.20	1.35	2.06	3.65	7.06	15.26	15.7
119	1.16	.01	16.95	18.11					18.11	17.4
120	1.14	.01	16.78	17.93					17.93	14.8
121	1.15	.01	16.50	17.66					17.66	19.4
122	1.13	.02	16.39	17.54					17.54	18.6
123	1.12	.02	16.31	17.45					17.45	16.9
124	1.13	.02	16.27	17.42					17.42	19.1
125	1.15	.03	16.10	17.27					17.27	17.1
126	1.16	.03	15.90	17.09					17.09	17.8

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp
127	1.18	.03	16.03	17.24					17.24	18.5
128	1.24	.04	15.98	17.26					17.26	18.4
129	1.31	.04	16.18	17.52					17.52	16.8
130	1.40	.04	16.05	17.49					17.49	17.6
131	1.17	.02	16.69	17.87					17.87	19.2
132	1.16	.02	16.27	17.46					17.46	17.3
133	1.18	.03	15.96	17.17					17.17	17.4
134	1.22	.03	16.17	17.42					17.42	17.8
135	1.25	.04	16.09	17.38					17.38	17.4
136	1.27	.04	16.00	17.32					17.32	18.0
137	1.31	.04	16.07	17.42					17.42	17.4
138	1.35	.04	16.21	17.60					17.60	16.1
139	1.39	.05	16.24	17.67					17.67	20.1
140	1.41	.05	16.32	17.77					17.77	18.2
141	1.43	.05	16.32	17.80					17.80	17.1
142	1.47	.05	16.40	17.92					17.92	20.9
143	1.13	.02	16.40	17.55					17.55	18.2
144	1.13	.02	16.11	17.27					17.27	18.2
145	1.14	.03	15.90	17.07					17.07	17.2
146	1.15	.03	16.07	17.26					17.26	16.7
147	1.15	.04	16.00	17.19					17.19	17.1
148	1.18	.04	16.07	17.29					17.29	16.7
149	1.19	.04	16.15	17.38					17.38	17.5
150	.93	.01	16.25	17.19					17.19	17.4
151	.92	.02	15.89	16.83					16.83	17.4
152	.91	.02	15.49	16.42	.10	.02	1.59	1.71	18.13	18.1
153	.87	.02	14.73	15.63	.17	.16	2.12	2.44	18.07	15.6
154	.71	.02	12.36	13.10	.45	.71	3.07	4.22	17.32	15.8
155	.50	.02	9.36	9.88	.94	1.44	3.69	6.07	15.95	15.8
156	.43	.02	8.17	8.62	1.25	1.92	3.66	6.83	15.45	15.3
157	.33	.02	6.77	7.12	1.67	2.55	3.53	7.74	14.86	14.0
158	.34	.02	6.78	7.13	1.69	2.58	3.55	7.83	14.96	13.4
159	.31	.01	6.37	6.69	1.75	2.65	3.53	7.93	14.62	13.1
160	.86	.01	16.33	17.20					17.20	18.2
161	.85	.02	15.79	16.66					16.66	16.2
162	.75	.02	13.91	14.68	.22	.27	2.56	3.05	17.73	13.3
163	.76	.02	14.21	14.90	.20	.23	2.47	2.90	17.80	16.6
164	.73	.02	13.55	14.29	.26	.35	2.73	3.34	17.63	15.6
165	.53	.02	10.35	10.90	.69	1.06	3.59	5.34	16.25	15.3
166	.32	.01	6.95	7.29	1.33	1.86	3.93	7.13	14.41	14.4
167	.21	.01	5.35	5.57	1.60	2.19	3.76	7.55	13.12	12.3
168	.19	.01	4.96	5.16	1.69	2.32	3.71	7.72	12.88	13.4

Table 26 Continued.

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp
169	.20	.01	5.16	5.36	1.65	2.28	3.67	7.61	12.97	12.3
170	.18	.01	4.76	4.94	1.73	2.39	3.62	7.75	12.70	12.0
171	.82	.01	16.21	17.04					17.04	17.2
172	.81	.02	15.77	16.59					16.59	17.7
173	.77	.02	14.90	15.69	.13	.11	1.99	2.23	17.92	16.6
174	.72	.02	13.76	14.49	.23	.30	2.64	3.18	17.67	24.8
175	.78	.02	14.97	15.77	.13	.12	1.98	2.23	18.00	14.2
176	.54	.02	10.76	11.32	.61	.95	3.50	5.06	16.39	14.2
177	.45	.02	9.16	9.63	.93	1.45	3.60	5.99	15.62.	18.3
178	.45	.02	9.18	9.64	.96	1.54	3.50	5.99	15.63	21.6
179	1.03	.01	16.73	17.76					17.76	16.6
180	1.01	.01	16.36	17.38					17.38	17.1
181	1.00	.02	16.01	17.03					17.03	15.4
182	1.00	.03	15.76	16.79					16.79	13.9
183	1.00	.03	15.53	16.57					16.57	14.1
184	1.01	.04	15.39	16.44					16.44	15.4
185	1.01	.04	15.41	16.46					16.46	13.8
186	1.02	.04	15.29	16.35					16.35	14.9
187	1.02	.05	15.20	16.27					16.27	11.6
188	1.01	.05	15.11	16.17					16.17	13.6
189	1.04	.06	15.02	16.11					16.11	10.8
190	1.05	.07	14.81	15.93					15.93	15.8
191	.90	.06	13.31	14.27	.26	.40	2.03	2.69	16.96	23.0
192	.81	.06	12.52	13.39	.35	.59	2.31	3.25	16.64	30.5
193	.78	.01	16.24	17.03					17.03	15.0
194	.79	.01	15.82	16.62					16.62	15.6
195	.77	.02	15.60	16.38					16.38	14.3
196	.76	.03	15.33	16.11					16.11	15.2
197	.74	.03	15.00	15.77					15.77	15.1
198	.75	.04	14.79	15.57					15.57	14.2
199	.71	.04	13.97	14.72	.13	.11	1.72	1.95	16.67	14.0
200	.63	.04	12.58	13.25	.24	.38	2.26	2.89	16.14	19.3
201	.54	.04	11.42	12.00	.35	.57	2.65	3.56	15.56	10.4
202	.65	.01	15.86	16.52					16.52	15.0
203	.65	.01	15.64	16.30					16.30	13.2
204	.65	.02	15.36	16.03					16.03	13.1
205	.66	.03	15.09	15.77					15.77	13.1
206	.67	.03	14.86	15.55					15.55	12.8
207	.67	.04	14.65	15.36					15.36	12.4
208	.63	.04	13.49	14.16	.14	.16	1.89	2.20	16.36	12.4
209	.59	.04	12.72	13.35	.21	.32	2.19	2.71	16.07	11.4
210	.52	.04	11.43	11.98	.33	.54	2.65	3.51	15.50	9.7
211	.48	.01	15.31	15.81					15.81	14.7

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. Δp	EXP. Δp
212	.49	.01	14.97	15.48					15.48	13.8
213	.50	.02	14.65	15.17					15.17	13.8
214	.48	.03	13.49	14.00	.10	.09	1.82	2.00	16.00	12.7
215	.45	.03	12.59	13.07	.15	.20	2.26	2.61	15.68	4.4
216	.39	.03	11.11	11.53	.26	.39	2.80	3.44	14.97	12.1
217	.39	.02	10.92	11.53	.27	.40	2.87	3.55	14.88	12.4
218	.33	.01	13.69	14.03					14.03	11.1
219	.28	.01	11.47	11.76	.11	.09	2.79	2.98	14.74	11.9
220	.25	.01	10.30	10.56	.16	.17	3.31	3.64	14.20	12.5
221	.21	.01	8.58	8.79	.26	.29	3.87	4.42	13.21	10.8
222	.18	.01	7.66	7.85	.32	.37	3.97	4.66	12.52	10.0
223	.17	.01	6.97	7.15	.38	.46	4.00	4.84	11.99	8.7
224	.17	.01	6.96	7.14	.39	.46	3.97	4.82	11.96	10.3
225	1.13	.01	16.82	17.96					17.96	16.9
226	1.10	.01	16.56	17.67					17.67	16.2
227	.68	.01	11.29	11.97	.72	1.00	3.96	5.68	17.65	16.4
228	.81	.01	12.53	13.35	.56	.82	3.54	4.92	18.26	16.5
229	.62	.01	10.23	10.86	.96	1.37	4.06	6.39	17.25	17.3
230	.32	.01	9.26	9.59	.85	1.29	3.57	5.71	15.30	13.1
231	.26	.01	8.42	8.69	1.00	1.50	3.42	5.92	14.60	14.6
232	.18	.01	6.76	6.94	1.29	1.85	3.22	6.36	13.30	13.1
233	.14	.00	6.14	6.29	1.39	1.97	3.02	6.37	12.66	12.1
234	.10	.00	5.31	5.41	1.49	2.11	2.72	6.31	11.73	12.4
235	.09	.00	5.11	5.21	1.51	2.20	2.51	6.23	11.43	10.4
236	1.11	.01	16.76	17.89					17.89	18.1
237	.98	.01	14.60	15.59	.29	.35	2.72	3.36	18.95	18.0
238	.43	.01	7.29	7.73	1.68	2.16	4.47	8.31	16.04	13.0
239	.53	.01	9.20	9.74	1.24	1.80	4.00	7.03	16.77	22.8
240	.21	.01	5.25	5.46	2.08	2.69	3.78	8.55	14.01	14.2
241	.23	.01	6.50	6.74	1.57	2.16	3.61	7.34	14.08	14.9
242	.10	.01	3.58	3.69	2.29	2.93	3.21	8.43	12.12	13.4
243	.07	.00	2.76	2.83	2.42	3.19	2.88	8.49	11.32	7.3
244	.05	.00	2.34	2.39	2.30	3.11	2.67	8.08	10.47	16.6
245	.04	.00	2.35	2.40	2.15	3.00	2.52	7.67	10.07	10.2
246	.04	.00	2.56	2.60	1.82	2.86	2.33	7.00	9.61	10.1
247	.04	.00	2.57	2.61	1.73	2.85	2.25	6.83	9.43	11.5
248	1.10	.01	15.94	18.50					18.50	17.8
249	.89	.01	14.21	15.12	.32	.44	2.89	3.65	18.77	16.6
250	.10	.00	3.57	3.67	1.51	1.63	4.41	7.56	11.23	11.0
251	.08	.00	3.37	3.46	1.65	1.87	3.84	7.36	10.31	11.1
252	.06	.00	2.97	3.02	1.71	2.09	3.11	6.91	9.94	11.2
253	.04	.00	2.56	2.60	1.69	2.25	2.61	6.55	9.15	9.9
254	.03	.00	2.36	2.39	1.41	2.25	2.27	5.92	8.31	10.1

Table 26 Concluded

TEST NO.	SINGLE PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TWO-PHASE COMPONENTS FRICT.	ACCEL.	GRAV.	TOTAL	TOTAL CAL. ΔP	EXP. ΔP
1	1.12	.00	17.20	18.33					18.33	18.9
2	1.09	.01	16.97	18.06					18.06	17.8
3	1.07	.01	16.79	17.87					17.87	17.8
4	1.12	.01	16.70	17.82					17.82	18.0
5	1.01	.01	16.57	17.60					17.60	17.8
6	1.17	.01	16.93	18.11					18.11	17.8
7	1.15	.01	16.87	18.03					18.03	18.0
8	1.14	.01	16.79	17.94					17.94	17.8
9	1.13	.02	16.67	17.82					17.82	17.7
10	1.03	.02	16.68	17.73					17.73	17.7
11	.92	.01	16.66	17.59					17.59	17.8
12	.91	.01	16.59	17.52					17.52	17.5
13	.94	.02	16.48	17.44					17.44	17.5
14	.97	.02	16.45	17.44					17.44	17.2
15	.98	.02	16.43	17.43					17.43	17.4
16	.99	.02	16.49	17.50					17.50	17.3
17	1.04	.02	16.40	17.46					17.46	17.1
18	.61	.01	15.69	16.31	.13	.40	1.37	1.91	18.22	16.3
19	.58	.01	15.04	15.64	.29	1.23	1.14	2.66	18.30	15.5
20	.50	.01	13.15	13.66	.90	2.96	1.16	5.01	18.67	17.2
21	.74	.01	16.19	16.94					16.94	16.5
22	.76	.01	16.16	16.93					16.93	16.2
23	.76	.01	16.12	16.90					16.90	15.9
24	.76	.02	16.00	16.78					16.78	15.1
25	.65	.02	13.86	14.53	.48	1.72	1.35	3.56	18.08	16.3
26	.16	.00	5.96	6.12	3.82	6.51	1.28	11.60	17.72	20.3
27	.12	.00	4.55	4.68	4.60	7.37	1.31	13.28	17.96	16.3
28	.75	.01	16.28	17.04					17.04	16.7
29	.74	.01	16.18	16.93					16.93	16.9
30	.76	.01	16.09	16.86					16.86	16.4
31	.80	.02	15.99	16.80					16.80	16.2
32	.82	.02	16.02	16.86					16.86	15.7
33	.33	.01	9.68	10.02	1.78	4.00	1.42	7.20	17.22	16.0
34	.11	.00	4.35	4.47	4.57	7.25	1.32	13.15	17.62	15.5
35	.42	.01	15.86	16.29					16.29	16.2
36	.05	.00	4.34	4.39	1.80	2.44	1.50	5.74	10.14	11.3
37	.02	.00	2.79	2.81	1.44	2.39	1.19	5.02	7.82	12.6
38	.02	.00	2.40	2.42	1.39	2.23	1.21	4.83	7.25	14.1

NOTE: ALL PRESSURE DROP VALVES HAVE THE UNITS OF kN/m^2

Table 27 COMPARISON OF MEASURED PRESSURE DROP WITH THAT PREDICTED BY THE HOMOGENEOUS THEORY FOR THE BIPHENYL-BIPHENYL OXIDE TEST SERIES

TEST NO.	TEST COUNT NO.1	TEST COUNT NO.2	AVERAGE OF TEST COUNTS I	EMPTY TUBE COUNT I_2	FULL TUBE COUNT (COLD)	TEST SECTION EXIT TEMP.	FULL TUBE TEMP. CORRECT. FACTOR	CORRECT. FULL TUBE COUNT I_1	EXP. VOID FRACTION	CAL. TEST SECTION EXIT QUALITY
1	104532		104532	121001	104184	168.8	1.0278	107080		
2	104301	103870	104085	"	"	"	"	"		
3	103605	103749	103677	"	"	"	"	"		
4	103727	103616	103671	"	"	"	"	"		
5	103786	104079	103932	"	"	193.6	1.0326	107580		
6	105098	106122	105610	"	"	201.7	1.0340	107726		
7	111691	111524	111607	"	"	209.3	1.0354	107872	.296	.06
8	112935	112790	112863	"	"	208.2	1.0351	107840	.395	.08
9	114044	113810	113927	"	"	213.2	1.0360	107934	.473	.19
10	114758	114483	114620	"	"	210.2	1.0356	107892	.527	.29
11	114984	114712	114848	"	"	210.5	"	"	.545	.45
12	110360	111245	110802	119993	103841	209.6	"	107537	.273	.05
13	111366	111670	111518	"	"	209.3	1.0354	107516	.333	.05
14	111442	112422	111932	"	"	209.6	1.0356	107537	.365	.06
15	114067	113894	113981	"	"	209.3	1.0354	107516	.532	.21
16	113888	113654	113771	"	"	211.1	1.0357	107548	.514	.19
17	113796	114199	113997	"	"	210.2	1.0356	107537	.532	.17
18	102956	103650	103303	116950	102561	202.6	1.0342	106068		
19	103047	103127	103087	"	"	203.6	"	"		
20	106338	107726	107032	"	"	208.4	1.0354	106191	.082	.02
21	107668	107555	107611	"	"	209.6	1.0356	106212	.136	.03
22	112501	112523	112512	"	"	210.8	"	"	.598	.17
23	112653	112888	112770	"	"	210.2	"	"	.622	.18
24	113275	113135	113205	"	"	211.1	1.0357	106222	.662	.54
25	113068	113484	113276	"	"	"	"	"	.668	.48
26	113461	113398	113429	"	"	"	"	"	.682	.72
27	112895		112895	"	"	212.0	1.0355	106202	.634	.69
28	108742	108899	108820	118950	102132	208.8	1.0354	105747	.243	.01
29	109459	110017	109738	"	"	"	"	"	.315	.02
30	111912	111672	111792	"	"	"	"	"	.472	.07
31	112665	112094	112379	"	"	"	"	"	.517	.12
32	112148	111816	111982	"	"	209.0	"	"	.487	.20
33	113082	113565	113323	"	"	208.4	"	"	.588	.21
34	112781	112566	112673	"	"	208.8	"	"	.539	.32
35	112678	112672	112675	"	"	208.4	"	"	.539	.34
36	113133	112926	113029	"	"	"	"	"	.566	.41
37	113084	112292	112688	"	"	208.8	"	"	.540	.41
38	113788	113322	113555	"	"	209.3	1.0355	105757	.605	.58
39	113436	113635	113535	"	"	209.6	1.0356	105767	.603	.57
40	113629	113867	113748	"	"	"	"	"	.612	.72
41	113834	113403	113618	"	"	209.3	1.0355	105757	.610	.74
42	114282	113792	114037	"	"	210.2	1.0356	105767	.641	.70
43	103002	102433	102717	117764	101310	186.4	1.0311	104460		
44	102551	103135	102843	"	"	187.4	1.0314	104491		
45	107751	107918	107834	"	"	207.8	1.0351	104866	.241	.02
46	108949	109631	109290	"	"	208.2	1.0354	104896	.355	.02
47	102532	102734	102633	"	"	198.8	1.0335	104703		
48	102342	102361	102351	"	"	210.7	1.0357	104926		
49	112444	112362	112403	"	"	208.2	1.0354	104896	.597	.11
50	111270	111699	111484	"	"	207.6	1.0351	104866	.527	.09
51	111692	111347	111519	"	"	207.4	1.0349	104845	.531	.09
52	113596	113569	113582	"	"	208.6	1.0354	104896	.688	.34
53	113161	113219	113190	"	"	208.4	"	"	.658	.33
54	101753	102134	101943	115594	100435	194.9	1.0328	103729		
55	102167	102419	102293	"	"	208.4	1.0354	103990		
56	101079	101722	101400	"	"	222.8	1.0380	104251		
57	101584	101810	101697	"	"	233.6	1.0400	104452		
58	95875	96158	96016	109340	94525	200.5	1.0337	97710		
59	94792	95495	95143	"	"	211.4	1.0357	97899		
60	96019	96136	96077	108798	94752	232.6	1.0399	98533		
61	99467	99611	99539	"	"	244.0	1.0421	98741	.083	.03
62	101348	101796	101572	"	"	245.0	1.0423	98760	.290	.08
63	102506		102506	"	"	243.7	1.0421	98741	.386	.11
64	101526	102084	101805	"	"	244.8	1.0423	98760	.314	.09
65	103520	103828	103674	"	"	243.7	1.0421	98741	.503	.26
66	102990	102908	102949	"	"	241.9	1.0416	98693	.433	.15
67	95988	95930	95959	109884	94736	218.4	1.0370	98241		
68	95598	95917	95757	"	"	232.4	1.0399	98515		
69	97139	97578	97358	"	"	240.0	1.0412	98639		
70	101392	100648	101020	"	"	243.7	1.0421	98724	.215	.07
71	103376	103934	103655	"	"	245.2	1.0423	98743	.454	.15
72	103118	103028	103073	"	"	245.0	"	"	.401	.14
73	103767	104167	103967	"	"	243.1	1.0421	98724	.483	.22
74	104478	104648	104563	"	"	245.6	1.0423	98743	.536	.30
75	104445	104378	104411	"	"	244.8	"	"	.522	.41

TABLE 28 SUMMARY OF INTEGRAL COUNT MEASUREMENTS OBTAINED WITH THE GAMMA-RAY ATTENUATION APPARATUS FOR THE DETERMINATION OF THE TEST SECTION EXIT VOID FRACTION

TEST NO.	TEST COUNT NO. 1	TEST COUNT NO. 2	AVERAGE OF TEST COUNTS I	EMPTY TUBE COUNT I_2	FULL TUBE COUNT (COLD)	TEST SECTION EXIT TEMP.	FULL TUBE TEMP. CORRECT. FACTOR	CORRECT. FULL TUBE COUNT I_1	EXP. VOID FRACTION	CAL. TEST SECTION EXIT QUALITY
76	88735	88794	88764	99450	86368	236.0	1.0404	89857		
77	86289	86364	86326	96926	83990	234.0	1.0400	87350		
78	88367	88553	88460	"	"	240.4	1.0412	87450	.112	.01
79	91295	90856	91075	"	"	244.2	1.0423	87543	.388	.06
80	93163	93159	93161	"	"	244.6	"	"	.611	.14
81	93177	93264	93220	"	"	"	"	"	.617	.14
82	94007	94487	94247	"	"	244.4	"	"	.725	.24
83	94842	94205	94523	"	"	243.7	1.0421	87526	.754	.21
84	94581	94757	94669	"	"	244.6	1.0423	87543	.769	.32
85	94906	94577	94741	"	"	245.4	"	"	.776	.40
86	94720	95260	94990	"	"	"	"	"	.802	.53
87	94635	95043	94839	"	"	246.0	1.0424	87551	.786	.57
88	94904	94454	94679	"	"	245.6	1.0423	87543	.770	.58
89	86113	86087	86100	97052	83590	239.0	1.0411	87025		
90	88258	88962	88610	"	"	241.9	1.0416	87067	.161	.01
91	89070	89724	89397	97052	83590	242.5	1.0416	87067	.242	.03
92	91813	91700	91756	"	"	245.0	1.0423	87126	.480	.08
93	92253	92385	92319	"	"	245.2	"	"	.537	.10
94	93149	93922	93535	"	"	245.0	"	"	.658	.18
95	93785	93954	93870	"	"	245.4	"	"	.691	.21
96	94202	94461	94331	"	"	245.0	"	"	.736	.27
97	93566	94318	93942	"	"	244.2	1.0422	87117	.698	.29
98	94482	94376	94429	"	"	244.6	1.0423	87126	.746	.39
99	94037	94588	94312	"	"	244.4	1.0422	87117	.735	.48
100	94996	94729	94863	"	"	244.6	1.0423	87126	.789	.63
101	94506	94877	94691	"	"	244.4	1.0422	87117	.772	.62
102	94467	94414	94440	"	"	243.7	1.0421	87109	.748	.74
103	94871	-	94871	"	"	244.6	1.0423	87126	.789	.74
104	94630	-	94630	"	"	245.0	"	"	.766	.76
105	94411	-	94411	"	"	244.6	"	"	.744	.77
106	83316	83095	83205	93342	80281	217.2	1.0368	83235		
107	82988	83210	83099	"	"	224.6	1.0383	83355		
108	82205	81658	81931	92748	79788	227.6	1.0390	82899		
109	81804	81786	81795	"	"	242.8	1.0419	83131		
110	81944	82114	82029	"	"	251.2	1.0433	83242		
111	81859	81988	81923	"	"	257.6	1.0446	83346		
112	81798	82452	82125	"	"	264.8	1.0460	83458		
113	82094	81578	81836	"	"	266.0	1.0462	83474		
114	81865	82225	82045	"	"	269.8	1.0469	83530		
115	83524	83756	83640	"	"	280.0	1.0488	83681		
116	86088	86287	86187	"	"	283.4	1.0495	83737	.282	.10
117	85930	86171	86050	"	"	284.2	1.0497	83753	.265	.09
118	89012	-	89012	"	"	284.6	1.0498	83761	.597	.33
119	79846	80405	80125	90423	77669	236.6	1.0406	80822		
120	79897	79721	79809	"	"	245.8	1.0423	80954		
121	79831	79832	79831	"	"	254.2	1.0440	81086		
122	79703	79722	79712	"	"	261.8	1.0454	81195		
123	80308	79781	80044	"	"	267.4	1.0464	81272		
124	80391	80217	80304	"	"	270.7	1.0471	81327		
125	80185	80185	80185	"	"	274.2	1.0479	81389		
126	80518	81007	80762	"	"	281.2	1.0490	81475		
127	81097	80799	80948	"	"	284.4	1.0498	81537		
128	81152	81565	81358	"	"	285.0	"	"		
129	80874	80567	80720	"	"	282.4	1.0493	81498		
130	82329	82388	82358	"	"	285.0	1.0498	81537		
131	77358	77555	77456	87391	75202	250.6	1.0433	78458		
132	77727	78053	77890	"	"	267.0	1.0464	78691		
133	78299	78480	78389	"	"	278.4	1.0486	78857		
134	78018	77864	77941	"	"	276.0	1.0481	78819		
135	78885	78481	78683	"	"	279.2	1.0488	78871		
136	79506	79146	79326	87391	75202	282.7	1.0494	78916		
137	79627	79237	79432	"	"	"	"	"		
138	79578	79432	79505	"	"	281.5	1.0492	78901		
139	79225	79399	79312	"	"	282.4	1.0493	78909		
140	79790	79749	79769	"	"	282.7	1.0494	78916		
141	79075	79799	79437	"	"	282.4	1.0493	78909		
142	79978	79923	79950	"	"	283.4	1.0495	78924		
143	76720	76935	76827	86411	74680	259.5	1.0450	78040		
144	77453	77563	77508	"	"	272.6	1.0474	78219		
145	78915	78960	78937	"	"	281.2	1.0490	78339		
146	78045	77881	77963	"	"	278.8	1.0487	78317		
147	78989	78521	78755	"	"	282.4	1.0493	78361		
148	79256	78884	79070	"	"	282.1	"	"		
149	78814	79115	78964	"	"	282.4	"	"		

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TEST NO.	TEST COUNT NO. 1	TEST COUNT NO. 2	AVERAGE OF TEST COUNTS I	EMPTY TUBE COUNT I_2	FULL TUBE COUNT (COLD)	TEST SECTION EXIT TEMP.	FULL TUBE TEMP. CORRECT. FACTOR	CORRECT. FULL TUBE COUNT I_1	EXP VOID FRACTION	CAL.TEST SECTION EXIT QUALITY
150	76368	76419	76394	85143	73271	261.6	1.0454	76597		
151	76135	76007	76071	"	"	276.0	1.0481	76795		
152	77526	77342	77434	"	"	281.5	1.0492	76875	.071	.01
153	78573	77957	78265	"	"	283.6	1.0495	76898	.173	.02
154	79908	80225	80066	"	"	285.6	1.0499	76927	.394	.10
155	81629	81285	81457	"	"	285.0	1.0498	76919	.564	.22
156	82231	81828	82030	"	"	285.9	1.0500	76934	.633	.31
157	82259	82628	82443	"	"	286.8	1.0508	76993	.680	.44
158	82825	82685	82755	"	"	284.2	1.0498	76919	.720	.43
159	82565	82101	82333	"	"	287.7	1.0508	76993	.666	.47
160	75503	75261	75382	84245	72977	259.8	1.0450	76260		
161	76270	75765	76017	"	"	278.4	1.0486	76523		
162	77984	78461	78222	"	"	283.4	1.0495	76589	.221	.04
163	77997	78235	78116	"	"	"	"	"	.207	.04
164	77944	78032	77988	"	"	283.6	"	"	.190	.05
165	80385	79991	80188	"	"	284.2	1.0498	76611	.480	.17
166	81707	81805	81756	"	"	"	"	"	.684	.34
167	82123	82016	82069	"	"	285.0	"	"	.725	.48
168	82264	82445	82355	"	"	"	"	"	.761	.52
169	82402	82407	82404	"	"	284.6	"	"	.767	.52
170	82284	82019	82151	"	"	285.3	"	"	.735	.56
171	75696	75499	75597	84841	72824	264.2	1.0460	76173		
172	75911	75571	75741	"	"	279.6	1.0490	76392		
173	76373	77074	76723	"	"	283.8	1.0497	76443	.035	.02
174	78069	77798	77933	"	"	284.2	1.0498	76450	.184	.05
175	76901	76672	76786	"	"	283.8	1.0497	76443	.043	.02
176	79651	79640	79645	"	"	284.8	1.0498	76450	.393	.16
177	80126	79933	80030	"	"	286.8	1.0508	76523	.434	.25
178	81009	80911	80960	"	"	286.5	1.0501	76472	.549	.27
179	73372	73466	73419	82966	71492	246.6	1.0423	74516		
180	73345	73358	73351	"	"	264.2	1.0460	74780		
181	73964	73133	73548	82966	71492	277.6	1.0483	74945		
182	73505	73276	73390	"	"	289.2	1.0506	75109		
183	74381	74045	74213	"	"	297.0	1.0522	75223		
184	73636	73759	73698	"	"	302.0	1.0530	75281		
185	74482	73900	74191	"	"	303.8	1.0534	75309		
186	73763	73938	73850	"	"	308.6	1.0544	75381		
187	73913	74156	74034	"	"	312.0	1.0551	75431		
188	73934	73913	73923	"	"	315.2	1.0556	75467		
189	73908	74868	74388	"	"	317.0	1.0561	75502		
190	75612	75095	75353	"	"	321.0	1.0568	75552		
191	76127	76467	76297	"	"	325.2	1.0574	75595	.099	.11
192	76299	77236	76767	"	"	325.8	1.0576	75610	.164	.17
193	73101	72755	72928	81473	70010	263.0	1.0457	73209		
194	73044	72769	72906	"	"	280.3	1.0490	73440		
195	73146	73264	73205	"	"	290.0	1.0508	73566		
196	73658	73562	73610	"	"	300.4	1.0527	73699		
197	73944	73169	73556	"	"	310.8	1.0549	73853		
198	74595	74640	74617	"	"	317.2	1.0561	73937		
199	74715	75157	74936	"	"	323.4	1.0573	74021	.128	.04
200	76124	76105	76114	"	"	324.2	"	"	.291	.15
201	76292	76855	76573	"	"	326.0	1.0576	74042	.351	.24
202	72174	72038	72106	80452	69177	276.8	1.0580	73189		
203	71890	72424	72157	"	"	288.6	1.0507	72684		
204	71788	71942	71865	"	"	299.1	1.0524	72802		
205	71795	71849	71822	"	"	308.4	1.0544	72940		
206	72356	72151	72253	"	"	315.8	1.0549	72974		
207	73196	73384	73290	"	"	322.8	1.0572	73133		
208	73903	73622	73762	"	"	324.0	1.0573	73140	.089	.07
209	74476	74496	74486	"	"	325.6	1.0574	73147	.191	.14
210	74911	74560	74735	"	"	325.2	"	"	.226	.24
211	71659	71664	71661	79667	68821	291.2	1.0510	72330		
212	71765	71757	71761	"	"	303.2	1.0534	72496		
213	72023	72297	72160	"	"	313.2	1.0504	72289		
214	73426	73727	73576	"	"	323.4	1.0573	72764	.122	.05
215	74235	74195	74215	"	"	324.4	1.0574	72771	.217	.12
216	75013	74583	74798	"	"	325.6	1.0576	72785	.302	.23
217	74684	74866	74775	"	"	"	"	"	.299	.24
218	72625	72330	72477	79241	68484	320.6	1.0568	72373		
219	73571	73215	73393	"	"	324.0	1.0573	72408	.150	.09
220	74472	74300	74386	"	"	324.8	1.0574	72415	.298	.16
221	75500	75808	75654	"	"	324.2	1.0573	72408	.486	.27
222	75944	75411	75677	"	"	325.6	1.0574	72415	.489	.37
223	76377	76184	76280	"	"	325.8	1.0576	72428	.576	.46
224	76332	76159	76245	"	"	325.4	1.0574	72415	.572	.46

TEST NO.	TEST COUNT NO. 1	TEST COUNT NO. 2	AVERAGE OF TEST COUNTS I	EMPTY TUBE COUNT I_2	FULL TUBE COUNT (COLD)	TEST SECTION EXIT TEMP.	FULL TUBE TEMP. CORRECT. FACTOR	CORRECT. FULL TUBE COUNT I_1	EXP. VOID FRACTION	CAL. TEST SECTION EXIT QUALITY
225	69280	68909	69094	78047	66894	241.6	1.0416	69676		
226	69487	69308	69397	"	"	252.4	1.0435	69803		
227	73298	73571	73434	"	"	254.8	1.0440	69837	.452	.08
228	71419	72370	71894	"	"	255.4	1.0442	69850	.260	.06
229	74196	73733	73964	"	"	255.7	"	"	.516	.10
230	74036	74603	74319	"	"	256.4	1.0444	69864	.558	.18
231	74699	74452	74575	"	"	256.8	1.0445	69870	.589	.24
232	74873	75092	74982	"	"	256.0	1.0442	69850	.639	.35
233	75069	75302	75185	"	"	256.4	1.0444	69864	.663	.43
234	75788	75665	75726	"	"	256.8	1.0445	69870	.727	.56
235	75900	76526	76213	"	"	256.4	1.0444	69864	.785	.65
236	68304	67890	68097	76749	66023	243.7	1.0418	68783		
237	70828	71418	71123	"	"	256.4	1.0444	68954	.289	.03
238	74410	74142	74276	"	"	256.8	1.0445	68961	.694	.17
239	73950	73935	73942	"	"	"	"	"	.692	.14
240	74678	74543	74606	"	"	255.1	1.0442	68941	.736	.33
241	74392	74769	74580	"	"	257.4	1.0445	68954	.732	.31
242	75434	75074	75234	"	"	256.6	1.0444	68961	.816	.53
243	75163	74925	75044	"	"	259.8	1.0450	68994	.789	.70
244	75438	75621	75529	"	"	256.0	1.0442	68941	.851	.80
245	75611	75614	75612	"	"	254.8	1.0440	68928	.861	.85
246	75965	74958	75461	"	"	256.4	"	"	.842	.96
247	75658	75176	75417	"	"	255.7	1.0442	68941	.837	1.00
248	67921	67613	67767	76262	65707	236.3	1.0408	68387		
249	69885	70512	70198	"	"	256.0	1.0442	68611	.216	.03
250	74006	74368	74187	"	"	256.6	1.0444	68624	.739	.31
251	74170	74575	74372	"	"	"	"	"	.762	.40
252	74329	74423	74376	"	"	256.4	"	"	.763	.59
253	74483	74433	74458	"	"	256.2	1.0442	68611	.773	.80
254	74689	74393	74541	"	"	255.4	"	"	.784	1.00
				TESTS WITH BIPHENYL-BIPHENYL OXIDE						
1	55353	54890	55121	62480	54483	246.6	1.0335	56308		
2	54326	54715	54521	"	"	264.8	1.0365	56471		
3	54772	55039	54906	"	"	277.8	1.0388	56596		
4	55256	54948	55102	"	"	286.2	1.0402	56673		
5	57855	56762	57308	"	"	295.4	1.0418	56760		
6	52998	53161	53080	61406	53395	268.9	1.0372	55381		
7	53442	53724	53583	"	"	277.6	1.0388	55466		
8	54447	54866	54656	"	"	284.6	1.0399	55525		
9	56255	55938	56096	"	"	291.6	1.0412	55595		
10	56324	56342	56333	"	"	293.8	1.0416	55616		
11	52606	53237	52921	60920	53019	288.6	1.0407	55177		
12	52271	52503	52387	"	"	295.6	1.0418	55235		
13	52599	52828	52713	"	"	306.1	1.0437	57649		
14	53810	53251	53530	60920	53019	312.4	1.0448	55394		
15	54026	54013	54020	"	"	314.6	1.0452	55415		
16	54158	53804	53981	"	"	315.2	1.0453	55420		
17	55164	55264	55214	"	"	320.0	1.0460	55458		
18	55484	-	55484	"	"	320.6	"	"	.005	.02
19	55690	56040	55865	"	"	323.1	1.0466	55489	.072	.06
20	56616	56942	56779	"	"	324.2	1.0468	55500	.245	.14
21	53104	53155	53130	60684	52861	318.6	1.0459	55287		
22	53370	53507	53439	"	"	326.6	1.0473	55361		
23	54646	54600	54623	"	"	332.4	1.0484	55419		
24	56676	55726	56201	"	"	339.2	1.0494	55472		
25	56688	56970	56829	"	"	341.0	1.0496	55482	.268	.09
26	57233	57465	57349	"	"	"	"	"	.369	.62
27	57641	57708	57675	"	"	"	"	"	.433	.72
28	52421	51649	52035	59795	51821	313.2	1.0449	54147		
29	52066	52284	52175	"	"	324.2	1.0468	54246		
30	52505	52538	52521	"	"	332.2	1.0484	54329		
31	53996	53824	53910	"	"	342.2	1.0498	54402		
32	54021	54242	54131	"	"	343.6	1.0500	54412		
33	56494	56508	56501	"	"	343.0	1.0499	54406	.400	.34
34	56191	56545	56368	"	"	341.8	1.0497	54396	.376	.73
35	51579	52191	51885	58583	50861	333.6	1.0485	53327		
36	56566	56673	56620	"	"	343.0	1.0499	53398	.632	.62
37	56955	56277	56616	"	"	342.8	"	"	.631	1.00
38	56094	56376	56235	"	"	342.2	1.0498	53393	.560	1.00

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