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Cavitation Inception in Immersed Jet Shear Flows

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Abstract. Cavitation inception occurring in immersed jets was investigated in a purpose-built mechanical flow rig. The rig utilized custom-built cylindrical and conical nozzles to direct high-velocity jets of variable concentration n-octane-hexadecane mixtures into a fused silica optically accessible receiver. The fluid pressure upstream and down-stream of the nozzles were manually controlled. The study employed a variety of acrylic and metal nozzles. The results show that the critical upstream pressure to downstream pressure ratio for incipient cavitation decreases with increasing n-octane concentration for the cylindrical nozzles, and increases with increasing n-octane concentration for the conical nozzle.

1. Introduction

Cavitation inception in immersed liquid jet flows into liquid has been investigated extensively over the years. The results obtained have been inconsistent and ambiguous, and largely dependent on the particular experimental configuration [1]. It is thought that cavitation inception in shear jet flows is specified by the behaviour of the turbulent vortices that develop in the liquid surrounding the jet [2]. The transition of a homogeneous liquid flow to a multi-phase cavitating flow is important in a number of engineering and scientific applications, ranging from cavitating flows in hydraulic pumps [3], in the neighbourhood of, and on the surface of marine propeller blades [4], to cavitating flows occurring inside diesel injector nozzles [5], and diesel fuel injection equipment (FIE) spill-return valves [6].

This paper is focused on the determination of the conditions necessary for cavitation to occur in diesel pumps and nozzles using diesel-like mixtures. Cavitation occurring in these devices may result in surface erosion and/or carbonaceous deposits [6]. This may lead to declining performance, and in extreme cases, equipment failure.

2. Experimental

2.1. Experimental Setup

A custom mechanical flow rig was designed and manufactured at City University in order to investigate and determine the variables affecting cavitation inception occurring in high-speed liquid jets into stationary liquid. The different components of the rig are shown in Figure 1 below. The high pressure bottles and control valve enabled the variation of absolute fluid pressure upstream of the nozzle from 0.2 MPa to 10.0 MPa, while the fused silica receiver and downstream control valve enabled the variation of absolute fluid pressure downstream of the nozzle from 0.1 MPa to 2.0 MPa. The fused silica receiver was 150 mm long, with an inner diameter of 60 mm inner diameter and an outer diameter of 70 mm. It provided optical access to the cavitating jet flow and was capable of supporting a fluid pressure of up to 2.7 MPa. Upstream and downstream fluid pressures were



measured using pressure gauges. Custom cylindrical and conical nozzles with 0.14 mm and 0.25 mm nozzle exit diameters with sharp internal edges were manufactured in the City University School of Engineering workshop using acrylic (for optical access), brass and aluminium. Figure 2 shows the design profile of the three nozzle types employed in this study.

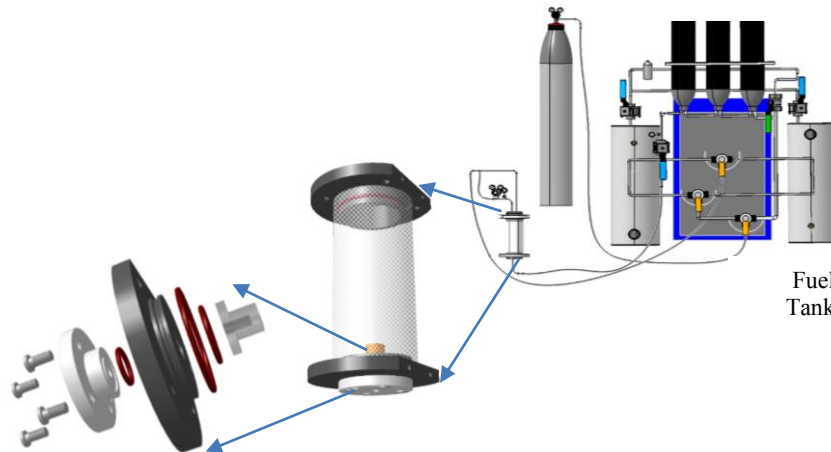


Figure 1: Detailed design of the mechanical flow rig used for the study of incipient cavitation.

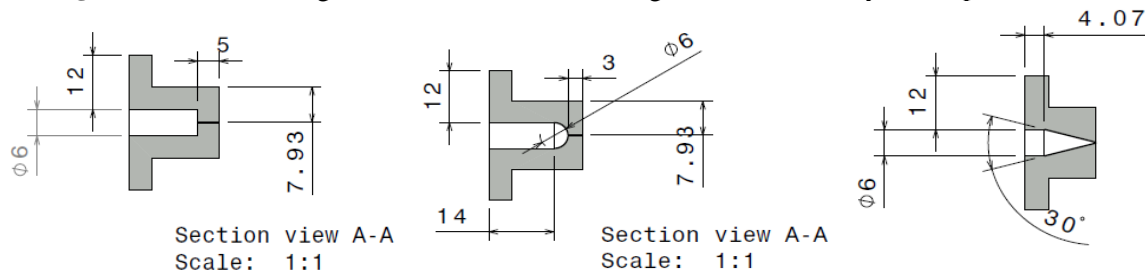


Figure 2: Nozzle design layout for cylindrical, hemispherical, and conical nozzles.

2.2 Liquid Samples

various mixtures of n-octane in n-hexadecane were prepared for the incipient cavitation experiment (0.1%, 1.0%, and 10.0% v/v). The hexadecane and n-octane were both 99% pure, supplied by Alfa-Aesar and Sigma-Aldrich respectively. The mixture properties are specified in Table 1 below.

Mixture (% n-octane- hexa-decane v/v)	0.10%	1.0%	10.0%
Density @ 20 °C (kg/l)	0.7734	0.7727	0.7664
Estimated Viscosity @ 20 °C (Ns)	0.003462	0.003361	0.002548

Table 1: Properties of n-octane-hexadecane mixtures.

2.3 Experimental Methodology

The high pressure bottles containing approx. 10.5 l of fuel mixture in total were filled in sequence using 2 atm pressure obtained from a nitrogen bottle, which was connected to the tank through a priming valve. Once the high-pressure bottles were filled and isolated, the high-pressure valve was opened to admit high pressure nitrogen, which was employed to force the mixture through the nozzle into the fused silica receiver, and then on to the receiving tank at ambient pressure.

In order to obtain incipient cavitation in the nozzle or receiver, the downstream fluid pressure was initially set to ambient. The upstream fluid pressure was adjusted and set using the upstream needle valve. This caused the mixture to cavitate in the receiver. The downstream receiver mixture pressure was then increased until the cavitation stopped. Fine adjustment of the downstream mixture pressure enabled the determination of the critical downstream pressure corresponding to the point of cavitation

inception. The measurements were repeated 25 times each in order to obtain a mean and standard deviation of the downstream pressure for incipient cavitation.

3. Results

Cavitation inception could always be observed to occur in the receiver a short distance downstream of the nozzle exit. On occasion, cavitation inception was also observed to occur at the entrance to the nozzle hole. The incipient cavitation in the receiver was always coincident with cavitation being initiated at the entrance to the nozzle. The incipient cavitation was also observed to produce sound noise, which could be heard.

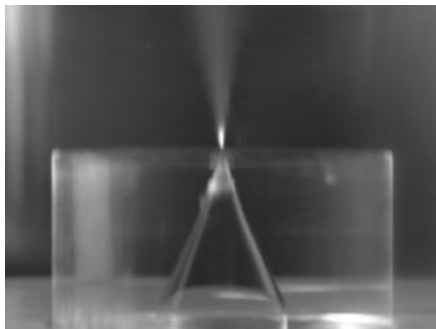


Figure 3: Near incipient cavitation in receiver downstream of nozzle.

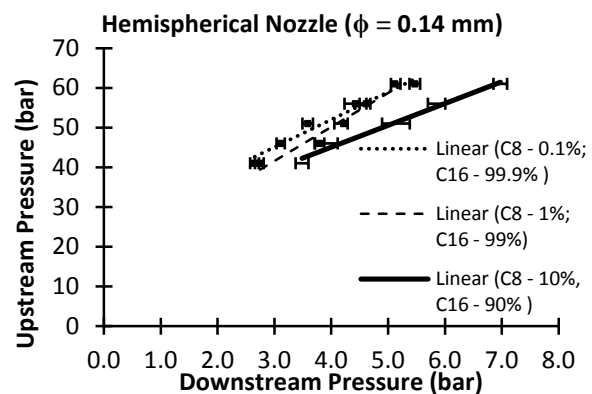


Figure 4: Upstream-downstream incipient cavitation pressure ratio for hemispherical bore nozzle.

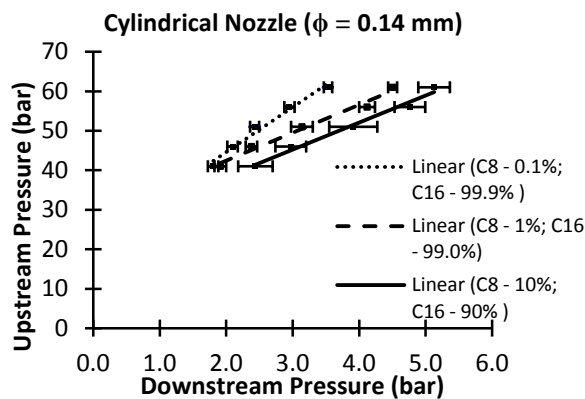


Figure 5: Upstream-downstream incipient cavitation pressure ratio for cylindrical bore nozzle.

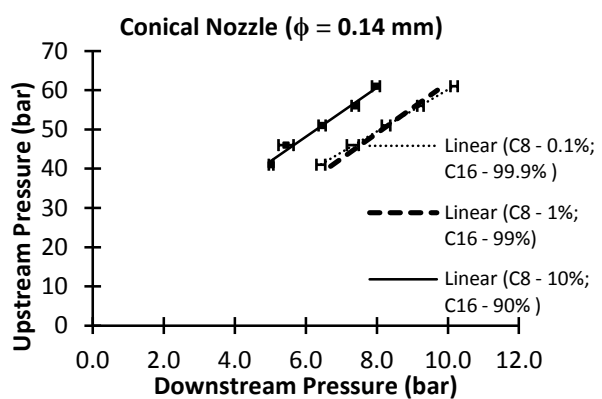


Figure 6: Upstream-downstream incipient cavitation pressure ratio for conical nozzle.

Figure 3 shows a photograph of near incipient cavitation occurring in the receiver, using a conical nozzle. The results of the incipient cavitation measurements are shown in the graphs contained in Figures 4 to 6. Figure 4 shows the upstream to downstream pressure ratio for incipient cavitation for the three n-octane-hexadecane mixtures (0.1%, 1.0%, 10.0% v/v), using a 3 mm long, 0.14 mm diameter cylindrical-hemispherical nozzle. Figure 5 shows the upstream to downstream pressure ratio for incipient cavitation for the three n-octane-hexadecane mixtures, using a 5 mm long, 0.14 mm diameter cylindrical-cylindrical nozzle. Figure 6 shows the upstream to downstream pressure ratio for incipient cavitation for the three n-octane-hexadecane mixtures, using a conical nozzle.

4. Discussion

The graphs presented in Figures 4 and 5 show that the pressure ratio required for incipient cavitation decreased as a function of n-octane concentration in the n-octane-hexadecane mixture, for both the cylindrical nozzles. This was to be expected, as the saturated vapour pressure of the mixture increased

with increased n-octane concentration. However, the conical nozzle appeared to produce the opposite result: the pressure ratio for incipient cavitation increased with increasing n-octane concentration: a counter-intuitive finding.

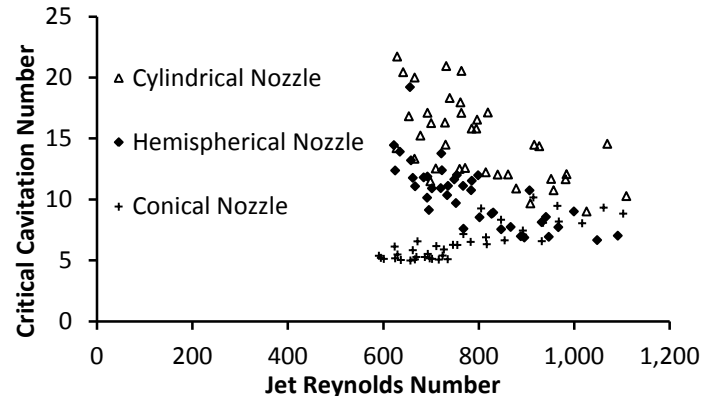


Figure 7: Scatter-graph of Critical Cavitation Number for Inception versus Jet Reynolds Number

Figure 7 shows the critical cavitation number for inception plotted against the jet Reynolds number for the jets developing from the three nozzles. The two cylindrical hole nozzles produce a decreasing critical cavitation number with jet Reynolds number, while the conical nozzle produces an increasing critical cavitation number with jet Reynolds number. This suggests that the character of the flow producing cavitation may be different for the conical nozzle compared with the cylindrical nozzles.

It is thought that cavitation inception in shear jet flows was caused by the fluid pressure in the centre of turbulent vortices adjacent to the jet dropping to below the critical pressure for cavitation to occur. In the case of the cylindrical nozzles, the internal flow was laminar, and the velocity profile was fully developed. This was in contrast to the flow exiting the conical nozzle, which had the character of a plug flow, or even a flow with maximum velocity near the edge of the jet, decreasing towards the central axis [7]. This difference in flow velocity profile appeared to give rise to the difference in the upstream to downstream pressure ratio required for cavitation inception.

5. Conclusion

Cavitation inception has been investigated in mixtures of n-octane in hexadecane in a purpose designed and built mechanical flow rig. Two nozzles with 0.14 mm diameter cylindrical holes and a conical hole nozzle have been employed in the investigation. The flow in the cylindrical nozzle holes was fully developed, laminar flow, leading to a decrease in the upstream to downstream pressure ratio as a function of increasing n-octane concentration in hexadecane (increasing saturation vapour pressure). This is in contrast to the results obtained from the conical nozzle, which showed an increasing upstream to downstream pressure ratio with increasing n-octane concentration in hexadecane. The difference for cavitation inception obtained from the two nozzle types is thought to be caused by the variation in flow velocity profile and resultant turbulent shear mixing in the receiver.

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