
This is the unspecified version of the paper.

This version of the publication may differ from the final published version.

Permanent repository link: http://openaccess.city.ac.uk/2068/

Link to published version:

Copyright and reuse: City Research Online aims to make research outputs of City, University of London available to a wider audience. Copyright and Moral Rights remain with the author(s) and/or copyright holders. URLs from City Research Online may be freely distributed and linked to.
Instabilities and soot formation in high pressure, rich, iso-octane-air explosion flames

R.D. Lockett, R. Morishima
Introduction

• Flame instabilities
• Schlieren and OH PLIF experiments in the Leeds Bomb
• Results
• LII experiments in the Shell Bomb
• Results
• Soot formation hypothesis
• Conclusion
Flame Instabilities

1. Rayleigh-Taylor Instability

This instability is a result of a cold fluid above a hot fluid. The hot fluid is less dense than the cold fluid. Therefore the hot fluid is buoyant relative to the cold fluid.

Therefore irregularities at the interface of the two fluids grow, in order to achieve convection.
Flame Instabilities

2. Landau-Darrius (Hydrodynamic) Instability

Courtesy of R. Woolley, Univ. of Leeds
3. Thermal-Diffusive Instability

\[ Le = \frac{\alpha}{D} < Le^* \equiv O(1) \]
The Leeds Bomb
Schlieren Cinematography in the Leeds Bomb

Conditions:

Iso-octane-air mixture
\( \varphi = 1.0, p = 5 \text{ bar} \)

Viewing diameter
\( D = 15 \text{ cm} \)

Courtesy of R. Woolley, Univ. of Leeds, 2005
OH PLIF in the Leeds Bomb
OH PLIF in the Leeds Bomb

Unprocessed OH PLIF Image of a $\varphi = 1.5$ bar Iso-octane-Air Explosion Flame obtained in the Leeds Bomb (Flame radius $\approx 60$ mm, $Pe \sim 600$)

This reveals the influence of the Darrius-Landau (hydrodynamic) instability.
Schlieren Cinematography in the Leeds Bomb

Conditions:

Iso-octane-air mixture
$\phi = 1.4, p = 5 \text{ bar}$

Viewing diameter
$D = 15 \text{ cm}$

Courtesy of R. Woolley,
Univ. of Leeds, 2005
Schlieren Images of Iso-octane-Air Explosion Flames
(flame radius ~ 60 mm, Pe ~ 600)

\[ P = 5 \text{ bar}, \phi = 1.0 \quad \text{and} \quad P = 5 \text{ bar}, \phi = 1.4 \]
Schlieren Images of Iso-octane-Air Explosion Flames
(flame radius ~ 60 mm, Pe ~ 600)

P = 5 bar, $\varphi = 1.0$

P = 5 bar, $\varphi = 1.4$
OH PLIF in the Leeds Bomb

Unprocessed OH PLIF Image of a \( \phi = 1.4 \), 5 bar Iso-octane-Air Explosion Flame obtained in the Leeds Bomb (Flame radius \( \approx 60 \text{ mm} \), Pe \( \approx 600 \))

This reveals the influence of the Darrius-Landau (hydrodynamic) instability and the thermal-diffusive instability.
Cell Length Scale Analysis

5.5 cm

Cell length (mm)

No. of cells

0 < l < 0.5
0.5 < l < 1.0
1.0 < l < 1.5
1.5 < l < 2.0
2.0 < l < 2.5
2.5 < l < 3.0

Cell Length (mm)

No. of cells

0 < l < 1
1 ≤ l < 2
2 ≤ l < 3
3 ≤ l < 4
4 ≤ l < 5
5 ≤ l < 6
6 ≤ l < 7
7 ≤ l < 8
8 ≤ l < 9
9 ≤ l < 10
10 ≤ l < 11
11 ≤ l < 12
12 ≤ l < 13
13 ≤ l < 14
14 ≤ l < 15
15 ≤ l < 16
16 ≤ l < 17
17 ≤ l < 18
18 ≤ l < 19
19 ≤ l < 20
Soot Formation Measurements in the Leeds Bomb
Simultaneous Rayleigh/OH PLIF Spectroscopy

Nd:YAG Laser @ 532.2 nm

Scanmate III dye laser @ 292.95 nm

Focussing lenses

1m spherical telescope

ICCD Cameras

Optically accessible Bomb
Soot Formation in the Leeds Bomb

Soot formation in a 2 bar, $\varphi = 2.0$ iso-octane-air flame.

Note the soot formed behind deep cracks in the flame.
LII/Mie Scattering in the Shell Bomb

Imaging window at base of bomb

28mm laser sheet

532 nm laser beam
LII/Mie Scattering in the Shell Bomb

Mirror beneath bomb

Al mirror

ND filters

532nm mirror

380nm - 440nm filter

CCD Cameras
LII/Mie Scattering in the Shell Bomb

Processed LII image obtained from a $\varphi = 1.8$, 5 bar, iso-octane-air flame (flame radius ~ 60 mm)

(relative soot volume fraction)

Processed Mie scattering image obtained from a $\varphi = 1.8$, 5 bar, iso-octane-air flame

Relative soot particle size distribution $d_{63}$

Relative soot particle number density
Soot Formation in Rich, High Pressure, Spherically Expanding Explosion Flames
Conclusions

1. Two distinct length scales associated with flame cracking have been observed from the Schlieren images and the OH PLIF images.

2. These length scales are identified with hydrodynamic effects and thermal-diffusive effects. The large length scale cracking (5 mm to 1 cm) is associated with the hydrodynamic instability, while the small length scale cracking is associated with the thermal-diffusive instability (~ 1 mm).

3. High pressure flames that are stable to thermal-diffusive cracking develop hydrodynamic cracks which do not develop into discrete cells, while high pressure flames unstable to thermal-diffusive cracking exhibit full cellular structure and hydrodynamic perturbations.

4. Flame reaction quenching has been observed in the regions between the smaller length scale flame cells.
Conclusions Cont.

5. In highly enriched, high pressure explosion flames ($\phi > 1.8$), soot was observed to be formed in a honeycomb-like structure behind the flame.

6. The soot cell size was observed to be of the order of 5 mm to 1 cm, which corresponded with the larger length scale cellularity, determined by the hydrodynamic instability.

7. A plausible hypothesis for the formation of soot in highly enriched, spherical explosion flames has been suggested.