BESPOKE RESEARCH AND CONSULTANCY FROM HSE

Flammable mist hazards involving high-flashpoint fluids

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Safety and Reliability Society (SaRS) Midlands Branch webinar

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Outline

- Background and motivation
- MISTS1 Joint-Industry Project (JIP)
  - Literature review
  - Fluids classification
  - Experiments
  - Modelling
  - Guidance
- Updated review of flammable mist incidents
- MISTS2 JIP: Ongoing/future work
- Summary

What is the “flashpoint”?

- The minimum temperature at which a liquid forms vapour above its surface in sufficient concentration that it can be ignited (units: °C)

https://www.stanhope-seta.co.uk/product/seta-multiflash-cleveland-flash-point-module/

Substance	Flashpoint
Gasoline	-43 °C
Kerosene (Jet A1)	38 °C
Diesel	58 °C
Light fuel oil (Class E)	81 °C
Bio-diesel	145 °C
Hydraulic oil (Mobil DTE)	223 °C

Flammable vapour at ambient temperature (Gasoline)

Vapour not flammable at ambient temperature (Kerosene to Hydraulic oil)

Background and Motivation

- **EU ATEX Directive (UK DSEAR Regulations)** – Employers must:
  - Identify and classify areas of the workplace where explosive atmospheres may occur
  - Ensure that appropriately certified safe equipment is used in the hazardous zones
- **For flammable gases and dusts**:
  - Detailed hazardous area classification guidance currently available in various standards, e.g. BS EN 60079, IGEM/SR/25, EI15
- **For flammable mists from high-flashpoint fluids**?
  - BS EN 60079-10-1 Annex D: limited guidance on flammable mists (only qualitative, not quantitative)
  - Energy Institute EI15:
    - High-flashpoint fluid mists / sprays treated as Category C Fluids and hazard radii are provided (see next slide), but…
    - "there is little knowledge on the formation of flammable mists and the appropriate extents of associated hazardous areas … Further research is needed"

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Energy Institute EI15 Guidance

MODEL CODE OF SAFE PRACTICE PART 15
AREA CLASSIFICATION FOR INSTALLATIONS HANDLING FLAMMABLE FLUIDS

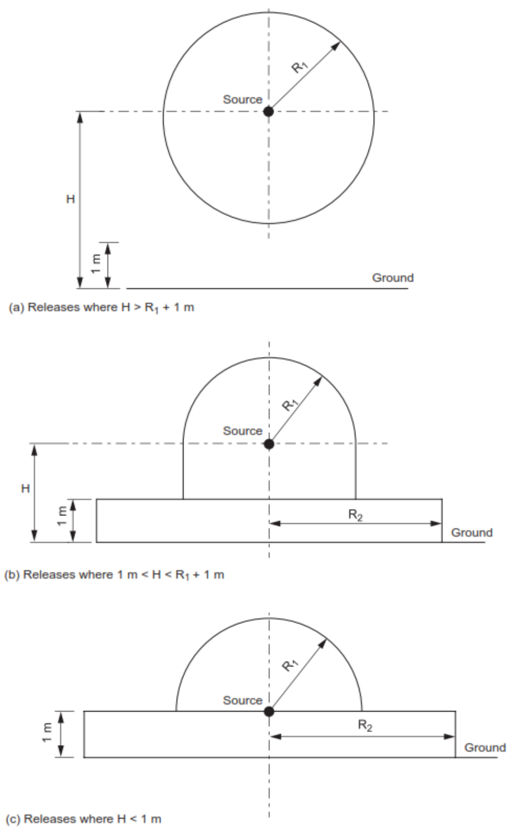

Figure 3.6: Shape factors for pressurised releases

Table C4: Hazard radii R_1 and R_2 for pressurised releases

Fluid category	Release pressure see note 4 (bar(a))	Hazard radius R_1 (m)				Hazard radius R_2 (m)			
		Release hole diameter				Release hole diameter			
		1 mm	2 mm	5 mm	10 mm	1 mm	2 mm	5 mm	10 mm
A	5	2	4	8	14	2	4	16	40
	10	2,5	4	9	16	2,5	4,5	20	50
	50	2,5	5	11	20	3	5,5	20	50
	100	2,5	5	11	22	3	6	20	50
B	5	2	4	8	14	2	4	14	40
	10	2	4	9	16	2,5	4	16	40
	50	2	4	10	19	2,5	5	17	40
	100	2	4	10	20	3	5	17	40
C	5	2	4	8	14	2,5	4	20	50
	10	2,5	4,5	9	17	2,5	4,5	21	50
	50	2,5	5	11	21	3	5,5	21	50
	100	2,5	5	12	22	3	6	21	50
G(i)	5	< 1	< 1	<1	1,5	< 1	< 1	1	2
	10	< 1	< 1	1	2	< 1	< 1	1,5	3
	50	< 1	1	2,5	5	< 1	1,5	3,5	7
	100	< 1	1,5	4	7	1	2	5	11
G(ii)	5	< 1	<1	1,5	3	< 1	< 1	2	4
	10	< 1	1	2	4	< 1	1	2,5	5
	50	< 1	2	4	8	1	2	6	11
	100	1	2	6	11	2	3	8	14
LNG	1,5	2,5	3	6	10	2	3	7	30
	5	3	5	10	17	2	4	11	40
	10	3	5,5	10	20	2,5	4,5	13	37,5

High-flashpoint mists / sprays treated as Category C fluids

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Mist Fire and Explosion Incidents

IChemE SYMPOSIUM SERIES NO. 155 Hazards XXI

MIST FIRES AND EXPLOSIONS – AN INCIDENT SURVEY†

R C Santon
Health and Safety Laboratory, Harpur Hill, Buxton, SK17 6PJ

The ignition of mist formed from flammable liquids at temperatures below their flash point is a well known phenomenon. The more frequent consequence of ignition is fire, although a very small number of explosions have often been quoted as examples. A literature survey has exposed a significantly larger number of incidents than had been previously listed. Together with other incident records already noted, a total of 27 relevant records detailing 37 incidents including 20 explosions have been listed. It is notable that nine incidents alone were collectively responsible for a total of 29 fatalities.

The paper includes summaries of all the incidents, and, so far as possible, comments on the fuels and sources of ignition.

Mist explosions in marine diesel crankcases

CRANKCASE EXPLOSIONS: AN INVESTIGATION INTO SOME FACTORS GOVERNING THE SELECTION OF PROTECTIVE DEVICES

By H. G. Freeston (*Associate Member*)*, J. D. Roberts†, and A. Thomas, Ph.D.‡

Proc. Institution of Mechanical Engineers (IMechE), 170, p811-824, 1956.

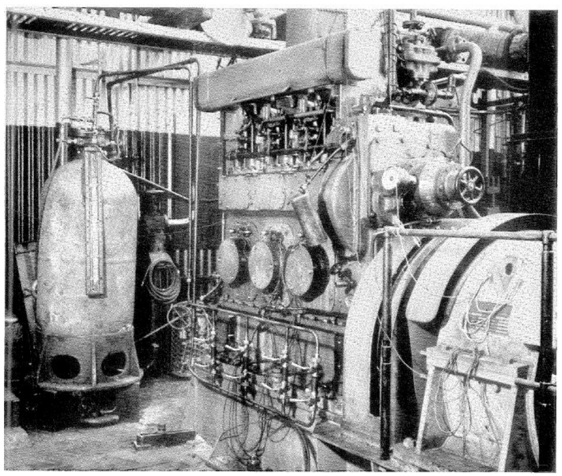


Fig. 49. Front of Engine Arranged for Tests

and finally in the whole crankcase. It had been hoped that it would be possible to investigate the effect of venting upon explosions in a running engine, but unfortunately damage was caused to the engine during the first explosion in the crankcase under static conditions, which made it impossible to run the engine in the subsequent tests. The large-scale

Fig. 14. General View of Building After the First Explosion

Mists 1 Joint Industry Project

Aims:

- To undertake scientific research that can be used to develop formal guidance on:
  - Formation of flammable mist
  - Mitigation measures
  - Area classification zone and extent
  - Protected equipment concepts, and equipment selection

- To develop practical criteria that define the likelihood of mist formation that can be used as part of an area classification exercise

MISTS1 Joint Industry Project

Scope: Mists/sprays/aerosols of liquids that are below their flashpoint at ambient temperature:

- Lubricating oil
- Vegetable oil
- Hydraulic oil
- Light/heavy fuel oil
- Heat transfer fluid
- Kerosene
- Diesel

Outside scope:

- Pressure-liquefied gases, e.g. propane
- Low-flashpoint fluids, e.g. gasoline

MISTS1 Joint Industry Project

- **Sponsors**: HSE, ONR, RIVM, GE, Siemens, EDF/British Energy, RWE, Maersk Oil, Statoil, BP, ConocoPhilips, Nexen, Syngenta, Aero Engine Controls, Atkins, Frazer Nash, Energy Institute
- Budget: £477k
- Kick-off meeting: 5 December 2011
- Final meeting: 9 July 2015

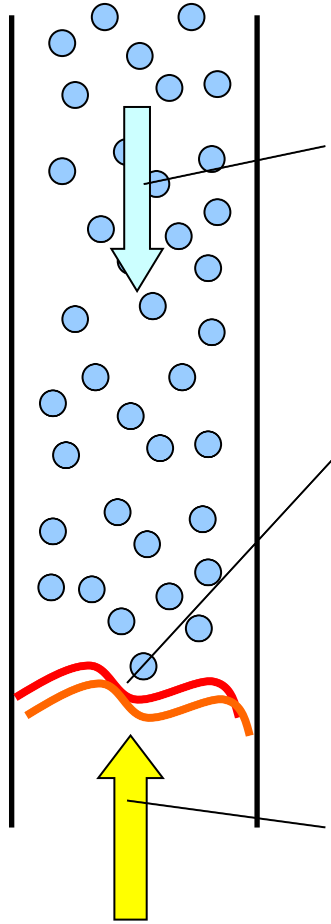
MISTS1 Joint Industry Project: Work Packages

1. Literature review
   - When is a mist flammable?
   - How do you generate a flammable mist?
   - Review data on: LEL, MIE, MIC, MESG, MHSIT
   - Mitigation measures
2. Fluids classification
3. Experiments
4. CFD modelling
5. Comparison of CFD to Energy Institute EI15 guidance
6. Development of (tentative) guidance

Lower Explosive Limit (LEL)

Concentration when flame can propagate through mist

Sedimentation effect in flame tube:



Droplets fall under gravity

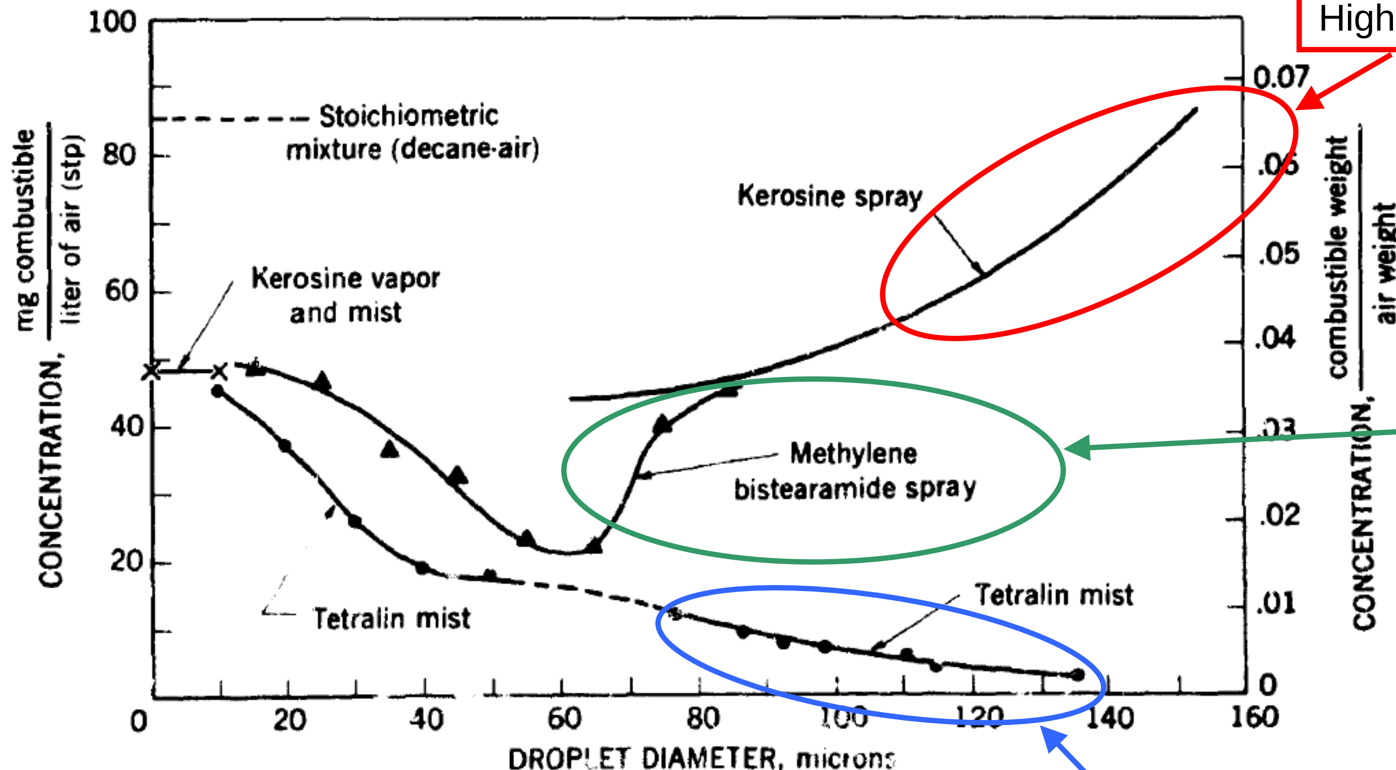
Relative speed increases mass flux of fuel into flame front

Result: Reduction in LEL as compared to vapour

Flame propagates upwards through mixture (assisted by buoyancy)

Lower Explosive Limit (LEL)

Graph from Zabetakis (1965)



High velocity spray

Anson (1953)

Rao & Lefebvre (1976)

Solid wax circulated in closed loop

Browning, Tyler & Krull (1957)

Should we assume: $LEL_{mist} \approx {}^{1}/_{10} \times LEL_{vapour}$?

Nearly quiescent mist

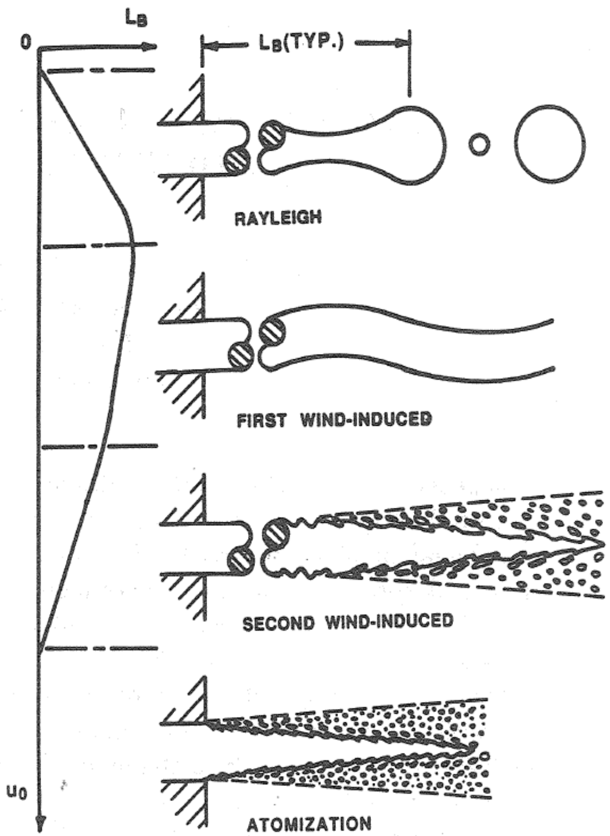
Burgoyne & Cohen (1954)

Burgoyne & Taylor (1957)

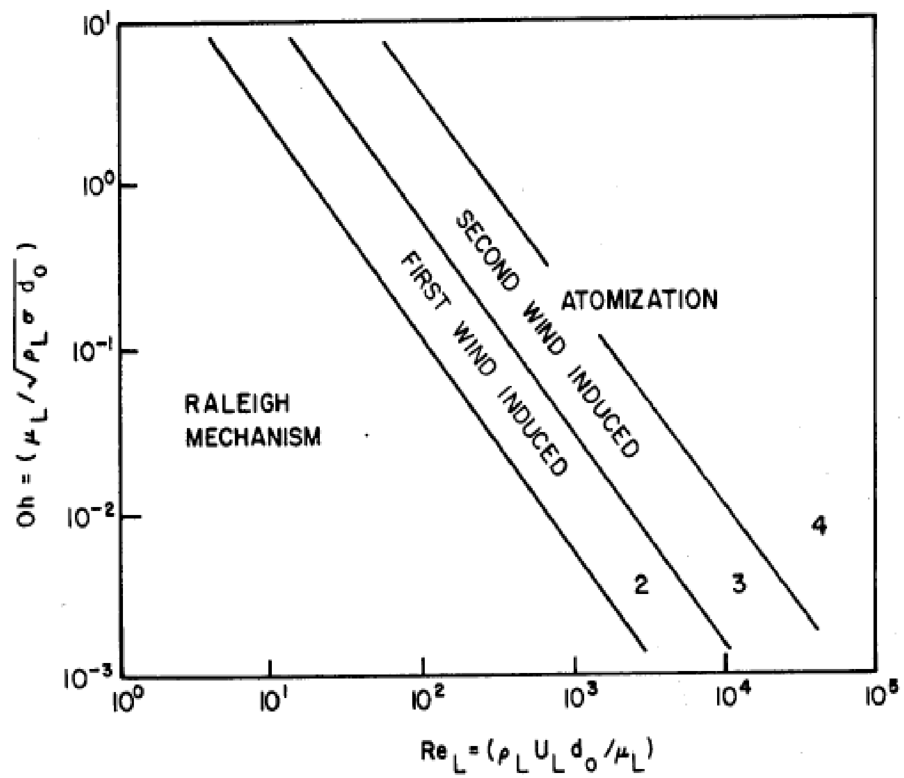
Cook, Cullis & Good (1977)

Spray Physics

- When do sprays atomize and produce droplets?



Faeth (1990)



Lefebvre (1989)

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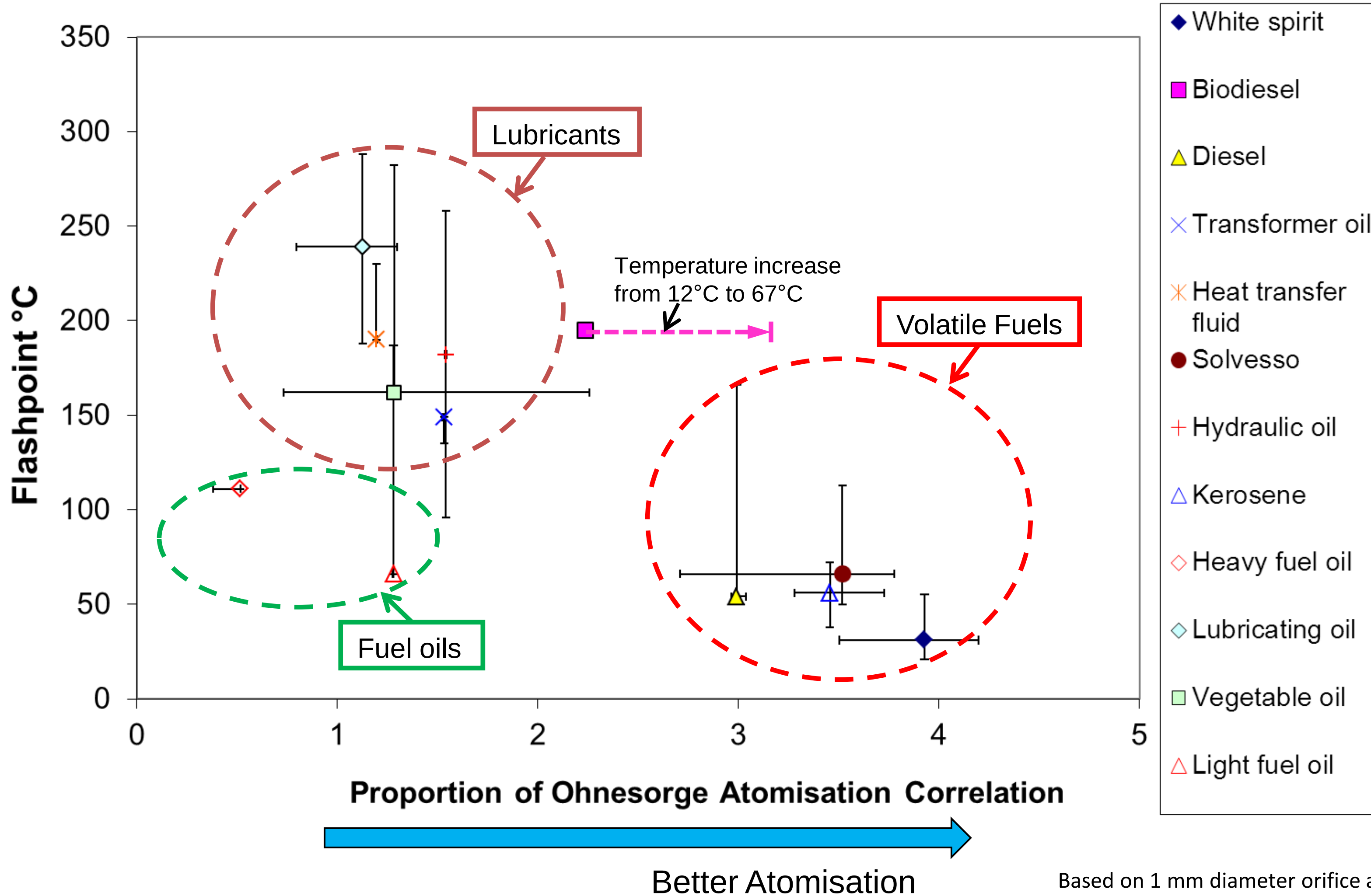
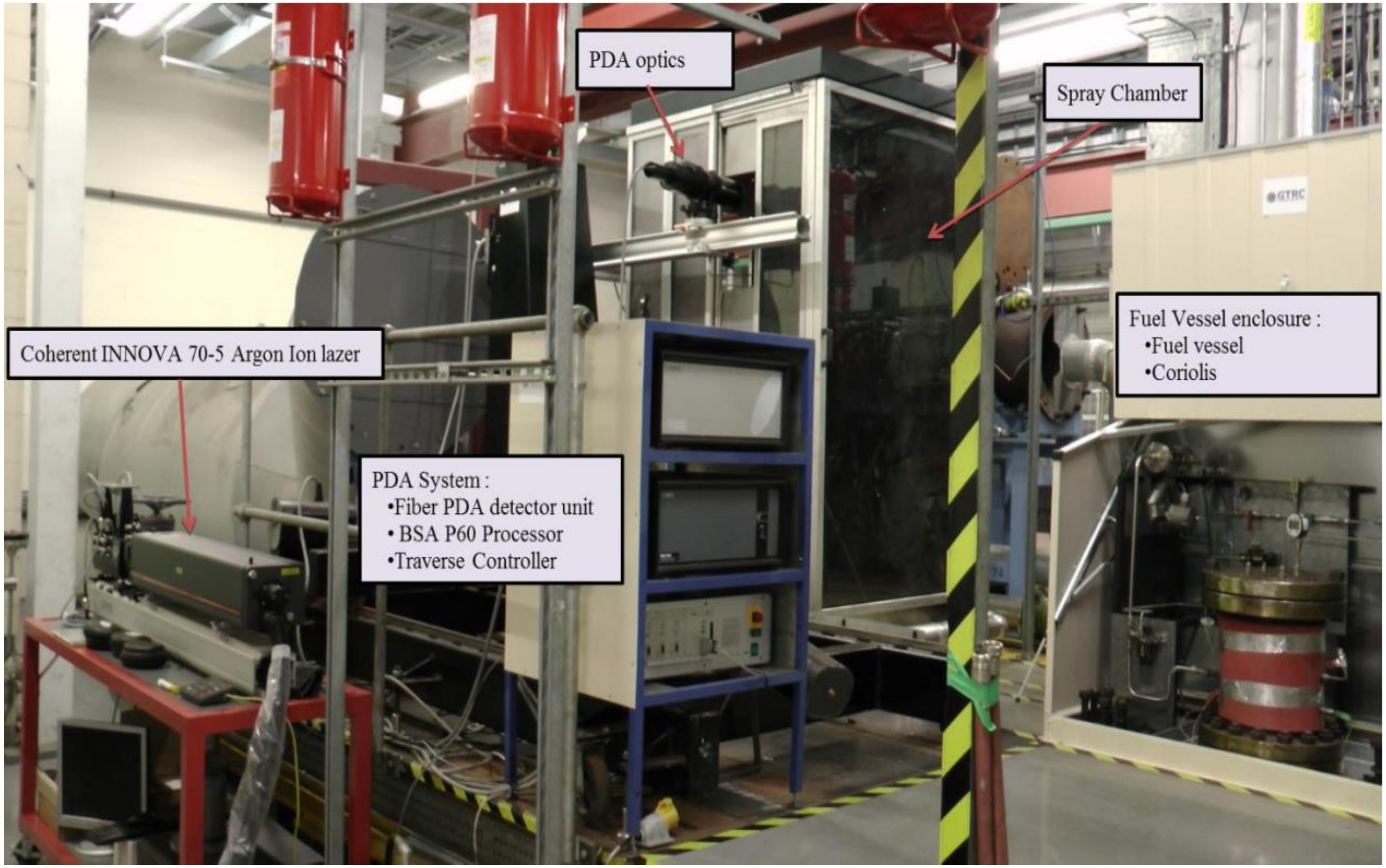
2. Fluids Classification



Based on 1 mm diameter orifice at 10 bar

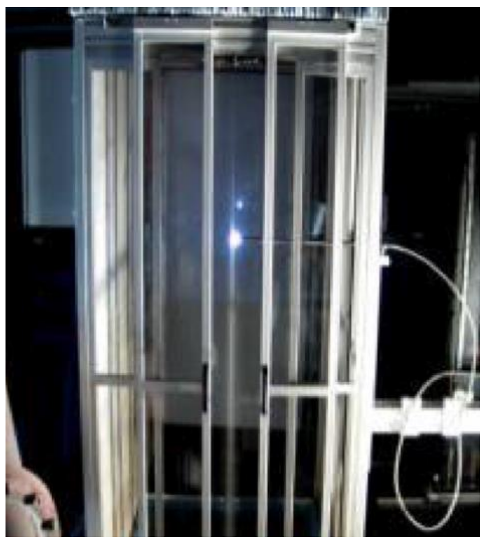
3. Experiments at GTRC, Cardiff University



3. Experiments

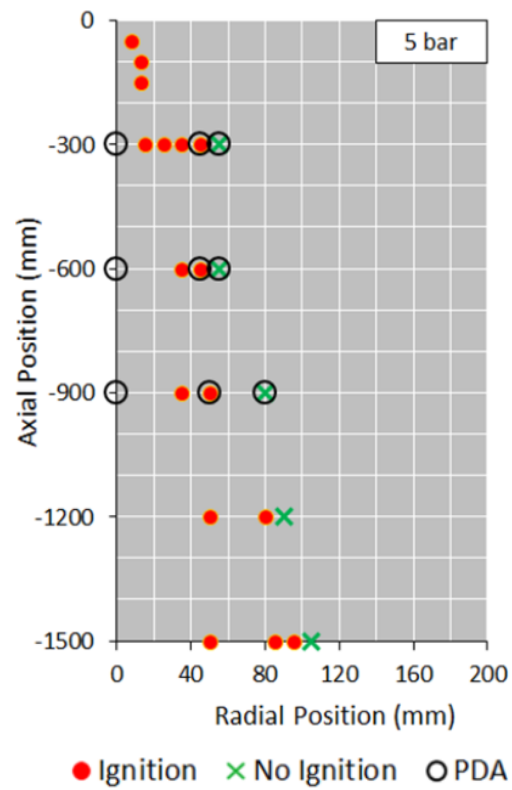
- Fluids tested: Jet A1 kerosene, hydraulic oil, light fuel oil
- 1 mm dia, L/D = 2, plain circular orifice
- Pressures mostly 5 – 20 barg
- 1 J spark igniter, PDA droplet sizing

Kerosene



Hydraulic oil

Kerosene



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3. Experiments at GTRC, Cardiff University

Spray Geometry	Fluid	Pressure (barg)	Temperature	Ignited?
Free spray	Jet A1	1.7, 2, 3, 4, 5, 10, 15, 20	Ambient	At all pressures
Free spray	Hydraulic oil	5, 10, 15, 20, 30, 70, 110, 130	Ambient	No, but some “flashes” at highest pressures
Free spray	Light fuel oil	5, 10, 15, 20	Ambient	No
Free spray	Light fuel oil	5, 10, 15, 20	70 °C	At all pressures
Impinging	Hydraulic oil	5, 10, 15, 20	Ambient	No
Impinging	Light fuel oil	15, 20	Ambient	At 20 barg only
Impinging	Light fuel oil	5, 10, 15, 20	70°C	At all pressures

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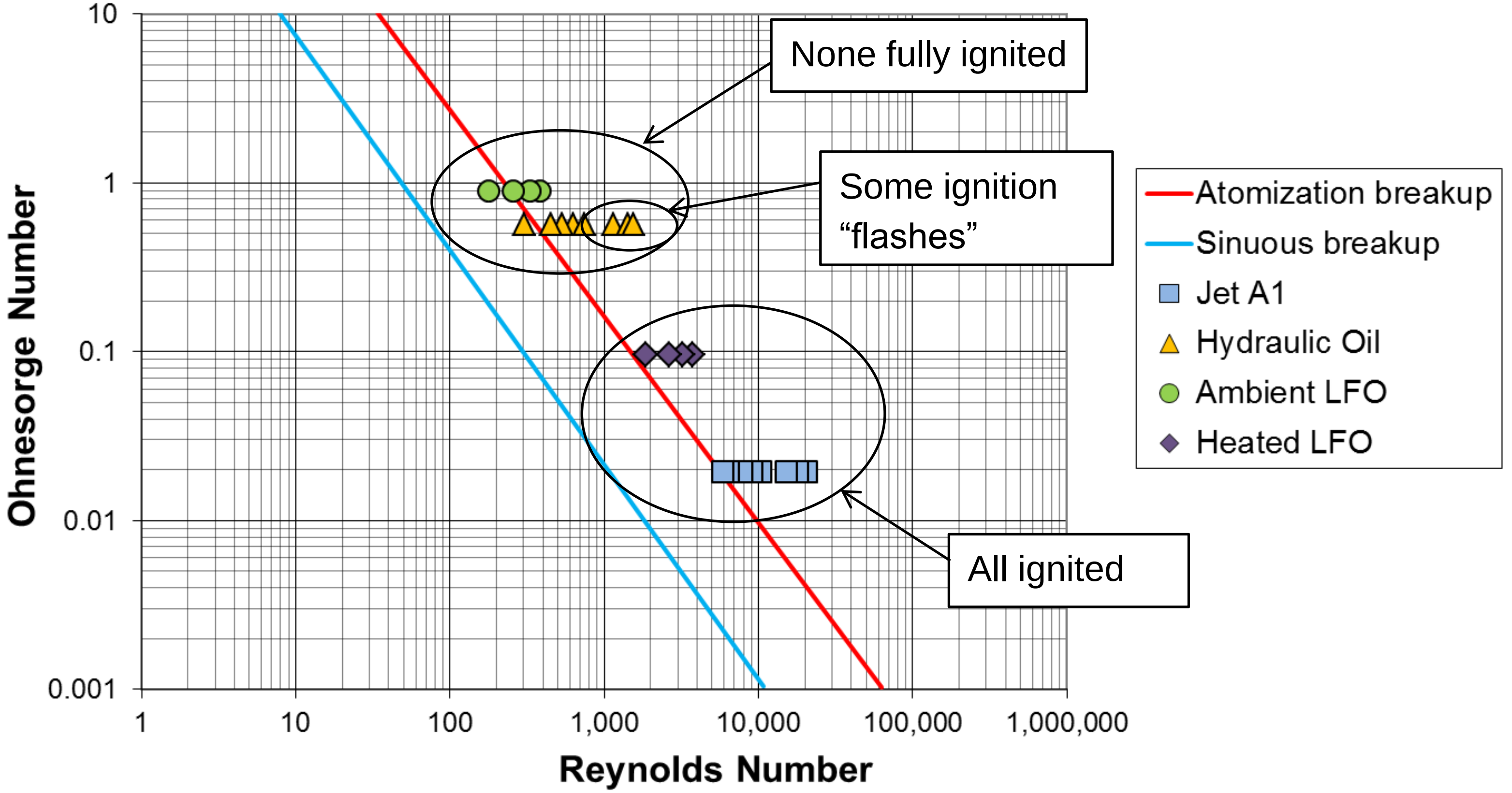
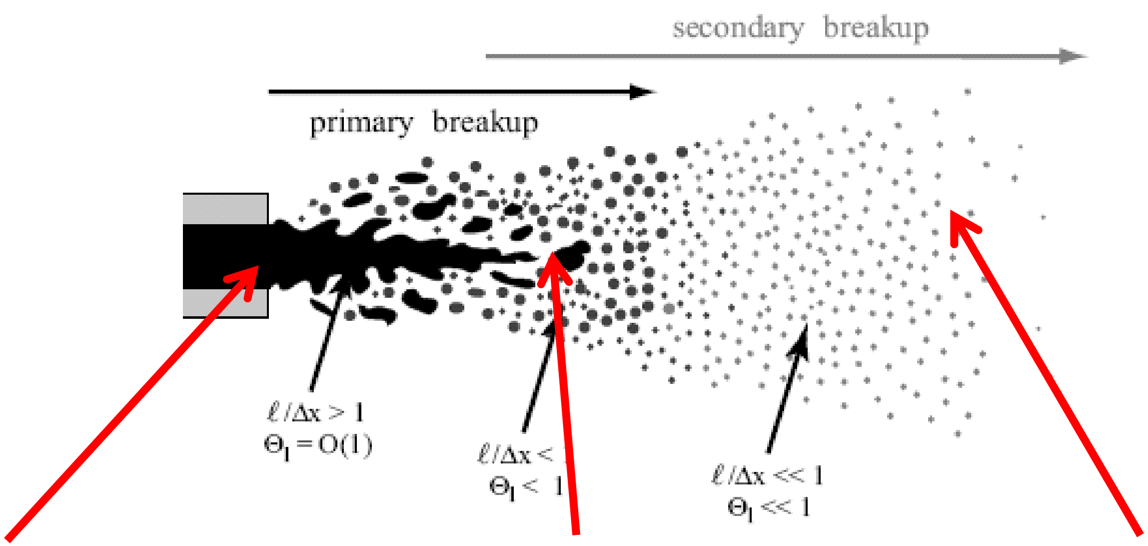
3. Experiments at GTRC, Cardiff University



4. CFD modelling



Herrmann (2003)

1. Outflow

- Mass release rate
- Velocity
- Area
  - Vena contracta
  - Cavitation

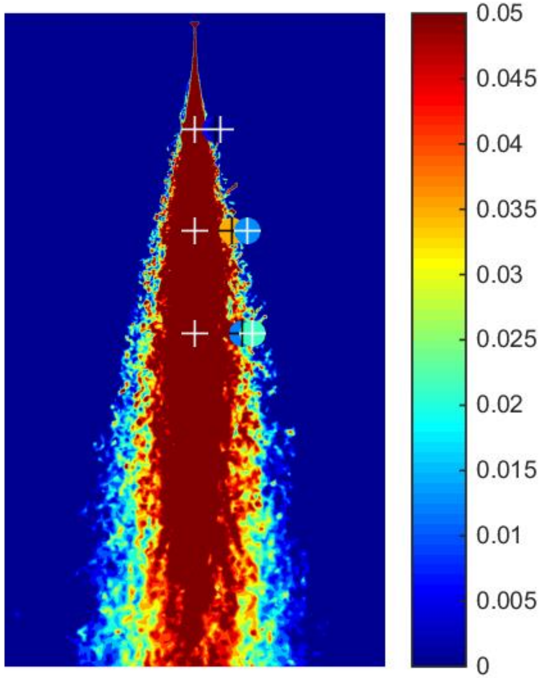
2. Primary breakup

- Spray cone angle
- Droplet diameter
  - Sauter Mean Diameter
  - Size distribution
- Droplet velocity

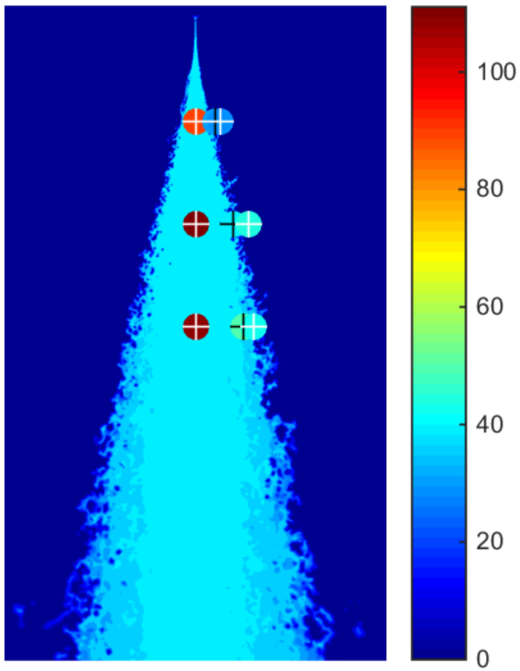
3. Secondary breakup

- Aerodynamic forces reducing droplet size

4. CFD modelling



Droplet concentration (kg/m^3)



Droplet Sauter Mean Diameter (μm)

- DNV Phase III JIP RR droplet size correlation gave results within factor-of-two of measurements for concentration and diameter with Jet A1

- CFD model assumed atomised spray of droplets: poor agreement with non-atomizing hydraulic oil and light fuel oil

5. Comparison to EI15 Code of Safe Practice

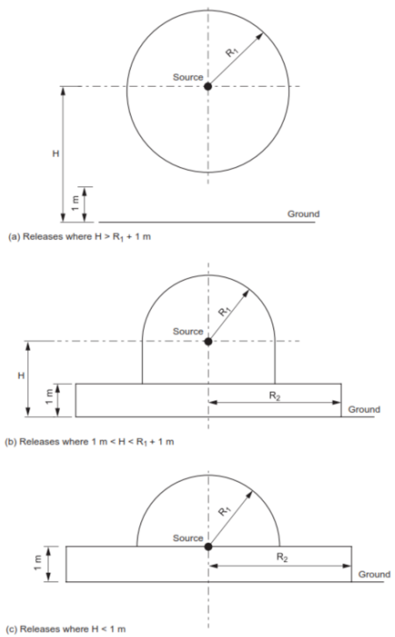
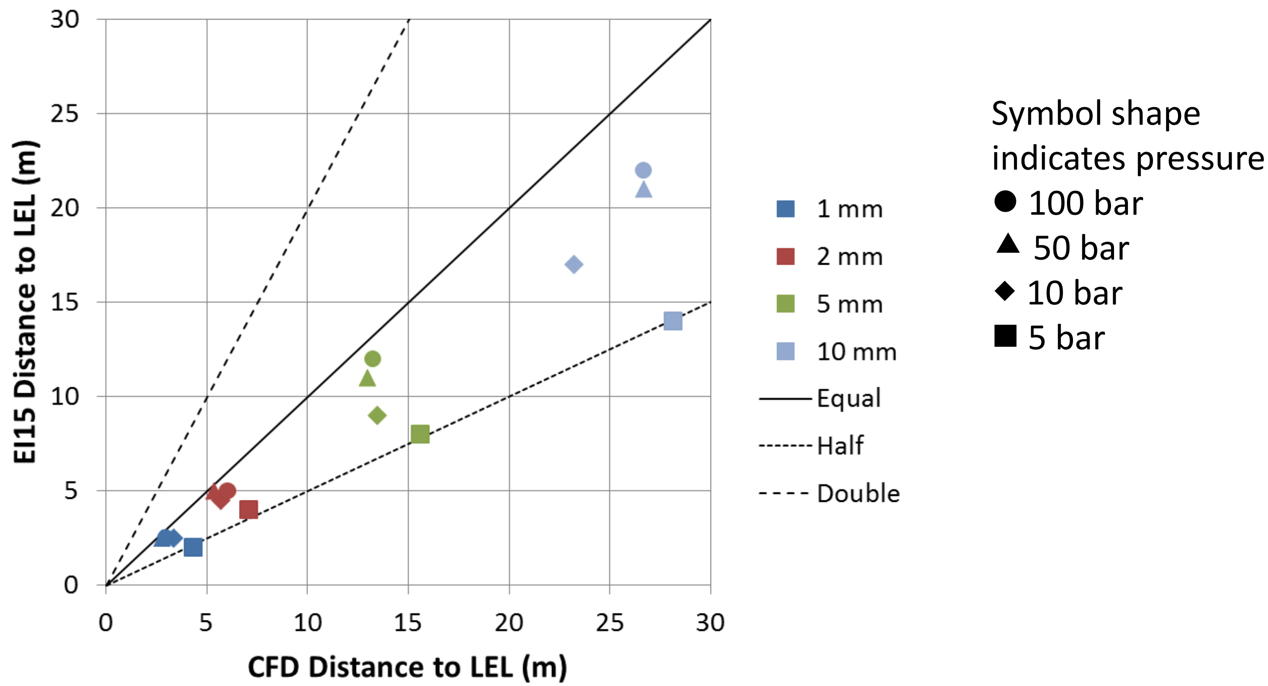
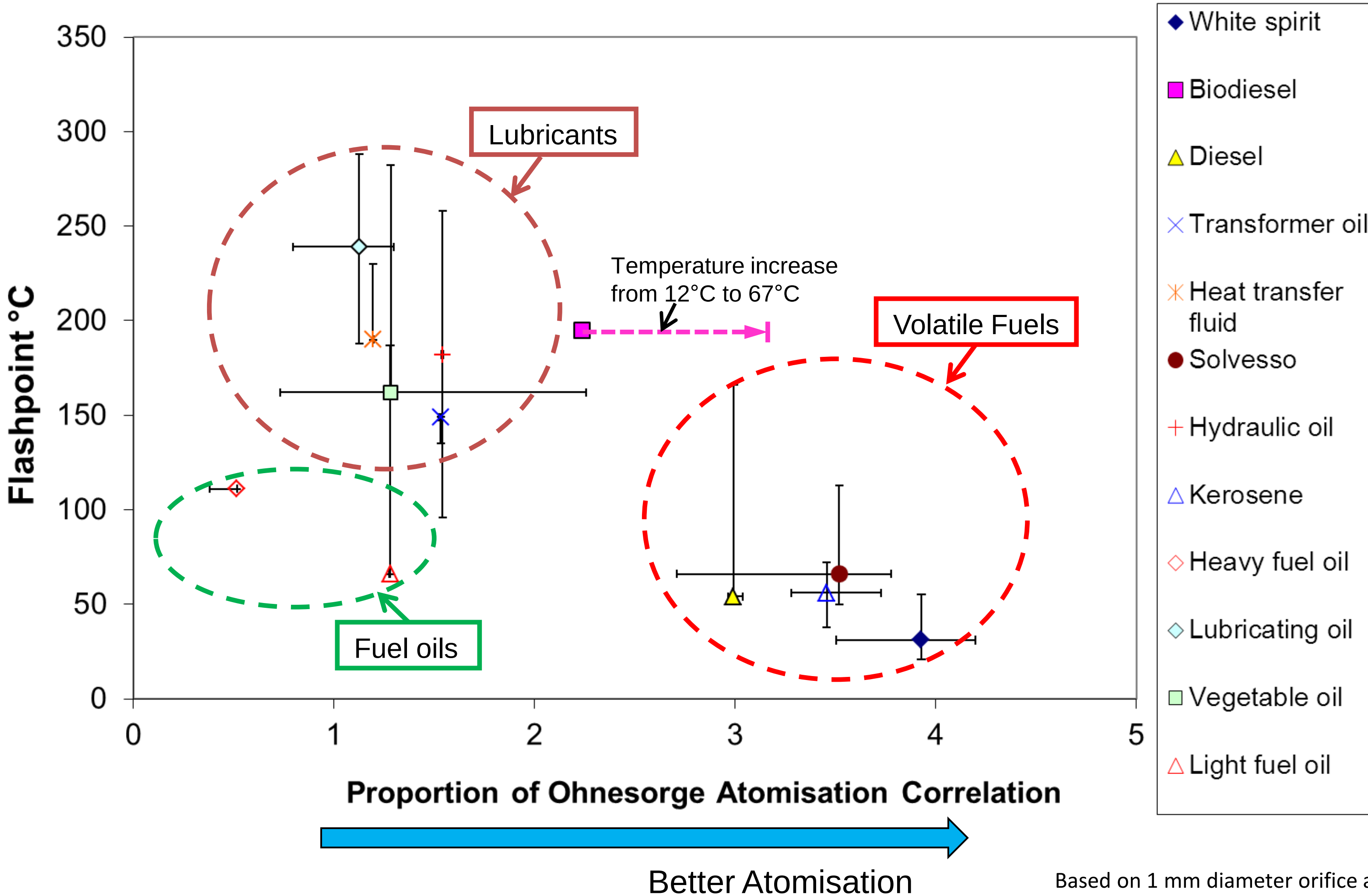


Figure 3.6: Shape factors for pressurised releases



- Results broadly consistent between CFD and EI15
- Hazard range may be larger than given in EI15 for vertically downwards releases, especially at lower pressures

6. Tentative Area Classification Guidelines



Based on 1 mm diameter orifice at 10 bar

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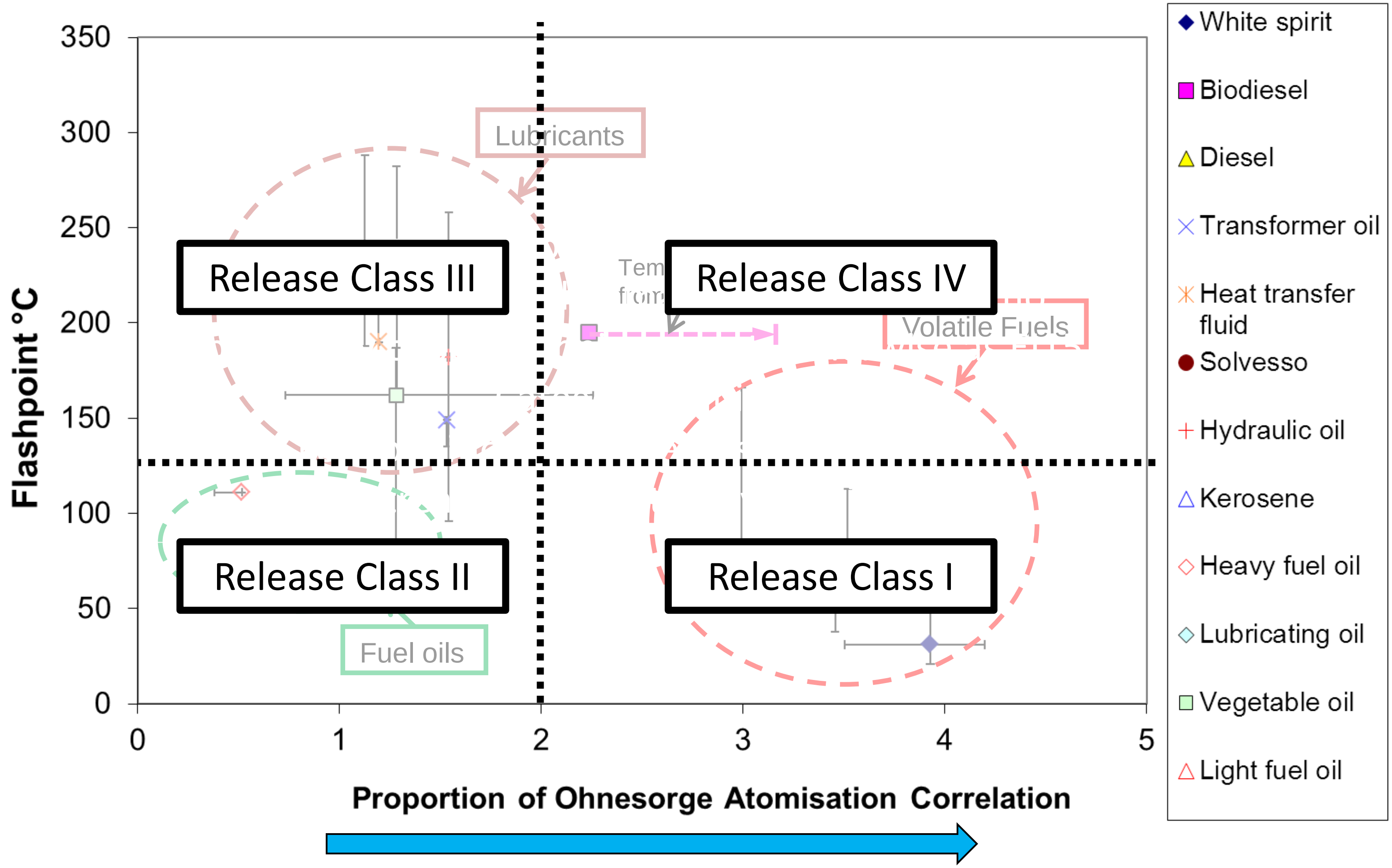
6. Tentative Area Classification Guidelines



Based on 1 mm diameter orifice at 10 bar

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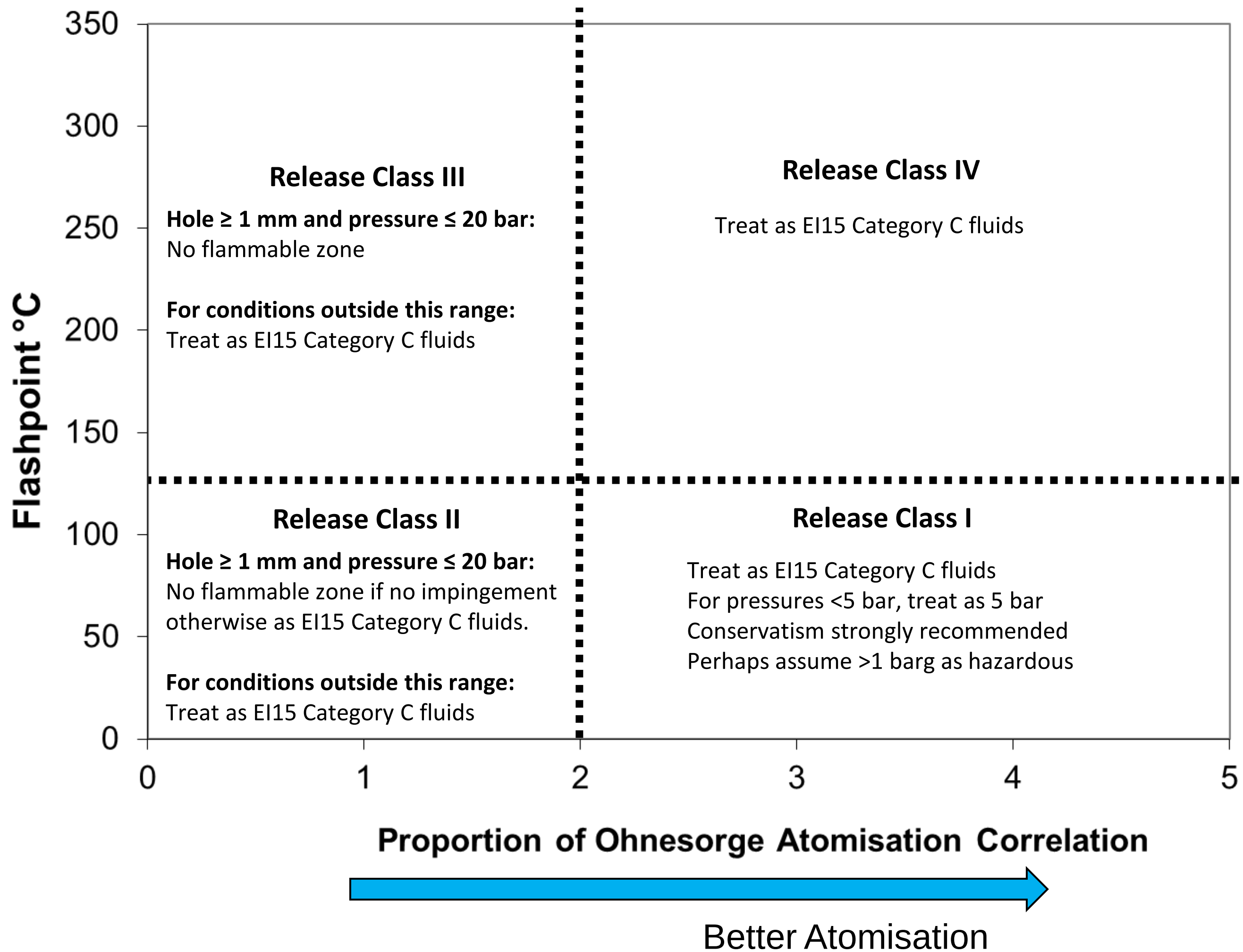
6. Tentative Area Classification Guidelines



6. Tentative Area Classification Guidelines

- Tentative guidelines are based on the findings of the JIP experiments and modelling
- For more complex spray release situations, e.g. impingement on hot surfaces, the assessment will need to take other factors into account
- Guidelines should be reviewed as more information on flammable mists becomes available.
- Only suitably ignition protected equipment should be installed within hazardous zone
- No current standard against which equipment may be certified as safe in a flammable mist
  - Ingress Protection (IP) of 5 (or higher) against liquid ingress
  - Surface temperature rating below the auto-ignition temperature
  - Other protection concepts, e.g. intrinsic safety, encapsulation, or pressurisation

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- Background and motivation
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  - Literature review
  - Fluids classification
  - Experiments
  - Modelling
  - Guidance
- Updated review of flammable mist incidents
- MISTS2 JIP: Ongoing/future work

Recent review of mist incidents

- HSE analysed incidents in the UK Offshore Hydrocarbon Release Database
  - Oil and gas installations operating on UK continental shelf
  - Unintended releases (>1 kg gas, 60 kg liquid unignited), any ignited releases, dangerous occurrences, fatal/serious injuries
  - New question recently added for dutyholders to complete: “Did a liquid spray / mist release occur?”
- INERIS and Université de Lorraine analysed data in French and German (ARIA and ZEMA) incident databases

Hazards 29

SYMPOSIUM SERIES NO 166 HAZARDS 29

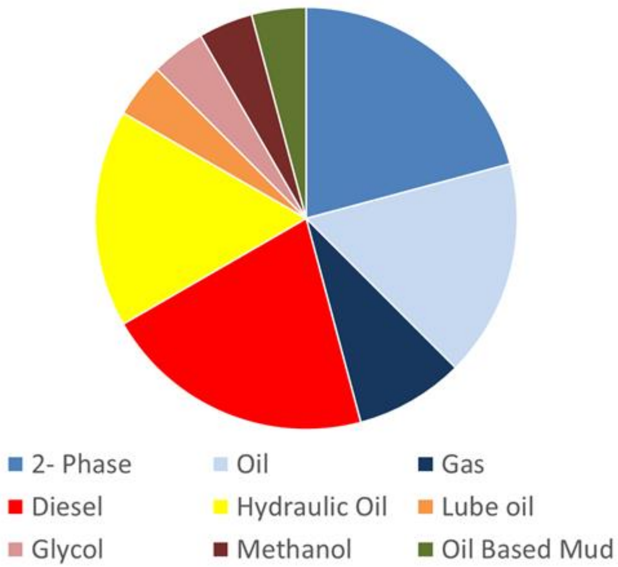
Review of recent incidents involving flammable mists

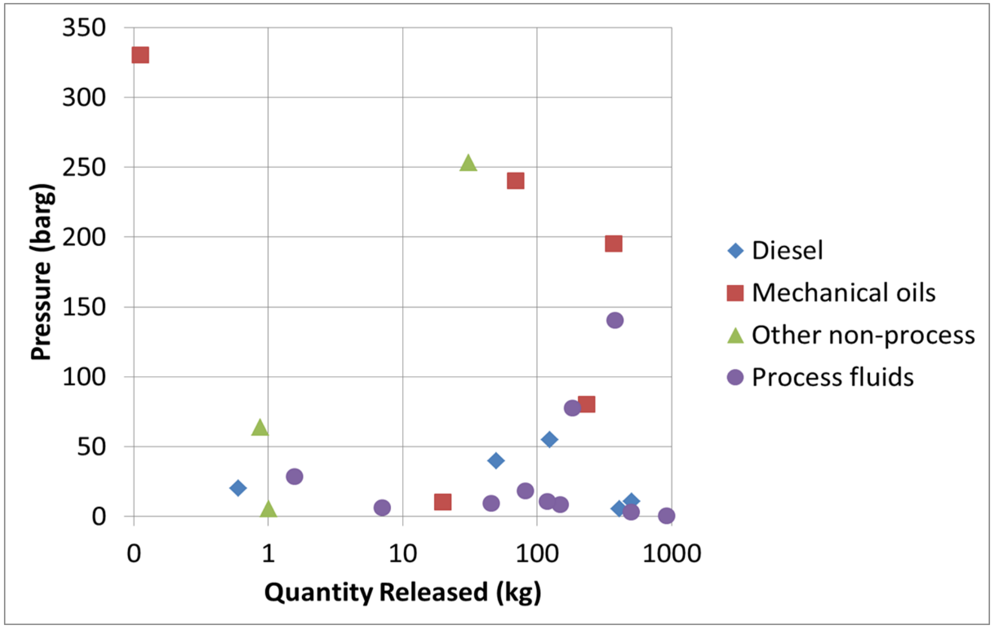
Philip Lees[1], Simon Gant[1], Richard Bettis[1], Alexis Vignes[2], Jean-Marc Lacome[2] and Olivier Dufaud[3]

1 Health and Safety Executive (HSE), Harpur Hill, Buxton, SK17 9JN, UK
2 Institut National de l’Environnement et des Risques (INERIS), Parc Technologique ALATA, BP 2, 60550 Verneuil-en-Halatte, France
3 Laboratoire Réactions et Génie des Procédés, Université de Lorraine, CNRS, LRGP, F-54000 Nancy, France

UK Hydrocarbon Release Database

- Data from Jan 2016 to July 2018 (30 months)
- Total of 258 incidents: 25 involving sprays / mists
- Two releases ignited (diesel and methanol)
- Hole sizes: a third close to 1 mm, majority < 10 mm diameter
- Hole shapes: circular/pinhole (nearly half), annular, slit, diamond





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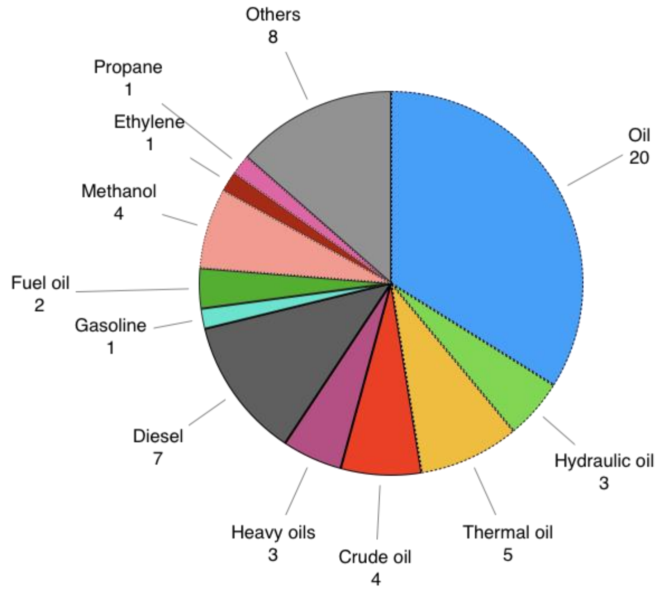
French ARIA and German ZEMA incident databases

- ARIA: 9,725 atmospheric releases: 40 spray/mist incidents
- ZEMA: 464 atmospheric releases: 19 spray/mist incidents
- Quantified releases usually >100kg, 8 releases >1 tonne
- 36 out of 40 ARIA incidents record a fire or explosion
- 50% of releases at pressures between 5 and 30 bar
- Typical hole size: 10 mm diameter

Industries involved in ARIA incidents

- Wood Panel Manufacturing
- Metal Industry
- Food Industry
- Waste Treatment
- Glass Industry
- Synthetic Fibre Manufacture
- Computer Industry



Conclusions of incident review

- Around 10% of incidents in the hydrocarbon release database involved mists: it is a real problem
- Fires / explosions from flammable mists involve a range of different fluids (process, utility fluids) across a range of industries
- Real world incidents often involve pressures, temperatures, hole sizes and geometries and impurities not seen in laboratory experiments
- Guidance on flammable mists hazards is still very limited

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MISTS2 Joint Industry Project

- Aim: to address knowledge gaps following MISTS1
- Three work packages:
  1. Where does diesel fit into the classification scheme?
  2. How does the hole shape affect ignitability?
  3. What is the extent of the flammable zone?
- Work package currently on hold
  4. Are mist explosions the same as gas explosions?
- Start date: Q4 2018
- Duration: 24 months
- Sponsors: HSE, Shell, EDF, ONR, Energy Institute, INERIS

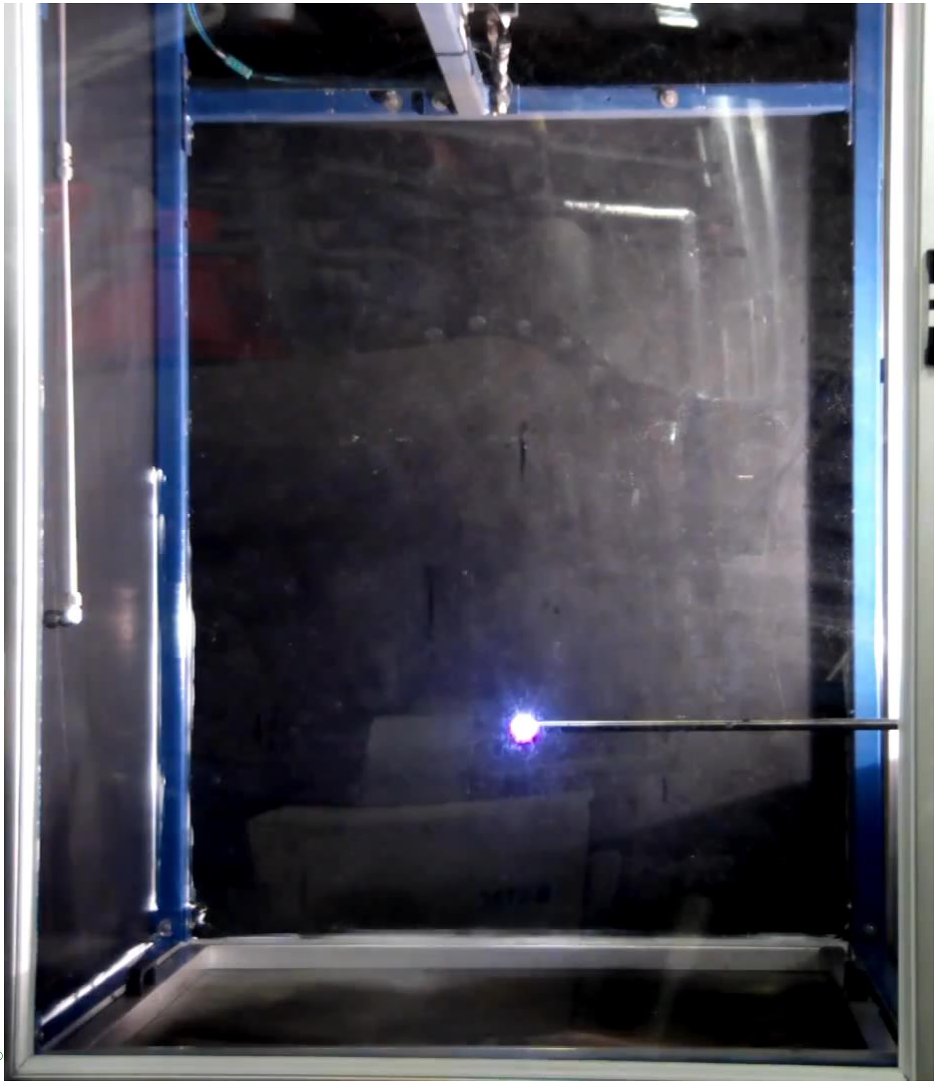
Work Package 1: Diesel experiments

- Ultra-low sulphur diesel, bio-diesel
- 1 mm dia, L/D = 2, plain circular orifice
- 1 J spark igniter, PDA droplet sizing

Findings to date:

- Ultra-low sulphur diesel
  - Ignited at 5 – 20 barg (not at 3 barg)
- Biodiesel
  - Ignited at 20 barg (but not at 5 – 15 barg)

WP1 Preliminary results: diesel at 5 barg

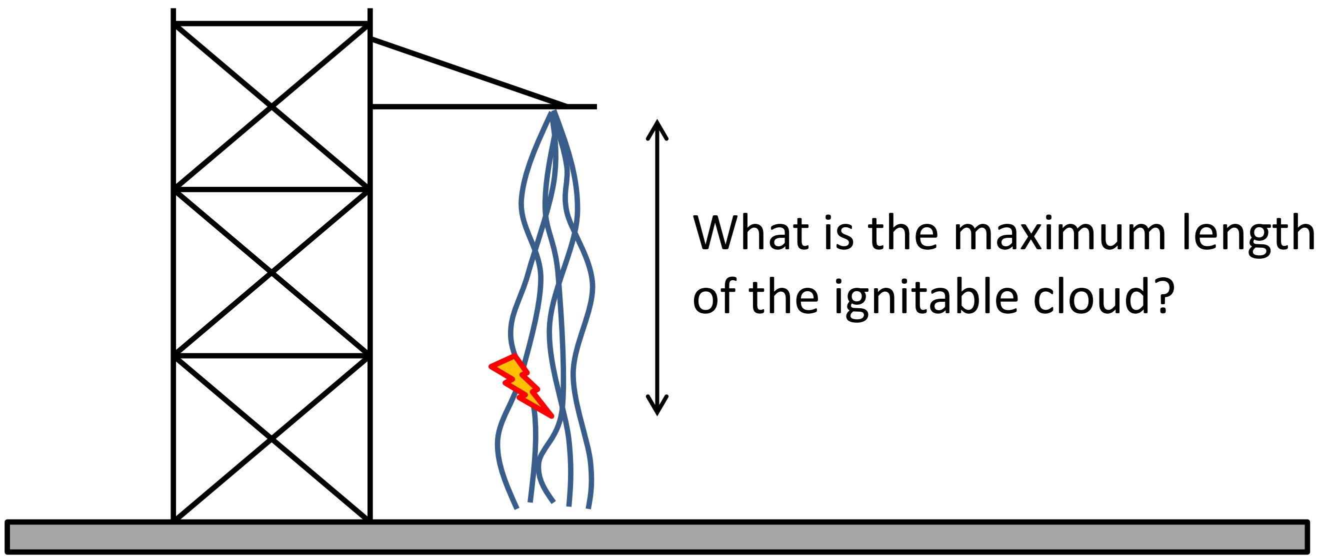


Video of 5 barg ultra-low sulphur diesel ignition test

- WP1: Work ongoing to characterise diesel and bio-diesel droplet sizes and concentrations
- WP2: Work planned on different orifice shapes

Work Package 3: Burn Hall Tests

- **Aim**: to measure the maximum extent of the flammable mist cloud
- Initial tests
  - 1 mm diameter plain circular orifice used in MISTS1 project
  - Diesel or kerosene
  - Ignition using 1 Joule spark igniter



Work Package 3: Burn Hall

Summary

- Overview provided of:
  - MISTS1 and MISTS2 Joint Industry Projects
- Mist incident reviews in 2009 and 2019
- MISTS1 findings:
  - Jet A1 kerosene ignited at pressures ≥ 1.7 barg
  - Tentative guidance based Release Classes I - IV
- MISTS2 findings:
  - Diesel ignited at pressures of ≥ 5 barg
  - Work ongoing on orifice shape and zone extent
- Please contact us if you are interested in future work

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Thank you

Any Questions?

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