Title	Offshore Technology Report 94 463: Investigation of factors of relevance during explosion suppression by water sprays
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Executive Summary	The present report summarises the activities undertaken on agreement Matsu 847312937 for the Offshore Safety Division of the U.K. Health and Safety Executive, a programme of work to study certain aspects of explosion mitigation by water sprays. The main objectives were to develop an understanding of the dynamics of water sprays in accelerating gas flows and to investigate techniques for transient spray characterisation. Of especial interest were the droplet acceleration and the criteria for aerodynamic break-up. These parameters are significant when establishing optimum spray characteristics for mitigation and are crucial factors that must be considered if such mitigation effects are to be incorporated into explosion prediction codes. In addition the influence of droplet evaporation on combustion has been investigated. The work presented in this report covers five areas of investigation. • Flame acceleration due to spray induced turbulence • Small scale studies of spray dynamics, break-up and explosion mitigation • Numerical and analytical studies of spray dynamics and break-up • Development of techniques for transient spray characterisation • Theoretical limits for laminar flame quenching by water mist evaporation The progress to date in each area can be summarised as follows. **i) Turbulence induced flame acceleration** A short series of tests have been performed to study the degree of acceleration observed as a methane-air flame propagates in a tube that also contains a water spray. The sprays used were characterised using two commercial sizing techniques. Both gave self consistent results between sprays but gave differing values for standard characteristic droplet size parameters when the results from the same spray were compared. The combustion results indicate turbulent flame velocities of the order 4-8 times the theoretical laminar burning velocity in the mixtures. These values are consistent with the acceleration observed in larger scale tests. Calculations based on standard correlations of turbulent burning velocity and gas phase turbulence intensity were attempted, using scale lengths based on droplet size and vessel dimensions. Both gave results of the order measured but no firm conclusions could be drawn although the work has identified the desirability of LDA measurements of the gas phase turbulence intensities. **ii) Experimental studies of spray dynamics and mitigation** A 5 m long 76 mm diameter explosion tube has been used to investigate the mitigation of methane-air explosions by water sprays. A combined technique capable of monitoring simultaneously both flame front propagation (based on emission) and bulk spray motion (based on attenuation) has been used successfully. The studies have confirmed that conditions of critical explosion development exists below which mitigation is not observed. The ability of a spray to mitigate against an explosion have been shown to correlate with the rate of gas flow acceleration that is generated during an explosion. **iii) Numerical studies of droplet acceleration and the onset of break-up.**

Simple analytical calculations of single droplet acceleration have been performed for droplets in a fluid that accelerates from rest. From the calculated instantaneous velocity difference between the droplet and fluid a time varying Weber number can then be computed for a range of gas accelerations and droplet diameters. Assuming a critical Weber number for break-up (based on existing shock break-up data) predictions have been made of critical droplet size and gas accelerations and of the corresponding breakup times. The calculations assume a constant drag coefficient and critical Weber number.

iv) Experimental studies of droplet acceleration and onset of break-up.

A series of tests have been performed to study the acceleration of droplets placed in an accelerating gas flow. The flows were generated in the expansion section of a shock tube. High speed video recordings were used to monitor droplet motion and break-up.

Critical flow accelerations were observed, below which droplets did not break-up. The critical conditions could be related to a Weber number, based on the instantaneous relative velocity between the droplet and the flow and the maximum distorted drop diameter. For low Weber numbers, a more catastrophic break-up of the droplet was observed than would be expected from the majority of previous steady flow break-up studies using shock flow. The results are more in agreement with a previous investigation of break-up in transient flows. The results of previous studies based on steady shock tube flows are not applicable to transient explosion type flows.

The main conclusion of relevance to explosion mitigation appears to be that the explosion severity required to effect break-up (characterised by decreasing rate of gas flow accelerations) decreases as the mean droplet sizes increases, provided that critical relative velocities between the gas and droplet are established.

v) Droplet sizing and mist detection

Simple attenuation and transmission measurements using light emitting diodes and photodiode detectors have proved to be the most reliable method of detecting droplet break-up and provide an uncomplicated and low cost method of local detection.

A circuit for detecting water spray presence using the permittivity of water to modify a capacitative probe has also been developed and will be tested on transient water sprays shortly. If successful this will provide loading density information. This approach has the potential, when coupled with light attenuation measurements, to give information on droplet size and number density.

More detailed light scattering techniques have been reviewed and are applicable for detecting spray residues with significant fractions below 30 pm, but the complexity of the measurements did not make this a practical proposition during the present studies.

vi) Predictions of laminar flame quenching due to droplet evaporation

A series of calculations have been performed using a one-dimensional flame calculation code, with full chemistry, and thermodynamics. Both heat loss and changes in the local gas water vapour mass fraction could be modelled.

The calculations confirm previous findings that droplets of diameter less than 20-30 pm behave effectively as a vapour, due to the rapid evaporation. For these and larger droplet sizes, critical number densities of droplets that gave rise to quenching could be estimated. The results suggest that for ideal laminar flames, only a small fraction of the flame energy need be abstracted to quench the flame, provided this is done prior to the position in the flame front associated with the

	flame ignition temperature. The predicted critical mass loading densities for sprays with droplet sizes bdow 10 pm are in reasonable agreement with existing experimental data. No data for other droplet size are readily available.
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