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Flashing liquid jets and two-phase droplet dispersion - II. Experiments for derivation of droplet atomisation correlations

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Abstract

The large-scale release of liquids at temperature above their local ambient boiling temperature is a scenario often given consideration in process industry risk analysis. Some hazard quantification software claim to model such situations, though most either employ overly simplistic or equilibrium two-phase approaches.

A review of this area previously identified deficiencies modelling the source-term atomisation process, which strongly influence localised rainout prediction. This paper reports the experimental work carried out as part of a JIP with the aim of providing a phenomenological sub-model for superheated atomisation which: (i) is simple enough to include as part of discharge and dispersion models, (ii) represents current data available in this field, and (iii) is an improvement on previous sub-models. Scaled water experiments were carried out measuring droplet velocity and droplet size distributions for conditions representing low to high superheat. These served to derive jet atomisation (droplet-size) correlations valid for non-flashing, the transition between non-flashing and flashing, and fully flashing jets. An overview companion paper provides a wider overview of the problem, and reports implementation of these correlations into consequence models and subsequent validation.

The approach adopted is based on establishing conditions corresponding to transition criteria identified in the external flow structure. Thermodynamic and geometrical conditions were varied during controlled experimental investigations, though the fluid utilised throughout is water. Hence, droplet correlations developed are based on non-dimensional representation of the data to allow extrapolation to other fluids, though verification of model performance for other fluids needs verification in future studies. Data is reduced via non-dimensionalisation in terms of the Weber number and Jakob number, essentially representing the hydrodynamics and thermodynamics of the system, respectively.

Experimental diagnostics utilised include high-speed shadowgraphy of the external flow structure, which allows identification of transition criteria. The atomisation quality is measured at various spatial locations utilising a DANTEC 2-dimensional phase Doppler anemometry system, providing distributions of droplet size as well as velocity components. The most appropriate droplet size data is presented via the Sauter mean diameter (SMD) and droplet-based cumulative mass undersize. Correlations are provided for both.

The SMD sub-model is based around 3 transition points. Below the first transition point, mechanical or 'hydrodynamic' processes predominate, and in this phase, a model developed previously is employed. Aerodynamic stripping generates the spray, and thermodynamic effects are realised only through fluid parameter dependence upon temperature. The first transition point is defined by first evidence of bubble growth in the external jet. The second transition point is defined by a catastrophic breakdown of the external jet, though a finite distance from the orifice. The third transition is defined by catastrophic breakdown immediately at orifice exit, indicating flashing within the orifice. At this stage of understanding, for SMD prediction the simplest linear model is employed to interpolate between transition points, based on the Jakob/Weber number formulation. Finally, a lower-limit threshold of $30\mu\text{m}$ is imposed, beyond which the SMD decays weakly with thermofluid conditions.

The droplet size distribution correlation is conveniently presented as a volume undersize distribution based on the Rosin-Rammler distribution. Different correlations are provided for the different atomisation modes. This form of correlation facilitates quick estimates of likely mass rainout quantities, as well as full distribution information for more rigorous two-phase thermodynamic modelling in the future.