Euler/Lagrange spray computations and modelling of droplet collisions

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Spray systems have numerous technical and industrial applications from combustion systems to food and pharmaceutical industries as well as minimum quantity lubrication (MQL) in machining. Additionally, the fluid to be atomised ranges from low to high viscosity liquids as well as solutions or suspensions. Naturally, any atomisation process produces, depending on the nozzle principle used, a more or less wide droplet size spectrum. As a consequence, the spray structure is greatly affected by droplet collisions and their outcome (bouncing, coalescence or separation) whose boundaries are summarised in so-called collisions maps. Such diagrams are obtained mostly experimentally (Kuschel & Sommerfeld 2013, Sommerfeld & Kuschel 2016) and the boundaries between the different collision outcomes depend on the physical properties of the involved liquid (e.g. viscosity, surface tension) and the size ratio. Therefore, knowledge of the collision map is a requirement to perform reliable numerical computations of the spray behaviour by an Euler-Lagrange approach. Quite frequently, the numerical computation of for example Diesel sprays was based on using boundary lines established for water (Post & Abraham 2002), which of course is not appropriate.

The boundary lines for constructing the collision maps are normally derived by applying energy balances which however mostly neglect dissipation due to viscous effects. The available theoretical boundary lines are analysed with regard to their performance for variable size ratio of colliding droplets and the involved model parameters. The boundary between coalescence and reflexive separation (RS-C) is based on the extended correlation by Ashgriz & Poo (1990) in order to account for elevated viscosity as described by Sommerfeld & Pasternak (2019). A more generalised boundary line coalescence/stretching separation (SS-C), which captures the effect of viscosity, is suggested based on the triple point location and the boundary line of Jiang et al. (1992). A novel composite boundary line is introduced for also including size ratio effects by combining this approach with the Brazier-Smith et al. (1972) correlation which is detailed in Sommerfeld & Pasternak (2019).

For validating the newly proposed boundary line models additional experiments are conducted for higher viscous droplets and for the first time looking at the collision of droplets with a size ratio as small as $D_S/D_L \approx 0.3$. The droplet collision events were observed by two Photron SA4 high-speed cameras operating up to 10,000 frames per second and the illumination of the collision process was realised by two 8 x 10 cm^2 backlight LED arrays.

The question is now, how sensitive are Euler/Lagrange spray computations with regard to the assumed collision regime maps, which are of course depending on liquid viscosity and colliding droplet size ratio. For that purpose, the hollow-cone spray nozzle analysed in Rüger et al. (2000) was considered with the spray outlet conditions obtained from measurements. Droplet collision modelling is performed on the basis of the stochastic droplet collision model (Sommerfeld 2001), also considering the influence of impact efficiency (Ho & Sommerfeld 2002), which so far was neglected for most spray simulations. The spray propagation was computed for several different collision map structures, for example a typical water-condition where bouncing is only observed for high impact parameters and a higher viscosity case where bouncing is also observed down to zero impact parameter at small Weber numbers. In addition, the boundary lines were hypothetically shifted to the right in order to mimic a very high viscosity case. As shown by Sommerfeld & Lain (2017) the consideration of the impact efficiency, where small droplet might move around larger ones with the relative velocity, will drastically reduce the collision rate in sprays. It is demonstrated, that variations in the collision map structure have a strong influence on the predicted droplet size spectrum and consequently on the Sauter mean diameter along the spray.

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