Energy Conversion in Effervescent Atomization

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Abstract

Atomization of liquids is, from the energy point of view, a process of conversion of an input fluid energy into surface energy of produced droplets accompanied with transformation amongst several energy types. In the paper, the spray generation in twin-fluid internally mixed atomizers is qualitatively described, starting with the gas injection into the liquid and ending with a far-nozzle droplet motion. Mechanisms involved in the two-phase mixture formation during internal flow, discharge of two-phase mixture and the spray formation are characterised based on our experimental results and available literature data with particular focus on the effervescent atomization. Near nozzle spray visualization with classical and thermovision camera elucidates the liquid breakup at different operation modes.

General energy equation for a steady one-dimensional homogeneous equilibrium flow without mass and energy conservation is used to explain the energy forms involved in the atomization process. Our estimation of the energy balance in effervescent atomization shows that the gas/liquid surface formation process during the internal mixing and during the discharge consumes a minor part of the input energy. Most of the input energy is spent for expansion work of the discharged gas, air entrainment process and losses related to the two-phase flow and discharge. Effectiveness of transfer of the input fluid energy (both gas and liquid) into the increased surface energy of the atomized liquid is quantified by the atomization efficiency η, which in the case of twin-fluid atomizers is given by a ratio of the surface energy of droplets in the spray, E_a, to the total energy E_i required to produce the spray. E_i consists of energy introduced by the pressurized gas, E_g, and energy of the supplied liquid E_l. Thus:

$$\eta = \frac{E_a}{E_i} = \frac{3 \cdot \sigma / ID_{20}}{p_l + GLR \cdot \frac{\rho_l}{\rho_g} \cdot \left(p_g + p_b\right) \cdot \ln\left(\frac{p_g + p_b}{p_b}\right)}$$

where p_g and p_l are gas and liquid gauge pressures (relative to ambient atmospheric pressure, p_b) upstream the exit orifice, ρ_g and ρ_l are their densities, ID_{20} is overall surface diameter of the droplets measured using PDA and σ is liquid/gas surface tension. Atomization efficiency of effervescent atomizers is found to be in fragments of % for common operation pressures and gas-to-liquid-ratios (GLRs) (Fig. 1 top) and it is inferior by about one order to the efficiency of simple pressure and pressure-swirl atomizers for comparable conditions. Atomization efficiency depends on operation conditions of the atomizer and declines with an increase in GLR and with increase in input pressure with approximately logarithmic tendency (Fig. 1 bottom). An increase in the pressure and GLR promotes atomization reducing Sauter mean diameter, D_{32}, as well as D_{20}. However atomization efficiency drops down so the input fluid energy is utilized less effectively similarly as in the case of airblast atomizers, where it is explained by an increased gas/liquid separation that reduces the fraction of gas participating on the breakup process.
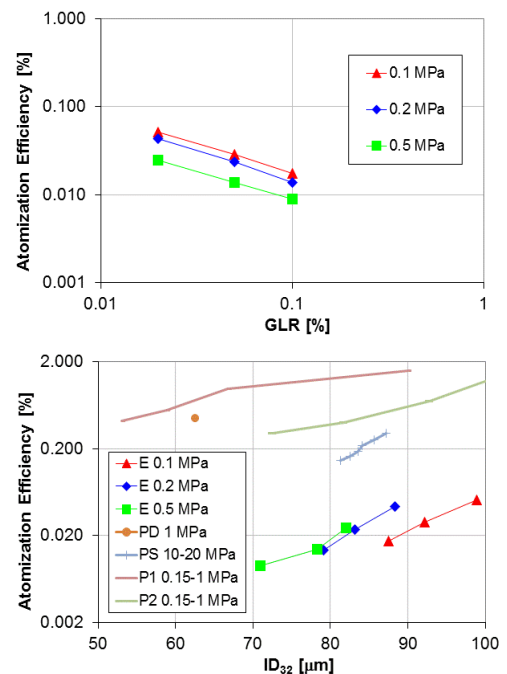

Figure 1 (top) Atomization efficiency of effervescent atomizer. (bottom) Atomization efficiency of different atomizers with regard to produced ID_{32}: e - effervescent atomizer with orifice diameter D_o=2.5 mm, operated with LHO/air; PS – pressure-swirl atomizer with D_o=2.8 mm, LHO; PD – simplex atomizer, D_o=0.4 mm, LHO; P1 – new pressure-swirl atomizer, D_o=0.36 mm, Kerosene; P2 – old pressure-swirl atomizer, D_o=0.36 mm, Kerosene.

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