Novel Modifications of Twin-fluid Atomizers: Performance, Advantages and Drawbacks

J. Jedelsky* and M. Jicha
Faculty of Mechanical Engineering
Brno University of Technology
Technicka 2896/2, 616 69 Brno, Czech Republic

Abstract

In this work we studied a single-hole effervescent atomizer spraying light heating oil with air as an atomising medium in the "outside-in" gas injection configuration. We focused on modification of geometry of the atomizer exit section. Two atomizers, one with moderate, and one with intense helical swirler in front of the exit orifice were designed to expand the spray cone angle by a swirl of the gas-liquid mixture. Performance of the atomizer modifications were compared with a plain-orifice atomizer. An experimental study of atomization process was made on cold test bench. Swirling the mixture led to a significant increase of the spray cone angle at low gas to liquid ratio by mass (GLR). An increase of the gas mass fraction in the mixture inhibits the swirl action on the spray cone expansion. The swirl effect diminishes with GLR rising above 15 %. Another two atomizers were designed with aim to reduce droplet size on the spray edge: an atomizer with secondary air at the exit orifice and an atomizer with secondary air beyond the exit orifice. The secondary air at the exit orifice gave by 5 % lower over-all Sauter mean diameter, using equal total amount of atomising air, compared to the plain orifice atomizer. The secondary air beyond the exit orifice did not bring any spray improvement but induced an undesirable contact of the liquid with the exit port wall.

Introduction

Effervescent atomizer belongs to twin-fluid atomizers with internal mixing and it is characterised by relatively simple construction [1]. It produces fine spray at low pressure and with low amount of atomising gas [2]. Regardless of it there is still potential to improve atomization characteristics such as too narrow spray cone angle of the single-hole atomizer in combustion applications and a presence of large droplets in the spray border which leads to worsening of exhaust gas emissions. Number of researchers focused their effort to reduce drop size changing internal geometry and dimensions of the exit orifice. A review of published results can be found in [2, 3]. Several authors also addressed the question of influence of the effervescent atomizer design and influence of operation conditions on the spray geometry. These authors are listed in [4].

Our aim is to develop a twin-fluid atomizer spraying suspensions with content of large particles for combustion applications. Such atomiser is supposed to not only effectively convert the gas and liquid input energy into enlarged surface area of the atomized liquid but also to provide wide enough spray and allow maintenance free operation. Large exit orifice and large cross-section of internal flow channels are needed when suspensions containing large particles are used. Our previous research have shown that swirling of the two-phase gas liquid mixture could enlarge the spray cone angle of the single-hole atomizer keeping the flow channels wide enough to avoid clogging by the particles [5]. Using this experience we have designed four new atomizers with modified exit ports and studied their atomization characteristics.

Materials and Methods

Experimental equipment includes effervescent atomizer, cold test bench with fluid supply system and Phase/Doppler Particle Analyzer. Description of our experimental facility and Dantec 1D P/DPA used for droplet size measurement can be found in [6].

Single-hole, plain-orifice effervescent atomizer, designed during our previous research and deeply studied in [5], was used here as a starting point and used also for comparison with the new designs. The atomizer is powered with light heating oil (LHO) and uses air as an atomizing medium in the "outside-in" gas injection configuration, see Fig. 1. It consists of a cylindrical body in which an aerator tube is inserted. The aerator is connected with an exit nozzle. The LHO enters the central orifice of the aerator from left side, while the air is injected into the liquid, through a set of small holes in the aerator envelope. Both fluids form a two-phase mixture, flow downstream and exit the atomizer through a discharge orifice to the ambient atmosphere in the form of a spray. A volume of a mixing chamber formed inside the aerator tube is given by the length downstream of the last row of air holes, l_c, and the internal diameter of the aerator tube, d_c. The length l_c, diameter d_c together with span

* Corresponding author: jedelsky@fme.vutbr.cz

length Δl, diameter d_a and number of aeration holes, N, are kept constant in this study and noted in the Fig. 1. Exit orifice has always diameter do of 3.5 mm and length of 0.7 mm. There is a conical junction with the apical angle of 120° in front of the orifice.

The atomizer was continuously operated and studied in the vertical downward position of the main axis. The air and oil supplies are controlled separately. Operational conditions of the twin-fluid atomizer with given geometry and fluids with defined physical properties can be basically described by any two independent parameters. We choose the air gauge pressure and GLR. Thus other parameters, liquid pressure, liquid and air flow rates, are dependent upon them. Experiments were performed for several air gauge pressures and GLR values. Gauge pressures and volumetric flow rates of LHO and atomizing air were measured, GLR was calculated. Temperatures of both fluids were kept at 20 +/- 3 °C. Physical properties of used LHO were: dynamic viscosity 0.0185 kg/(m s), surface tension 0.0297 kg/s^2 and density 874 kg/m^3.

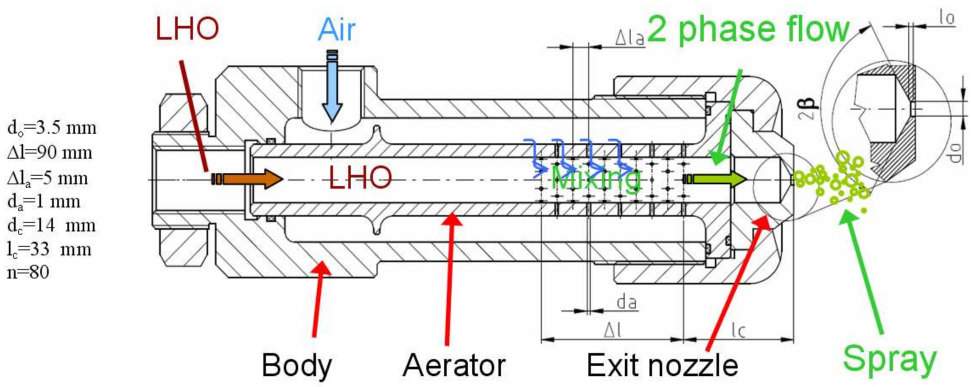

Figure 1. Plain-orifice atomizer (P) with dimensions

Several nozzles were designed and fabricated to test the effect of the swirl chamber on the spray:

- simple atomizer without swirler (P) for comparison of results, see Fig. 1,
- two modified atomizers with helical swirl insert: one atomizer with moderate swirler (I) and one atomizer with intense swirler (II) to extend the spray cone angle, see Fig. 2,
- one atomizer with introduction of the swirling secondary air beyond the exit orifice (III) and one atomizer with swirling secondary air at the exit orifice (VI) to reduce droplet size at spray edge.

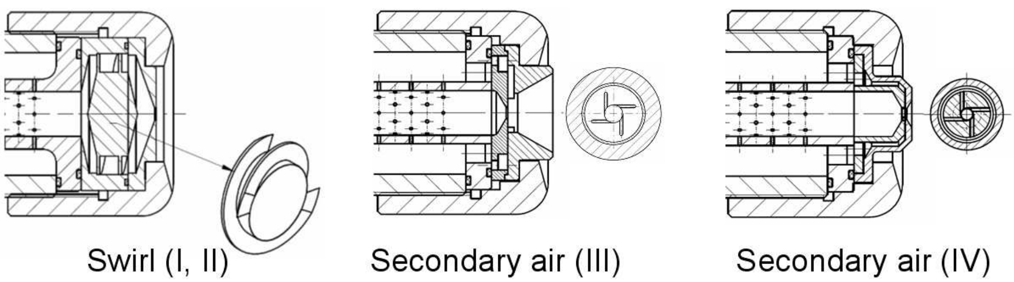

Figure 2. Newly designed atomizers

Swirling of the two-phase mixture using internal swirlers causes an introduction of the radial velocity component. This effect should lead to widening of the spray cone angle without significant influence on the drop size as two phase flow should appear very similar to those acquired with plain nozzle. Large cross-section of the swirl channels was used to avoid clogging when particle laden liquid used and also to reduce pressure drop in case of viscous liquids. Helical swirl ports were chosen as they only moderately enlarge the atomizer size. Dimensioning of the ports was dictated by the limitation of the external atomizer dimension, by the requirement of maximum cross-section area and the requirement of the maximum rotational energy to be added to the mixture.

The secondary air used with atomizers III and IV should disturb the discharged liquid pre-atomized using internally injected pressurized air. Tangential entry of the secondary air should introduce a rotational momentum to the discharged mixture and hence enlarge the spray cone angle as in the previous case. Usage of external air input does not influence exit cross-section size and more over it could lead to an intensification of the ligament break-up of the discharged liquid. This idea is based on works of Sutherland et al. [7] and Panchagnula et al. [8]. Sizing of the secondary ports was driven by a compromise between low total atomising air consumption and sufficient effect on the discharged mixture.

Note that the swirl atomizers (I) and (II) still can be classified as effervescent atomizers when operated at bubbly flow [9]. Resulting design in the case III and IV is a tri-fluid pneumatic atomizer where original effervescent part is combined with an air-blast part.

Results and Discussion

Spray cone angle

Spray cone angle (SCA) of three atomizers was evaluated using spray photography (Fig. 3). Atomizer P gives spray with maximal spray cone half-angle 20° at GLR 10 %. Decrease in GLR leads to the SCA reduction and to a collapse of the SCA if no air used (GLR= 0). Atomizers with moderate (I) and intense (II) swirler give wide spray when GLR=0. GLR increase reduces the cone angle as critical discharge of the two-phase mixture disturbs the swirl motion. Similar behaviour was noticed by other researchers that studied internally mixed twin-fluid atomizers with swirl ports [10, 11].

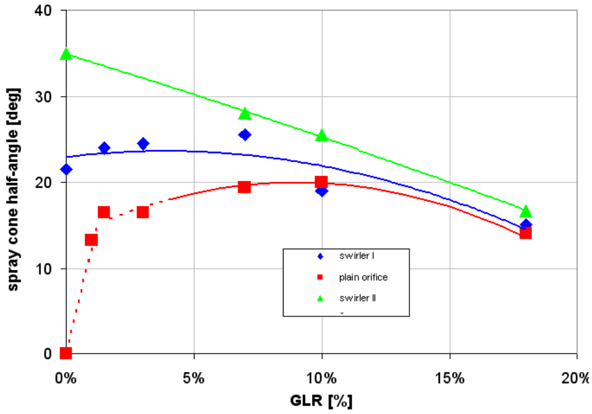

Figure 3. Influence of the mixture swirl on the spray cone half-angle.

Droplet size measurement

Exemplary results of the spray measurement using P/DPA for atomizer P and IV at a distance of 150 mm downstream the exit orifice are shown on Fig. 4 left. Measured radial profiles of Sauter mean diameter, D_{32}, show inversely bell shaped course. This general tendency is the same for both the atomizers. Atomizer IV produces smaller droplets, mainly out of spray axis, than the atomizer P. It is due to an interaction of the liquid with the secondary air at the exit orifice edge.

Overall comparison of the spray produced by the newly designed atomizers is shown in Fig. 4 right. To characterize the atomization quality by a single parameter, we introduced an Integral Sauter Mean Diameter, ID_{32}, which represents the whole spray at a certain cross-section perpendicular to the axis of the nozzle exit orifice [3]. The simplified equation for the calculation of ID_{32} reads:

$$ID_{32} = \frac{\sum_{i=2}^{n} \left(r_i \cdot D_{30,i}^3 \cdot f_i \right)}{\sum_{i=2}^{n} \left(r_i \cdot D_{20,i}^2 \cdot f_i \right)}. \qquad (1)$$

where $D_{30,i}$ and $D_{20,i}$ are the volumetric and surface diameters respectively of drops measured at the radial position r_i using P/DPA with drop arrival frequency f_i. Total number of measurement positions is n. The ID_{32} calculated from data measured in radial profiles of D_{32} is shown in Figure 4 right. The secondary air at the exit orifice (IV) gives the lowest ID_{32}, using the same total amount of atomising air. The secondary air beyond the exit orifice (III) (not shown here) did not bring any spray improvement while induced an undesirable contact of the liquid with exit port wall.

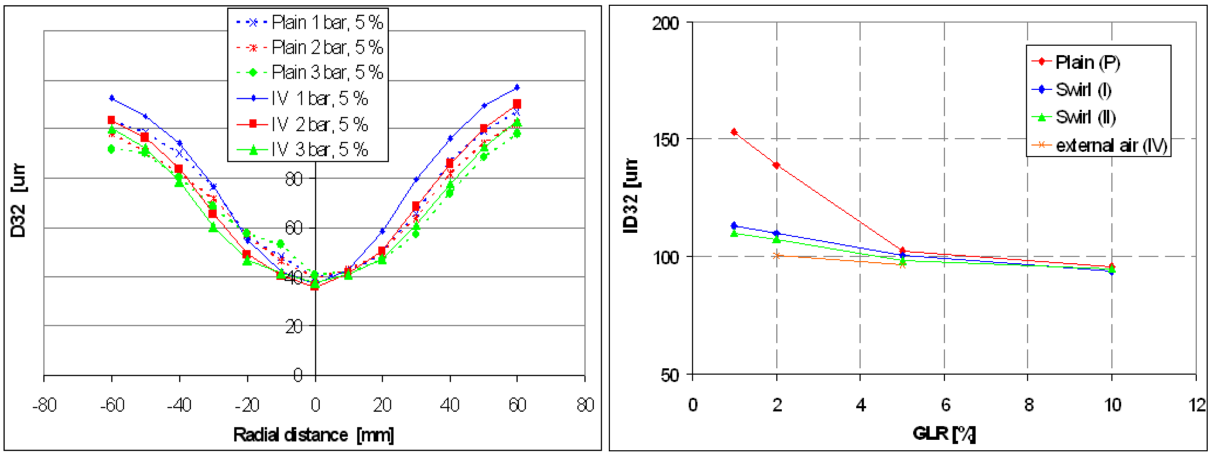

Figure 4. Influence of the air input pressure on ID_{32} for plain-orifice nozzle (P) and the nozzle with secondary air at the exit orifice (IV) at GLR 5 % (left); Influence of the GLR 5 % on ID_{32} at air input pressure 0.1 MPa (right).

Conclusions

Four new twin-fluid atomizers were designed based on effervescent atomizer in the "outside-in" gas injection configuration. Spray visualization documents fine and stable spray in the case of atomizers I, II and IV. Atomizer III gives coarse spray due to liquid-wall contact.

Internal swirl of gas-liquid mixture widens the spray cone angle heavily (I, II). Difference between swirl and plain orifice atomizer is distinct mainly at low GLR and diminishes with GLR rising.

Secondary air input at the nozzle orifice (VI) reduces droplet size for the same GLR. The external air in case of the atomizer (III) significantly widens the spray cone angle but future development is needed to overcome the problems with the body-wall splashing.

Nomenclature

D_{20}	Surface mean diameter [μm]
D_{30}	Volumetric mean diameter [μm]
D_{32}	Sauter mean diameter [μm]
ID_{32}	Integral Sauter mean diameter [μm]
f_i	drop arrival frequency (data rate) [Hz]
GLR	Gas to liquid mass flow ratio [-]
i	index of the measurement position [-]
n	number of measurement positions [-]
p	pressure [MPa]
r_i	radial position [mm]

Acknowledgement

Authors greatly acknowledge financial support from project GA 101/06/0750 funded by the Czech Science Foundation, from Netme Centre project – New technologies for Mechanical Engineering CZ.1.05/2.1.00/01.0002 funded by the Ministry of Education, Youth and Sports CR and from project BD 13001007.

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