Characterization of spray generated by multihole effervescent atomizer and comparison with standard Y-jet atomizer

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Abstract
The study of effervescent atomizers is being conducted with the aim to develop an effervescent atomizer for industrial burners that will generate a fine and stable spray in a large turn-down ratio, and provide a symmetrical flux distribution. The atomizer is powered with light heating oil and uses air as an atomizing medium. The atomizer is expected to replace Y-jet atomizer frequently used in burners. This research is a follow up of a research done previously with a single-hole effervescent atomizers with various geometrical features of both, the aerator and the body of the atomizer. Based on results of this study, four geometrical variants of a multi-hole effervescent atomizer were designed. All atomizers were investigated from the point of flow characteristics and operational conditions in the turn-down ratio 1:5. Results of this study are in another paper [1] presented by the same authors in these proceedings. Based on these results, atomizer with 6 orifices labeled as E8 was chosen for detailed measurements of SMD, velocity and fluxes. Results are compared with a standard Y-jet atomizer also with 6 individual orifices. In both atomizers, effervescent and Y-jet, the full cone that is formed by axis of individual orifices make 60°. SMD and velocities of droplets were measured with 1-component PDA system in horizontal plane 152mm from the orifice. Fluxes were measured with PLIF imaging system. Results show that SMD of the spray from both, effervescent and Y-jet atomizers are very similar as for the absolute minimum and maximum values, spray generated by effervescent atomizer is less affected by different fuel pressure and ALR. With Y-jet atomizer we can see asymmetry in SMD due to the impact of fuel and air streams in the mixing chamber which is projected also outside the atomizer. Distribution of fluxes show a certain nonuniformity as does also relative span factor $(D_{0.9} - D_{0.1})/D_{0.5}$ which is one of the most useful parameters that correctly characterizes combustion process.

1. Introduction

Effervescent atomizers are becoming more and more commonplace in numerous engineering applications in which a liquid must be fragmented into droplets. Effervescent atomizers in combustion applications lead to lower pollutant emissions due to presence of air in the spray core. As high grade hydrocarbon fuels become scarce, the effervescent atomizers will have to be replaced with other designs that can handle less refined fuels. Major advantage of effervescent atomizers is their relative insensitivity to fuel physical properties and ability to perform over a wide range of liquid flow rates and can provide good atomization over a wide range of operating conditions. Furthermore the E-atomizers can have larger orifice than conventional atomizers which alleviates clogging problems and facilitates atomizer fabrication.

When designing effervescent atomizers for industrial furnaces and combustors, a main attention must be paid to their real operation. Control system of both lines – liquid and gas – must be able to satisfactorily perform over required liquid flow rates. As the effervescent atomizers are operated at relatively low Gas-to-Liquid Ratio GLR, the pressure difference between liquid and air can be relatively low but this latter may significantly change with changing liquid flow rate and with different internal geometry of the atomizer. From this point it is important to know how the atomizer will be operated, whether at constant pressure difference $p=p_{fuel}-p_{air}$, at constant air pressure or both fluids, air and fuel will be adjusted independently. When the atomizer is operated with a burner, we have to take into account different control members in the air and fuel lines, like valves, regulators and their dynamic range, characteristics and accuracy. For instance shutting and opening valves (when starting operation of additional burners) may cause for a certain short time changes of pressure in one or both lines and can change characteristics of spray. Investigation of the atomizers from this point has been performed as part of another study, results of which are in the paper [1]. Based on this research we choose effervescent atomizer labeled E8 for further more detailed investigation including measurements of SMD, velocity, fluxes and different characteristic parameters derived from droplets size spectrum like relative span factor.

2. Experimental facility and atomizers

Figure 1 shows a schematic layout of the experimental facility. It consists of a gear pump #14 that supplies light heating oil from a main fuel tank 16 through a set of filters, control valves and flowmeters into the atomizer #7. The compressed air is delivered either from the central plant or from a two stage compressor #1 depending on the required pressure through an air chamber #2 and set of filters and control valve into the atomizer. Spray is collected in a vessel #12 and returned to the main supply tank. The collector is connected to an oil mist separator that keeps the spray zone free of aerosol but doesn't distort the spray. The gear pump delivers the oil with a pressure up to 3MPa, pressure of the compressed air can reach 2MPa. The maximum flow rate of the oil can reach 1800 kg/hour. Pressures and temperatures readings are taken at the atomizer inlets for both the fuel and air. The pressure measurements are complemented by the pressure difference measurement. The fuel is injected vertically downwards into the ambient atmosphere. The sampling distance was set to 152mm from the atomizer orifice.

In the test rig, the atomizer is turned by 30° from vertical so the spray is directed perpendicularly downward. To enable measurements of only one individual spray, a special collector was made and fixed to the tip of the atomizer. The collector is made in such a manner not to influence pressure field in the atomizer and returns all untested sprays to the main supply tank. The collector doesn’t disturb the observation field for additional PLIF and PDA measurements.

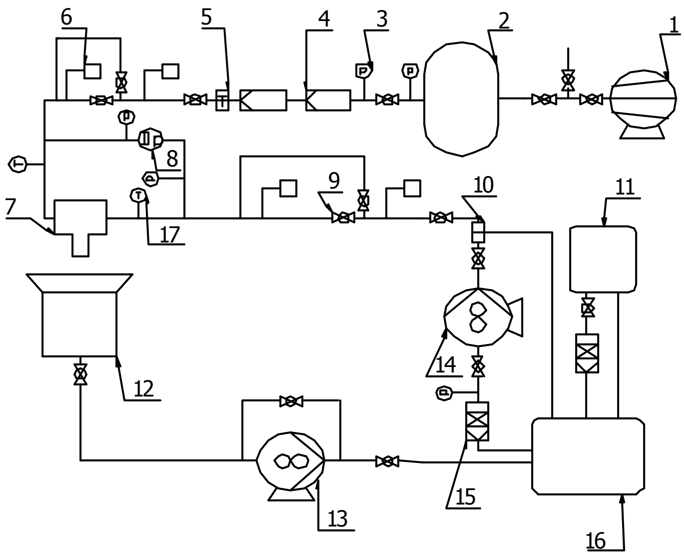

Fig. 1 Schematic layout of the experimental facility

Effervescent atomizer is shown schematically in Fig.2. The mixing chamber has the inner diameter of 16mm. There is a conical shaft placed inside the chamber so the gap gradually enlarges from 1mm at the position of the first row of aerator holes. There are 168 holes of the diameter of 1.2mm in 21 rows, 8 holes in one row always turned through 45°. The last row of the holes ends up at the position of the tip of the conical shaft. The tip of nozzle has 6 orifices of the diameter of 2.2mm. Axis of the orifices form a full angle of 60°. The Y-jet atomizer is also shown in Fig.2. The air flows in the central part of the atomizer and at the end it enters six individual channels with the diameter of 1.5mm. Fuel enters the enlarged part of the channel with an impact angle of 52°. The orifice has the diameter of 2.2mm. Axis of the orifices form a full angle of 60°. Design of effervescent atomizer was based on [2]. Design of Y-jet atomizer was done according methodology of First Brno Works.

As a fluid, light heating oil was used with the flow rate in the range from approximately 0.05 l/s to 0.5 l/min. Both, effervescent and Y-jet atomizers were operated at three different fuel pressures, namely 0.2, 0.6 and 1.0 MPa and three values of GLR 3, 5 and 10%.

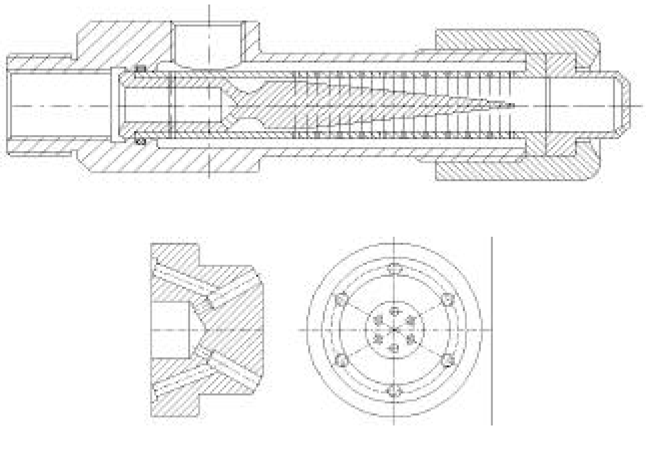

Fig.2 Schematic layout of effervescent (upper) and Y-jet atomizer (lower)

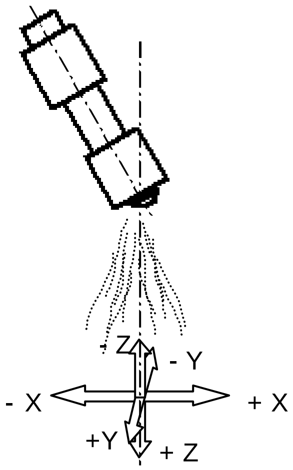

Fig.3 Schematic view of
coordinates of measured spray

3. Experimental procedure and results

Investigations have been conducted with the aim to provide detailed information on characteristics of sprays generated by standard multihole Y-jet and multihole effervescent atomizers (further named as E atomizer). Characterization was performed using 1-component PDA system and PLIF system. PDA system was used to measure size and velocity spectrum, PLIF system to measure concentration and from them mass flux distribution using data on velocity field from PDA. Measurements were done in the horizontal plane 152mm distant from the nozzle orifice and with PDA always in two perpendicular diameters marked in accompanying graphs as coordinates ± x, ± y with the purpose to see SMD and velocity symmetry of the sprays. For schematic view see Fig.3. Basic parameters of the set up PDA and PLIF systems are in Tab.1.

Results of SMD are in fig. 4 for Y-jet and fig. 5 for effervescent atomizer. From comparison we can see that the spray generated by the Y-jet atomizer is less symmetrical than that regenerated by E atomizer. The asymmetry is namely in the direction ± x which is the plane drawn through the fuel and air passages - see Fig.2.

Tab.1 Parameters of PDA and PLIF systems

PDA		PLIF	
Laser	Ar-Ion 300mW	Laser	Continuum Surelite 10 Hz
Wavelength	514,5 nm	Operation	4^{th} harmonics 266 nm
Beam diameter	0,82 mm	Pulsewidth	4,25 ns (4-6 ns)
Beam spacing	60,0 mm	Power	50 mJ (40 mJ)
Focal length of transmitting and receiving optics	500 mm	Repetition rate	10 Hz
Scattering angle	67,6°	Sheet thickness	cca 0,5 mm

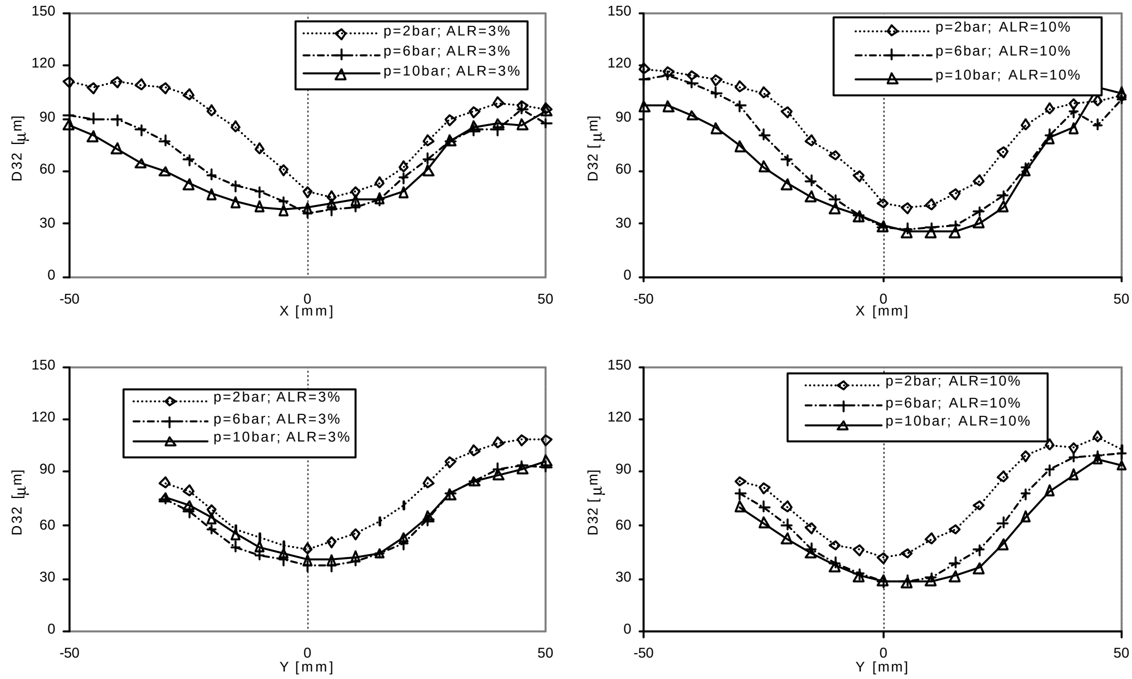

Fig.4 Sauter Mean Diameter D_{32} for Y-jet atomizer

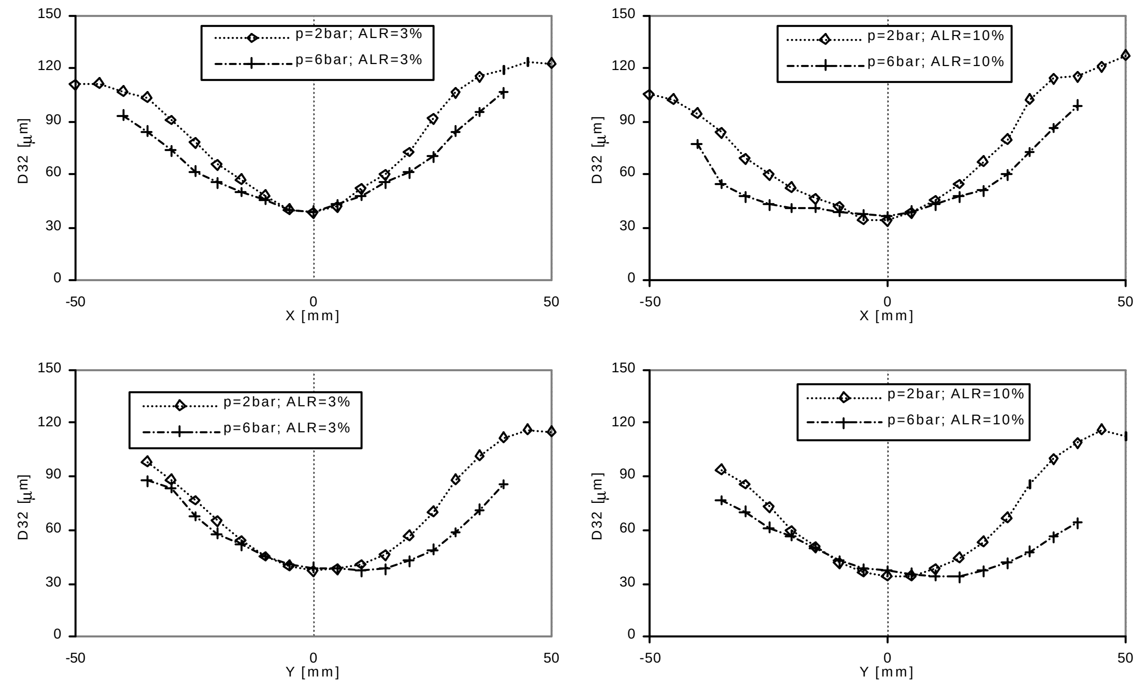

Fig.5 Sauter Mean Diameter D_{32} for effervescent atomizer

Asymmetry is more remarkable for lower fuel pressure and for higher Air-Liquid-Ratio ALR. In the plane ± x we can see that on the side of the fuel inlet to the mixing chamber (-x), the SMD is much more sensitive to the fuel pressure, this sensitivity being also seen in +y direction. With increasing ALR, this sensitivity also increases and appears in the +x and –y directions and namely in the center core of the spray. In the plane perpendicular to the plane described above the spray is more symmetrical. Very important in analyzing SMDs is its character at the outer edge of the spray. In –x direction, which is the outer part of the “multihole” spray, SMD are relatively high for both ALR 3 and 10% and their distribution is very flat saying that SMD keeps high for a large portion of the spray. This will probably mean that droplets flying through the flame from this part of the spray may show a short residence time in the flame and leave the flame zone unburned. On the other hand, the spray generated by E atomizer is much more symmetrical in both planes ± x, ± y, and also there is no noticeable influence of ALR. SMD at the outer edge decreases with a higher gradient than with Y-jet atomizer what means that a smaller part of the spray contains large droplets. Limiting values of SMD for both atomizers are very similar. Minimum values are about 30 μm at the axis, maximum values reach 120 μm at the outer edge of the spray. Lower sensitivity to pressure (and hence to fuel flow rate), better symmetry and smaller part of spray containing larger droplets makes E atomizer better suited.

One of the most useful parameters that correctly characterizes combustion process and indicates spray quality is the relative span factor $RSF = (D_{0.9} - D_{0.1})/D_{0.5}$. Diameters $D_{0.9}$, $D_{0.5}$ and $D_{0.1}$ denote that 90%, 50% or 10% of the liquid volume consists of drops with diameter smaller than D_i. Difference $D_{0.9} - D_{0.1}$ indicates the inclination of cumulative volumetric distribution curve. Smaller is the difference, both diameters $D_{0.9}$ and $D_{0.1}$ approach from below and above $D_{0.5}$ what indicates more uniform spray. So smaller is the value of *RSF*, more uniform spray is generated. On the other hand, in each combusting spray $D_{0.1}$ characterizes the ignition properties and $D_{0.9}$ determines the required length of a combustion chamber.

In Fig. 6 and 7 there is a distribution of RSF for Y-jet and E injectors. As can be seen for Y-jet atomizer in Fig.6, the span shows a certain chaotic behavior indicating very different homogeneity across the spray. The effervescent atomizer demonstrates a certain regularity in both directions ± x, ± y (more in ± x than in ± y) showing something like a saddle character – see Fig.7.

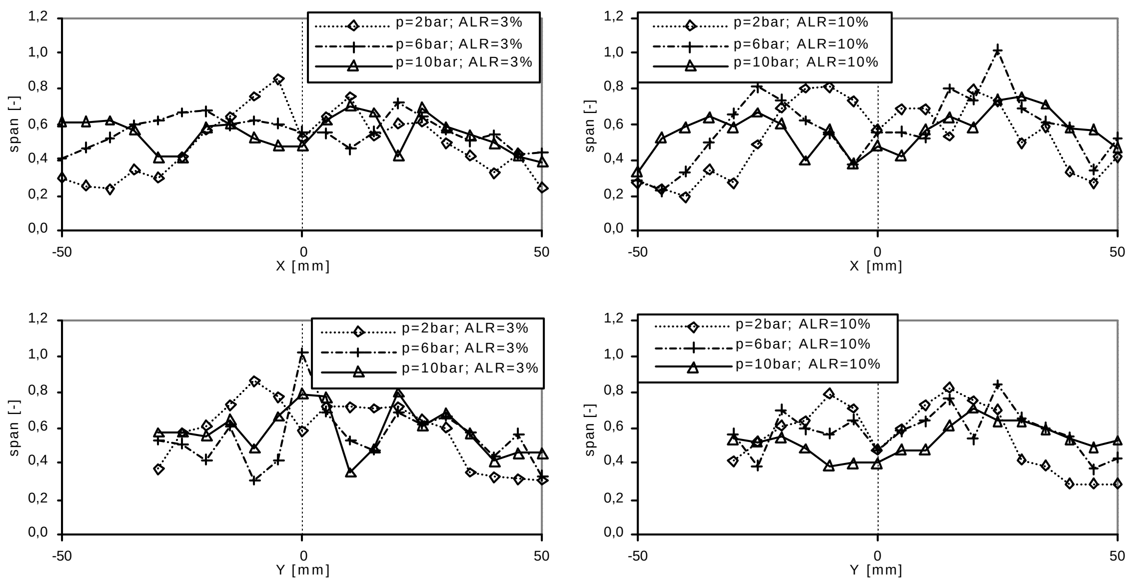

Fig.6 Relative span factor for Y-jet atomizer

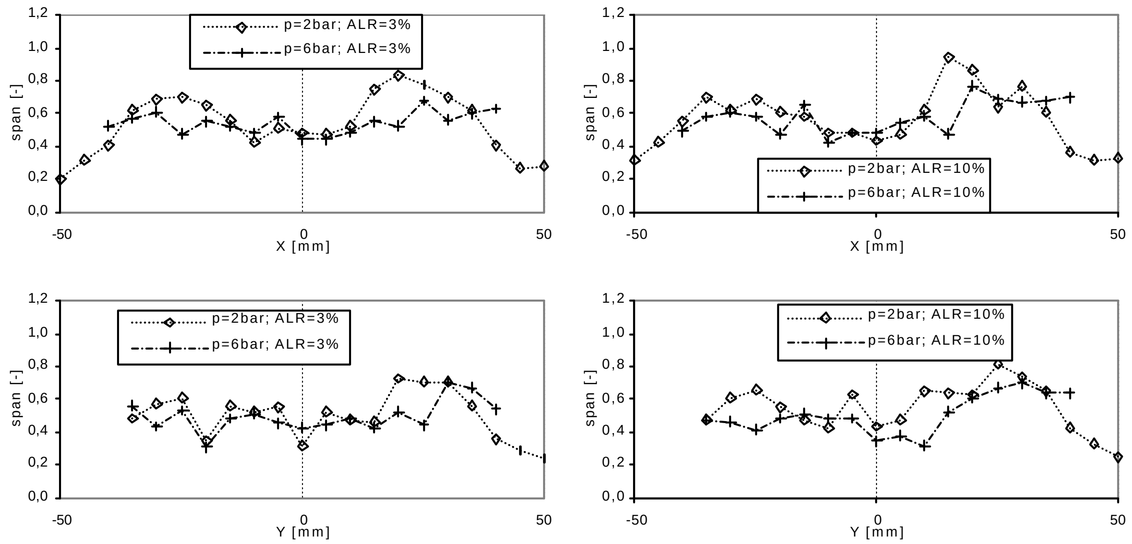

Fig.7 Relative span factor for effervescent atomizer

RSF distribution also reflects SMD distribution shown in Fig. 4 and 5. SMD generated by effervescent atomizers is less affected by fuel pressures and ALR and in this case from RSF distribution we can conclude that the homogeneity of the spray is better than in case of the spray generated by the Y-jet atomizer in which case the SMD is more affected by the fuel pressure and ALR.

Mass concentrations and mass fluxes were measured with PLIF system and the results of mass fluxes are in Fig. 8 and 9 for Y-jet and effervescent atomizers. Mass fluxes were obtained from mass concentrations by multiplying them with time averaged local velocity of droplets obtained from PDA measurements. As can be seen, distribution of mass fluxes is quite symmetrical around both axes, x and y and very similar for both types of atomizers. Symmetry increases with ALR, i.e.more dilute spray has more symmetrical flux distribution.

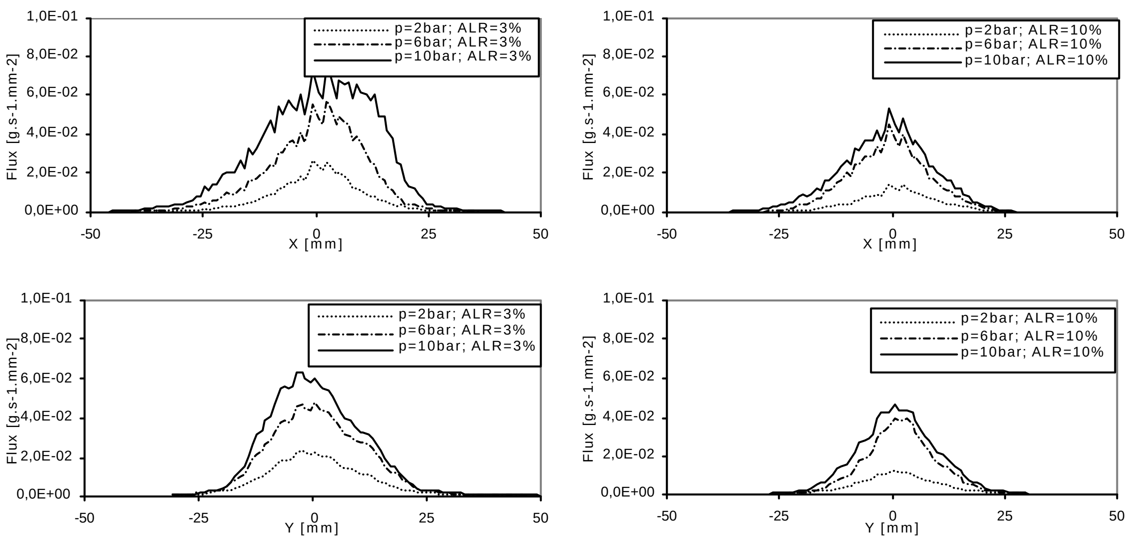

Fig.8 Mass flux for Y-jet atomizer

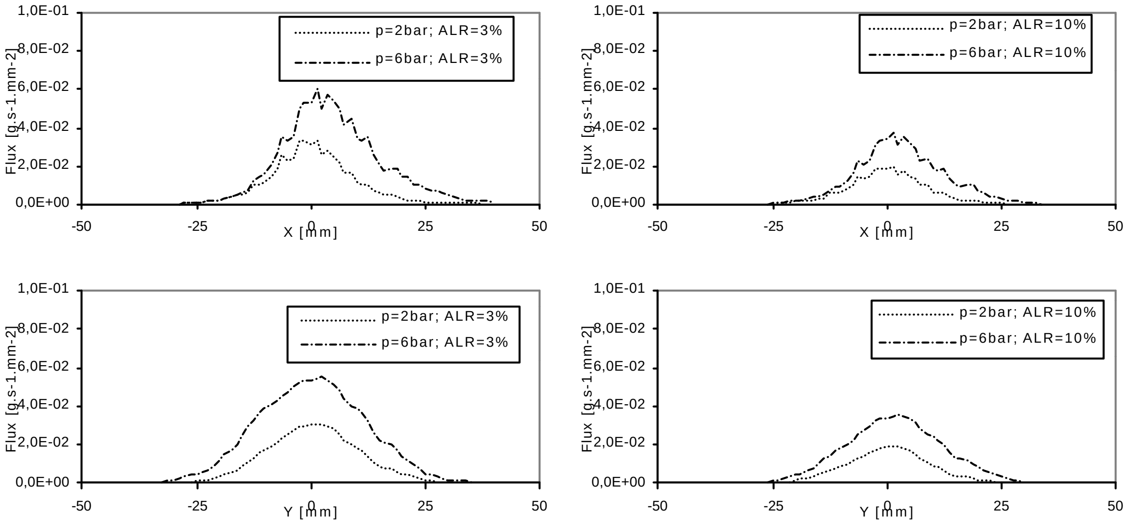

Fig.9 Mass flux for effervescent atomizer

From the current measurements it is difficult to say whether it is due to a larger content of air which tends to make the spray more symmetrical from the point of droplets distribution in the volume or due to a little narrower and sharper velocity profile (which is not presented here) of the spray.

5. Conclusions

From the measurements it can be concluded the following:

- SMDs of sprays generated by either atomizer are very similar in absolute minimum and maximum values, spray generated by effervescent atomizer is less affected by different fuel pressure and ALR. With Y-jet atomizer we can see asymmetry in SMD due to the impact of fuel and air streams in the mixing chamber which is projected also outside the atomizer
- Relative span factor which speaks out about homogeneity of the spray shows more uniform distribution with effervescent atomizer than with Y-jet atomizer.
- Mass flux distribution is very similar for both types of atomizers

Acknowledgement

We greatly acknowledge a financial support from the Ministry of Education of the Czech republic through the project Eureka E! 2517 BURNER, from Brno University Research Plan No. MSM262100001 and project GA 101/03/P020 funded by the Czech grant agency.

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