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On the spray pulsations of the effervescent atomizers

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Abstract. The presented paper focuses on the comparison of the two effervescent atomizer configurations—the outside-in-gas (OIG) and the outside-in-liquid (OIL). The comparison was based on the spray pulsation assessment by different methods. The atomizers were tested under the same operating conditions given by the constant injection pressure (0.14 MPa) and the gas to the liquid mass ratio (GLR) varying from 2.5 to 5%. The aqueous maltodextrin solution was used as the working liquid (μ = 60 and 146 mPa·s). We found that the time-averaging method does not provide sufficient spray quality description. Based on the cumulative distribution function (CDF) we found that the OIG atomizer generated the spray with non-uniform droplet size distribution at all investigated GLRs. Exceptionally large droplets were present even in the spray which appeared stable when was analyzed by the time-averaging method.

1 Introduction

Twin-fluid atomizers are widely used, as an alternative to pressure nozzles, for spraying of viscous liquids. These spraying devices are specific by using a pressurized gas to enhance the liquid breakup. The need to reduce atomizing gas consumption and working pressure led to the development of internal-mixing twin-fluid atomizers that are more energy saving than their external mixing counterparts. A number of internal mixing atomizer designs have been proposed and studied in detail in past decades [6], [9], [3]. Though these works provide sufficient amount of information about particular atomizer designs and their spray properties, there is a lack of their systematic comparison and applicability analysis [1]. In our previous works, we provided a comparison of the OIG, OIL, Y-jet and CFT atomizers based on the internal flow regime and a primary breakup conditions [6].

As we analyzed the time-averaged Sauter mean diameter ($D32_a$) of the droplet sizes, we found significant differences between the spray quality of the OIG and OIL atomizers. Therefore, we will focus our interest on the deeper investigation of the spray temporal behavior in this paper. We will analyze the measured time-dependent droplet sizes to judge the spray quality. This analysis will be further used to compare the OIL and OIG atomizers and their applicability potential.

2 OIG and OIL atomizers

The main feature of the investigated atomizers is the mixing chamber, where the internal flow is developed. This part of both the investigated atomizers has the same design (Fig. 1). It is designed as the tube with upper and side injection ports. These are used to introduce the liquid and the atomizing gas.

The OIG and the OIL configurations differ in the way of the working fluids injection. At the OIG atomizer is the liquid introduced through the top inlet port (port A, Fig. 1) and the gas is injected by the number of the side ports (ports B, Fig. 1). The only difference of the OIG and the OIL atomizers is that the liquid and the gas injection ports are switched. Even when this slight change may seem unimportant. It causes a dramatic change of the internal flow. As we previously observed [6], the internal flow of the OIG atomizer tends to develop as the plug or slug flow, while the liquid in the OIL atomizer tends to attach on the wall of the mixing chamber, which leads to the annular structure of the internal flow.

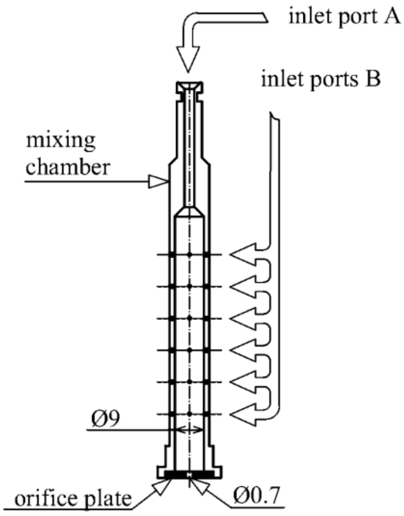

Fig. 1 Schematic drawing of the effervescent atomizer mixing chamber (both the configurations)

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3 Measurement of droplet sizes

The experiments were conducted on the test bench schematically drawn in Fig.2.
An eccentric screw pump at constant rotation speed was used to drive the liquid and the liquid mass-flow was controlled by a bypass line. The constant pressure of the atomizing gas (air) was maintained by a pressure relief valve. The air pressure regulation was thus independent of its mass-flow. All the experiments were performed at the room temperature. The detailed test bench parameters can be found in [6].
The atomizer working regimes were defined by the Δp and the GLR. We have chosen the inlet air pressure as an independent parameter because its contribution to the total energy balance dominates over the liquid inlet pressure [4]. Therefore, the inlet pressure can be related to the potential energy of the atomization process. The GLR has been chosen because it is a parameter which can be simply related to the effectiveness of the atomizers work.

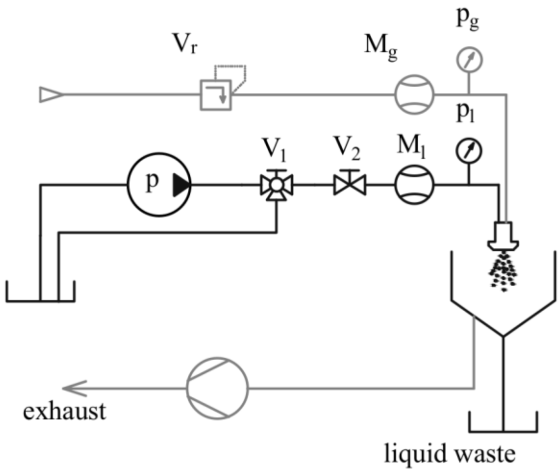

Fig. 2 Test rig

The droplet sizes were measured by the laser diffraction system (Malvern Spraytec) at the distance 100 mm downstream to the discharge orifice. The measurement frequency was 500 Hz and the measurement period was 25 s.

4 Spray pulsation analysis

The one way of the spray pulsation analysis is to use the time-averaged Sauter mean diameter (averaging was done over 12 500 samples for each working regime). The estimated standard deviation of the $D32_a$ can be therefore related to the spray pulsation. This method, however previously used and accepted, provides an only perfunctory view into the investigated problem. It can only differ between the regimes with and without pulsations and it cannot provide any other information about its nature (range of droplet sizes, periodicity….)

In our effort to investigate the spray pulsations more deeply, we investigated the time-dependent data. This was done by applying the cumulative distribution function, as proposed by [5]. This method provided us the more-relevant spray quality assessment tool.

5 Results

The simplest, but only qualitative, insight into the temporal spray behavior provide the records of the time-dependent droplet sizes in Fig. 3, 4. These figures show the comparison of the two atomizers at the same GLR and inlet pressure (Fig. 3) and the GLR atomizer working at two different gas consumption regimes (Fig. 4). It is obvious that both, the atomizer configuration as well as the GLR, strongly influences the spray quality. It is well-known that the droplet sizes generated by the twin-fluid atomizers decrease when the gas consumption rise. It is caused by the higher energy potential given by the compressed gas [4]. More surprising discover is that the same atomizer can produce spray with different quality when the gas and the liquid ports are switched, especially at the low GLRs. The Fig. 3 shows the difference.

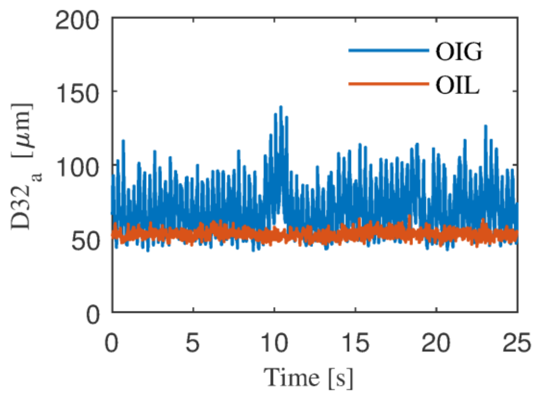

Fig. 3 Comparison of the time-dependent droplet sizes generated by the different atomizers for the same working regime (Δp = 0.14 MPa, GLR = 5%)

The droplet sizes time-record indicates that both, the D32 and its fluctuations are higher for the OIG atomizer configuration. Method of the spray comparison presented in Fig. 3, 4, however, simple to read, provides poor quantitative insight. The more suitable analysis is provided by time-averaged droplet sizes (Fig. 5). The diagrams show the dependence of time-averaged Sauter mean diameter in relation to the GLR for the different liquid viscosity. We can observe the decreasing trend of the droplet sizes as well as the pulsation intensity related to the standard deviation of the $D32_a$ (error bars in Fig. 5) for both the atomizers. As was outlined by the Fig. 3, the pulsations were more intense when the OIG atomizer was used, especially at the low GLRs. Now focus on the data measured for the less viscous liquid to simplify further analysis.

The error bars in Fig. 5 indicate, that for GLR > 5% was the spray pulsations intensity comparable. Now, the question is if this analysis provided all necessary information about the spray quality. For example, some applications, like spray-drying or oil burning require highly uniform droplet size distribution, which corresponds to the narrow error bars in Fig. 5.

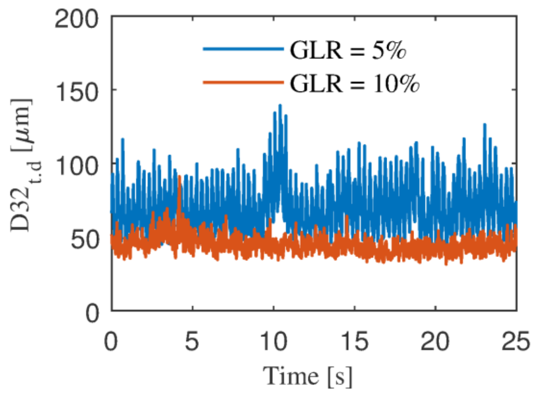

Fig. 4 Comparison of the time-dependent droplet sizes generated by the OIG atomizer at different GLRs

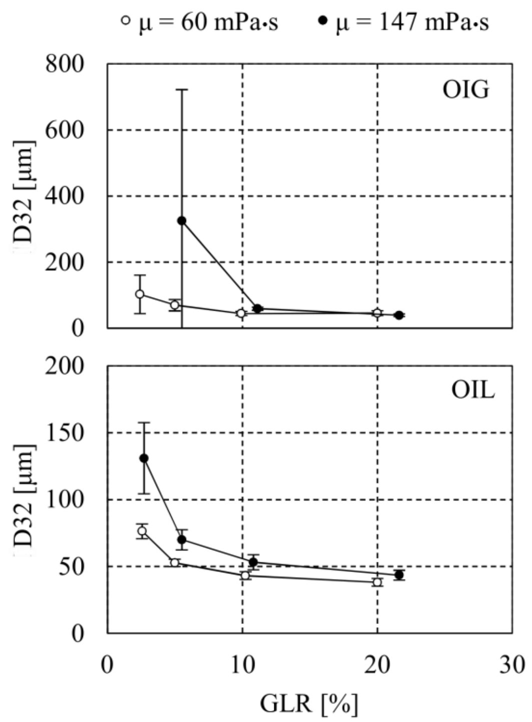

Fig. 5 Comparison of the cumulative distribution function for the two atomizers at GLR = 2.5% and inlet pressure 0.14 MPa

Even the small amount of the very large drops can cause serious problems in such applications. Problem is that a few the droplets highly excessing the average size do not affect the standard deviation of $D32_a$ and, therefore, is the presence of such droplets in Fig. 5 neglected.

A method for more-detailed droplet size analysis as proposed by [5] is based on the application of cumulative distribution function to the time-record of the measured droplet sizes. The results of this analysis can be seen in Fig. 6 and 7. The first diagram (Fig. 6) compares both the atomizers at the regime with the very low gas consumption. The results of this analysis show that the OIG atomizer produced generally larger droplets (~100 μm) than the OIL device (~75 μm), which is in accordance with the previous analysis. The additional information about spray pulsations (droplet sizes variations) is encoded in the shape of the CDF curve. The cumulative distribution function for the OIL is narrow and its slope is steep, which indicates that the droplet sizes variations were low (which also corresponds to the error bar in Fig. 5). For the OIG device is the CDF curve wider, which indicates more intense spray pulsations. In advance, we can analyze the composition of the droplets in the spray. The spray produced by this atomizer contained a number of the very small (50 μm), but also the very large (>150 μm) droplets. This can be seen in the bottom (CDF < 0.05) and top (CDF > 0.95) parts of the curve. However interesting are these findings they do not provide new essential knowledge about the spray, for the regime where the pulsations were obvious from Fig. 5 (GLR = 2.5%).

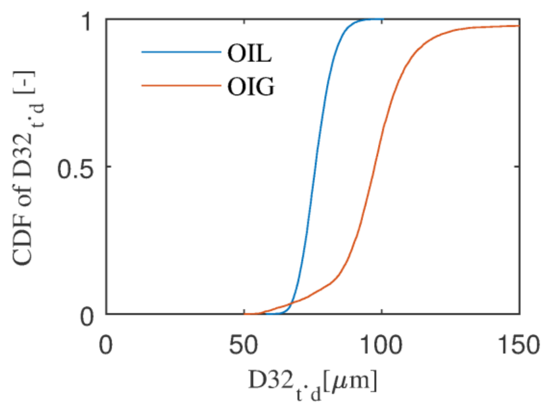

Fig. 6 Comparison of the cumulative distribution function for the two atomizers at GLR = 2.5%

The more important is this analysis for the regimes where the error bars did not signalize any significant droplet size variations (GLR > 5%). In Fig. 7, are the CDF curves for the regime characterized by the GLR = 5%. The OIL atomizer produced a very fine spray with the average droplet size about 55 microns. Also, the steep CDF curve indicates the uniform droplet size distribution. The measured data for the OIG configuration suggest that the spray contained a wide range of droplet sizes (from 45 to 115 microns). Even more important is that there were present a number of droplets larger than 100 μm. The CDF, therefore, revealed that even at relatively stable regimes (according to the Fig. 5), the spray quality might be insufficient for some applications where the high droplet sizes uniformity is required.

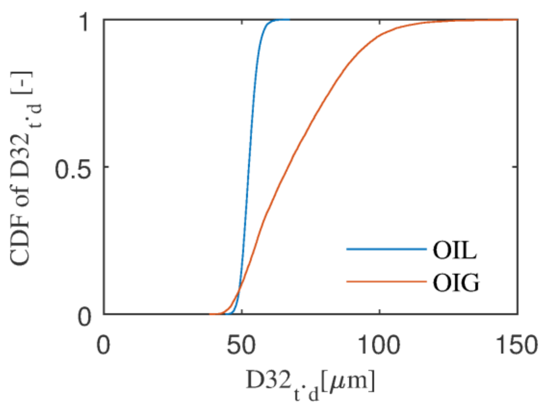

Fig. 7 Comparison of the cumulative distribution function for the two atomizers at GLR = 5%

From the previous analysis is clear that the spray quality (judged by the droplet size variations or pulsations) is highly sensitive not only to the GLR but also on the configuration of the effervescent atomizer injector ports. The main difference between the OIL and OIG atomizers lies in the internal flows. It was estimated [7] that the internal flows of these atomizers were of a different pattern. The flow in the OIG atomizer was the plug or slug flow. Such a flow is typical by varying of the large gas and liquid structures. This led to the temporal GLR variations in the discharge orifice of the OIG atomizer and caused spray pulsations. On the other hand, the flow in the mixing chamber of the OIL atomizer was wall attached with separated gas and the liquid streams. This caused relatively constant gas to the liquid mass ratio in the discharge orifice and therefore stable conditions for the liquid breakup.

6 Conclusion

The presented paper deals with the comparison of the two effervescent atomizer configurations. The comparison was based on the spray pulsation assessment by different methods. The main findings can be shortly concluded in the following points:

- The important factor influencing the spray quality is, except the working regime, also the configuration of the effervescent atomizer (OIL, OIG).
- The OIL atomizer not only produced the smaller droplets for all the investigated cases but also generated uniform spray with the low temporal droplet sizes variations. It was caused by the stable annular flow in the discharge orifice of the atomizer.
- The OIG atomizer generated the spray with the larger droplets. Its work was characteristic by the pulsations of the spray which led to the large standard deviation of the time-averaged sauter mean diameter of the droplets at the lowest GLR. At the GLR = 5% were the pulsations considerably lower, but the further analysis by the CDF showed, that the spray contained a considerable number of the very large (>100 microns) droplets. It was caused by the plug internal two-phase flow.
- When testing the atomizers dedicated for the spray quality sensitive applications (such the spray-drying), the detailed statistical analysis of the droplet sizes must be done. The time-averaging is not suitable as it neglects occasional presence of the very large (or small) droplets. These droplets can further cause non-optimal operation of the device.

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