PERFORMANCE OF PRESSURE AND EFFERVESCENT ATOMIZERS

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Abstract

The article deals with an evaluation of the efficiency of atomization for two different types of atomizers. The comparison between efficiency of the pressure and the effervescent atomization may help decide which type of the atomizer is suitable for a particular application. The evaluation of both types of atomization principles is based on experiments. The PDA (Phase Doppler Analyzer) was used to acquire information about the spray quality in particular measurement points within the spray cone. The experiments were carried out on a model of an effervescent atomizer and three small pressure atomizers.

Introduction

The groundwork of effervescent atomization research was laid in the second half of 80's of the last century [1]. There have been many researchers who dealt with this type of atomization [2]. The process of the spray generation is conducted by mixing of two media; most often water and air, or oil and air or steam. The aeration media is fed into a volume of liquid with a small overpressure somewhere upstream the final orifice. The mixing process affects the quality of two-phase flow in the mixing chamber and consequently the atomization. The behavior of the two-phase flow inside the mixing chamber is influenced by the operational conditions, geometrical arrangement of the mixing chamber and the properties of both the media [3].

The pressure atomizers are the most common in the industry, hence these were chosen for the comparison. If there is a need to decide which type of atomizers is suitable for an application, it is needed to determine a comparable characteristic which describe the produced spray or the construction parameters of the nozzle. One of the comparable characteristic is efficiency of the atomization process.

According Bayvel & Orzechowski [4] the efficiency of atomization for all traditionally used atomizers is very small, namely $\eta < 0.1\%$. Improvement of atomization is related to the energy demand, i.e. increased energy demand corresponds to a decrease of the atomization efficiency. Pressure atomizers have efficiency $\eta = 0.05 - 0.07\%$ for generating droplets with a diameter of 100 μm and several thousandths of a percent for generating droplets with a diameter of 50 μm. The efficiency of the atomization process of pressure atomizers is higher then of the pneumatic atomizers [5]. Effervescent atomizers should generate droplets of particular size with greater efficiency then other types of twin-fluid atomizers [6].

Nozzles description

For the experiments, there were three small pressure nozzles and one effervescent nozzle used. In order to compare the two atomization processes, two factors were

determined and kept comparable for both the atomization processes. The first one was the injection pressure and the second one was the flow rate of the atomized fluid. The atomizers were operated at the maximal injection pressure of 0.5 MPa and the flow rates ranged from 0.3 to 6 kg/min.

Due to the large turndown ratio of the effervescent atomizers three small pressure nozzles were used, which covered the whole range of flow rates of water. Small industrial nozzles Unijet [7] (TG 0.7, TG 2, TG 6.5) were used providing full cone. (see Fig. 1)

Fig. 1 UniJet nozzle

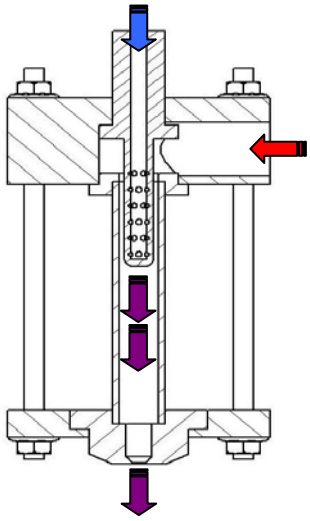

Fig.2 Effervescent nozzle

The construction of the experimental transparent effervescent nozzle comes from the industrial version of the nozzle, which is used for burners in furnaces of the performance up to 40 MW. In the relationship with the research in the field of two-phase flow, the oil physical properties are not suitable for the experiments hence water was applied [8].

The first of the transparent models was designed as the outside-in gas injection configuration. The disadvantage of such a model lies in its limitation to the research of geometrical variations of the nozzle, because it is possible to modify the model using different replaceable orifices only. Therefore, a new nozzle with the inside-out gas injection configuration was designed (Fig.2), which is more flexible to geometry configurations. This model enables to change dimensions of any parameter: length and inner diameter of the mixing chamber, diameter and shape of the orifice, diameter and number of holes in the supply of air. The model operation is similar to that of the normal industrial nozzle yet the maximal pressure is limited by the strength of the used material which, in this case, is Perspex pipe of the wall thickness of 2 mm. The maximal pressure used during the experiments was 0.5 MPa. The inner diameter of the mixing chamber was 8 mm. An aerator was formed from a small brass pipe with 32 aeration holes of the diameter of 1 mm. A free length from the end of the aerator to the discharge orifice for mixing of both media was 80 mm. The final discharge orifice was 2.5 mm in diameter. In Fig. 2, the red arrow illustrate input of water, the blue ones input of air and the violet ones figure two-phase flow after mixing.

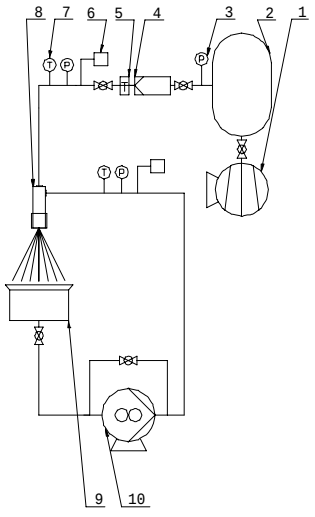

Fig. 3 Test circuit

Test rig

The test bench hydraulic circuit is sketched in Fig. 3. An effervescent nozzle (8) is mounted to a holder, which is a part of 3D track point device. The nozzle is connected to the liquid and air branches, both of them being equipped with sensors of pressure (3), temperature (7) and flow meter (6). The water pump (10) is connected to the back fluid vessel (9) which allows for continuous operation of the circuit. The water pump is

controlled by a frequency controller, whereby it is possible to change the water flow rate through the nozzle. The pump maximal flow rate is 8 $l \cdot min^{-1}$ at the overpressure of 0.8 MPa. The air branch is connected to the compressor (1) with an air pressure tank (2) by air pressure tank (2) by means of a gas pressure regulator (5) and a filter (4). Maximal pressure in the air distribution system is about 1 MPa. Measuring program, which runs under LabVIEW environment, was used for control of the measurement system and for data acquisition and its processing. The laboratory is also equipped with the ventilation system, which allows exhausting of air with water droplets out of the measuring space so to prevent it from the possibility of a foggy environment generation.

Phase Doppler Analyzer

The PDA (Phase Doppler Analyzer) is well known as one of the most useful techniques to study particle velocity and particle size distributions in sprays. There are many variations to the setup of this diagnostic system, especially its geometrical parameters. Schematic figures of the PDA system and the measurement volume with the important angles are in Fig.4. [9]

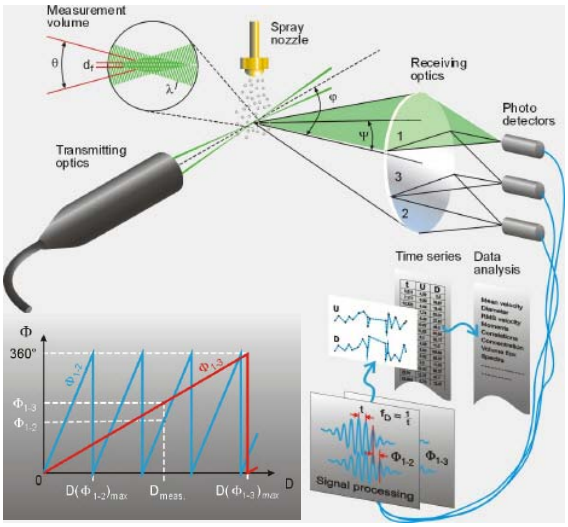

Fig. 4 PDA system principle

The receiver contains three photo-detectors, which provide improved accuracy of the measured droplet sizes. The transmitting optics consisted of Ar-Ion^+ laser with adjustable power (0-300 mW), beam splitter and transmitting lens with a focal length of 500 mm. The beam spacing of 60 mm led to the half-intersection angle between the beams of 3.43°. The measurement of size-velocity distributions in the spray cone were carried out in the area of the refracted signal (off-axis angle 30°. An overview of the most important settings is in Tab. 1.

Table 1. Overview of the PDA system parameters

Quantity	Value
Ar-Ion^+ Laser	max.300 mW
Transmitting lens focal length	500 mm
Beam spacing at transmitting lens exit	60 mm
Beam diameter at the lens exit	0.82 mm
Receiving lens focal length	500 mm
Scattering angle (Off-axis) ϕ	30°
Half-intersection angle between the beams $\theta/2$	3.43°
Elevation angle ψ	±0.68°

Integral parameters of the spray

For easier description of the whole spray, an integral value of mean diameters was used. It means only a single value represents the whole size distribution of the specific cut in the spray cone.

If there is a need to describe the spray cone using a single value of any quantity, it is suitable to use an integral value of this quantity. In the area of atomization processes, size distributions are represented by means of the average diameters [1]. Comparison of these distributions can be sometimes difficult and ambiguous, therefore the integral characteristics is beneficial to use. These characteristics are needed, for example when evaluating of the efficiency of atomization. The integral diameter characteristics were computed using the following equation:

$$ID = \frac{\sum_{i=1}^{n}\left(S_i \cdot D_i \cdot f_i\right)}{\sum_{i=1}^{n}\left(S_i \cdot f_i\right)} \tag{1}$$

where D_i is the mean diameter (for example D_{32} or D_{20}) of droplets measured at the i-th position at the representative cross section. An ensemble of droplets was measured at n points with the use of PDA with droplet frequency f_i. Value of the ID_{20} may be employed to compute the atomization efficiency.

Atomization efficiency

Understanding of efficiency of the atomization process of an effervescent atomizer can be useful for comparison with other types of atomizers and it also enables optimizing an atomizer operation conditions for desired spray quality. Total energy E_i required to generate a spray using effervescent atomizer consists of two energies; firstly E_g, the energy introduced by the compressed gas and, E_l, energy introduced by the liquid [10]. Isothermal compression energy (minimum necessary compression energy) needed to pressurize the gas mass M_g from atmospheric pressure p_b to the total pressure ($p_g + p_b$) in front of the nozzle and energy needed to put the gas through the nozzle reads:

$$E_g = \frac{M_g}{\rho_{gb}} \cdot p_b \cdot \ln\left(\frac{p_g + p_b}{p_b}\right) = V_{gb} \cdot p_b \cdot \ln\left(\frac{p_g + p_b}{p_b}\right) = V_g \cdot \left(p_g + p_b\right) \cdot \ln\left(\frac{p_g + p_b}{p_b}\right) \tag{2}$$

Where p_g is the gas gauge pressure upstream the exit orifice, ρg_b is gas density at atmospheric pressure, ρ_g is density of the pressurized gas, V_{gb} is gas volume at atmospheric pressure and V_g is volume of the pressurized gas. The potential energy of the supplied liquid mass flow rate, in accordance with [10] reads:

$$E_l = M_l \cdot \frac{p_l}{\rho_l} = V_l \cdot p_l \tag{3}$$

Using Eq.'s (2) and (3) and defining the equation for gas-to-liquid-ratio:

$$GLR = \frac{M_g}{M_l} = \frac{V_g \cdot \rho_g}{V_l \cdot \rho_l} \tag{4}$$

one can write:

$$E_i = E_g + E_l = V_l \cdot \left[p_l + GLR \cdot \frac{\rho_l}{\rho_g} \cdot \left(p_g + p_b \right) \cdot \ln\left(\frac{p_g + p_b}{p_b} \right) \right] \tag{5}$$

Transformation of bulk liquid into fine droplets is associated with enormous increase of surface. If bulk liquid with the volume V_l is subdivided into droplets having all the same radius IR_{20} (so called Integral surface radius), then the area of the droplet system will be $A = 3 \cdot V_l / IR_{20}$, where $IR_{20} = ID_{20} / 2$.

The corresponding surface energy increase neglecting the original surface energy of bulk liquid reads $E_a = A \cdot \sigma$ [11]. The efficiency of the atomization process finally is:

$$\eta = \frac{E_a}{E_i} = \frac{3 \cdot V_l \cdot \sigma / IR_{20}}{E_i} = \frac{3 \cdot \sigma / IR_{20}}{p_l + GLR \cdot \frac{\rho_l}{\rho_g} \cdot \left(p_g + p_b \right) \cdot \ln\left(\frac{p_g + p_b}{p_b} \right)} \tag{6}$$

Results

Results from the PDA measurement show symmetrical trends of the mean diameter distributions in the spray cone, thus the measurements were carried out over one plane located at the nozzle axis in the distance of 150 mm from the discharge orifice. The angle of the spray cone depends on the operational conditions thus the mean diameter distributions were not always plotted over the same region as shows Fig. 5. Size distributions are represented by the mean surface diameter value, which has its minimum in the centre of the spray cone. In this figure operational conditions for effervescent nozzle and three pressure nozzles at the pressure 0.1MPa is plotted. The minimal sizes of droplets are achieved at the highest values of GLR.

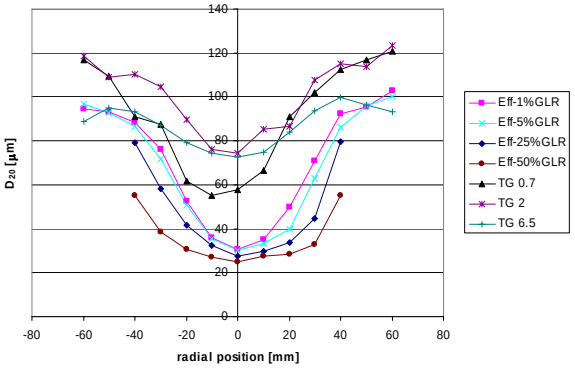

Fig. 5 D_{20} distributions in the spray cone

The efficiency of the atomization process of the effervescent atomizer at different operation pressures and GLR can be seen in Fig. 6. It is clear that the efficiency is less then 1% for common operation conditions of the effervescent atomizer and it decreases with GLR and with pressure. The efficiency of the pressure atomizers (1 - 3 %) is greater than the efficiency of the effervescent atomizer.

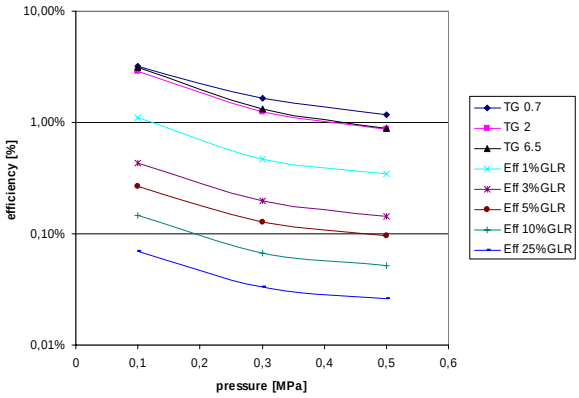

Fig. 6 Efficiency of the atomization process

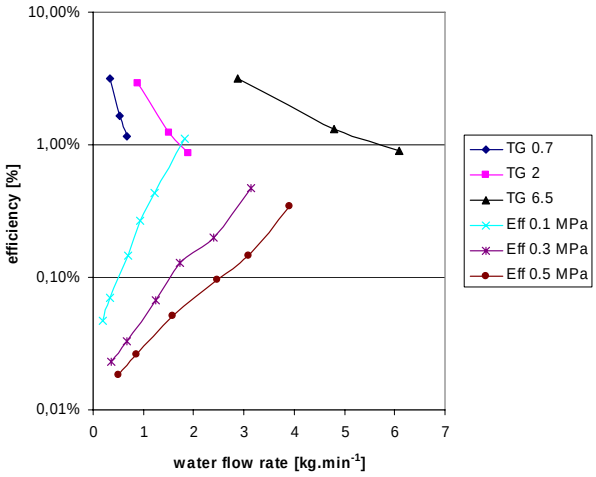

Fig. 7 Atomization efficiency against flow rates

In Fig. 7, there is the efficiency of the pressure and the effervescent atomization against the water flow rates plotted. It is clear the efficiency of the pressure atomization is higher for pressure nozzles than for effervescent ones over the same range of flow rates and pressure levels. High values of the efficiency were reached at the low pressure (0.1 MPa). Increasing the pressure level results the deterioration of the atomization efficiency.

The efficiency of pressure atomization achieves a quite high value (3%) which is a consequence of decrease in the injection pressure to the minimal possible pressure level and small diameter of the final orifice.

Conclusion

Spray characteristics of pressure and effervescent atomizers have been assessed by means of PDA measurement. Values of D_{20} were used for computation of the atomization efficiency. The pressure level of the atomized fluid has the main effect on value of the atomization efficiency.

Although the efficiency of atomization of effervescent atomizers is lower than that of the pressure atomizers, their main advantage can be seen in the possibility to produce the spray of the same quality at much lower pressure. Large free area of the exit orifice of the effervescent atomizers protects them from clogging and makes them useful for waste liquids.

Acknowledgement

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