Chemical Engineering and Processing 109 (2016) 32–38

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

The experimental studies on atomization for conical twin-fluid atomizers with the swirl motion phenomenon

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ARTICLE INFO

Article history:
Received 26 July 2016
Accepted 21 August 2016
Available online 24 August 2016

Keywords:
Pressure drop
Discharge coefficient
Euler number
Twin-fluid atomizers
Swirl motion

ABSTRACT

Measurements of the pressure drop and droplets sizes and mean droplet size produced by conical twin-fluid atomizers with the swirl motion phenomenon were carried out using the microphotography method. Atomizing gas flow rates of up to $5.6 \cdot 10^{-4}$ [m^3/s] and liquid flow rate up to $1.11 \cdot 10^{-4}$ [m^3/s] were used. The effect of atomizer dimensions on spray parameters was studied using several geometries of conical atomizers. It has been shown that the pressure drop depends on gas and liquid flow rates and dimensions of atomizer. Additionally, the swirl motion inside of atomizer affects the spray quality. The empirical correlation for Euler number and Sauter mean diameter were proposed. The obtained data is very important for atomizers designing, especially including some of twin-fluid atomizers.

1. Introduction

Atomization of liquids is important in many industrial processes such as spray cooling, spray drying, film costing, preparation of fine powders, combustion, making emulsions [1–7]. Most practical atomizers are of the pressure, rotary, or twin-fluid type. For these atomizers, the most important dimension for atomization is the diameter of the final discharge orifice, but other dimensions are important too: the extensional and shear stresses during atomization [6]. The shear rate and viscosity of liquid affect the shear stress at the atomizer. The shear rate γ at the exit of the atomizing nozzle for one-phase flow can be calculated by following equation [8]:

$$\gamma = \frac{32 \cdot Q_L}{\pi \cdot d_0^3} = \frac{8 \cdot w_L}{d_0} \tag{1}$$

where: γ is the characteristic shear rate, Q_L is the liquid flow rate through the atomizer, d_0 is the diameter of the outlet orifice of atomizer. The method of achieving a high relative velocity between liquid and air is to expose slow-moving liquid into a high-velocity stream of air. Devices based on this approach are usually termed air-assist, air-blast or, more generally, twin-fluid atomizers [7]. Effervescent atomization is a method of twin-fluid atomization with a relatively small amount of gas in a form of bubbles supplied to the liquid inside the atomizer [1,2,9–12]. The shear rate γ for two-phase flow can be calculated by following equation [13]:

$$\gamma = \frac{2 \cdot (w_{G-L} - w_L)}{d_0} \tag{2}$$

where w_{G-L} is the exit average velocity of both gas and liquid.

A knowledge on the flow resistance (Euler number or discharge coefficient) is very important with regards to the design of atomizers [9,11,12,14–16]. The discharge coefficient for liquid can be defined by the following equation:

$$C_D = \frac{w_L \cdot \rho_L}{(2\rho_L \cdot \Delta P)^{0.5}} \tag{3}$$

where w_L is liquid flow rate in outlet orifice of atomizer. The Euler number defined as:

$$Eu = \frac{\Delta P}{w_L^2 \cdot \rho_L} = \frac{C_D^{-2}}{2} \tag{4}$$

For one-phase flow the values of discharge coefficient and Euler number are usually given as a dependence on the Reynolds number [9,10,12,14,17–19]:

$$\mathrm{Re} = \frac{w \cdot d_0 \cdot \rho}{\eta} \tag{5}$$

A procedure for predictions of the flow resistance giving correct results is an interesting tool for the atomizer design [20]. The predictions for twin-fluid atomizers are often based on the empirical or semi-empirical correlations [10,17,21,22] containing

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http://dx.doi.org/10.1016/j.cep.2016.08.010
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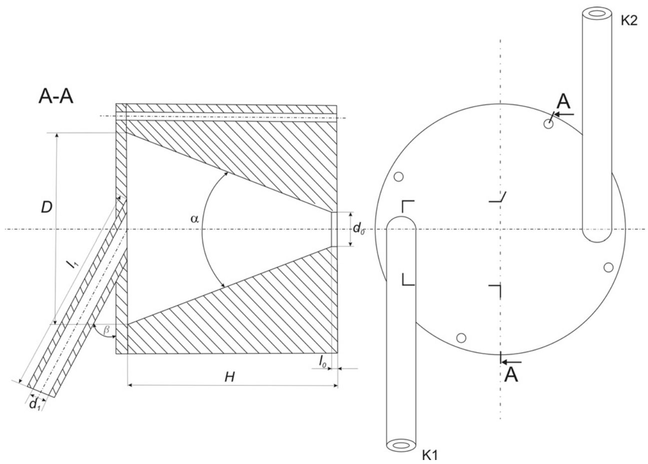

Fig. 1. The atomizers studied.

the gas to liquid mass flow rates ratio *GLR* defined as:

$$GLR = \frac{\dot{M}_G}{\dot{M}_L} \tag{6}$$

The predictions of the flow resistance should be confirmed experimentally.

Droplet size is of fundamental importance for the atomizers performance. The twin-fluid atomization produces a wide distribution of droplet sizes. The Sauter mean diameter (D_{32}), expressing the average ratio between the volume and the surface area of the droplets:

$$D_{32} = \frac{\sum_{i=1}^{i=n} N_i d_i^3}{\sum_{i=1}^{i=n} N_i d_i^2} \tag{7}$$

is the most appropriate mean diameter to represent the size distribution. The convenience of using a single mean diameter to represent the wide distribution of droplet sizes has been often criticized [23]. It has been shown that a calculated overall collection efficiency could be very different if the size distribution instead of a single mean droplet diameter were used.

This paper deals with the design of a twin-fluid atomizer of simple construction (without swirling elements). The swirl motion is obtained by tangential inlet of liquid. Additionally, the atomizing gas flowing by the second tangential inlet improve the atomization of liquid. The mechanism is similar to the mechanism for pressure swirl atomizers presented by Nonnenmacher and Piesche [14]. The main parameters analyzed were: pressure drop for the atomizers, distribution of droplet sizes and mean droplet size. The effect of the atomizer dimensions on spray parameters was studied using several geometries of conical twin-fluid atomizers with the swirl motion phenomenon.

2. Experimental set-up

The experiments were carried out in installation described in details by Ochowiak et al. [24]. The main elements of the installation were conical twin-fluid atomizers with the swirl motion phenomenon with two inlet ports for gas and liquid phases; tank; pump (Grundfos CHI 2–30); temperature stabilizer; compressor; measurement units of gas and liquid volumetric flow rates (rotameters VA-40 delivered by Krohne Messtechnik GmbH&Co KG); digital multichannel thermometer (Center 309 delivered by Center) and digital manometer (DigiComb 1900 delivered by Tecsis GmbH).

Reverse-lens microphotography has allowed to achieve the high magnification and visualization of the droplets. The reverse-lens method is described in details in the earlier article [25]. The main elements of the microphotography set-up were: Canon EOS 1D Mark III digital camera; DrelloScop 210 strobe with LE 210-01 lamp delivered by Drelo Ing. Paul Drewell; prime lens with manual aperture control (Canon EF 28–135 mm f/3.5–5.6 EF IS USM), and an adapter (Canon EOS EF/58 mm with Canon EOS 72 mm/58 mm reduction). The shutter speed (1/400 s) was synchronized with the flash strobe. The ISO was set at 1600. The droplets sizes were analyzed with the use of Image-Pro Plus 6.0 Media Cybernetics Inc. software [26,27]. The histograms were analysed using Statistica 12 software (StatSoft Inc.). The average droplet diameter D_{mean} and standard deviation σ values have been obtained.

The construction of atomizers studied is presented in Fig. 1. The dimensions of atomizers are presented in Table 1.

The studies were performed for two-phase systems with the gas flow rate up to 2 [m^3/h] and liquid phase volume flow rates ranging from 5 to 40 [l/h]. This corresponds to $\mathrm{Re}_G \in (990; 19800)$ and $\mathrm{Re}_L \in (700; 5660)$, respectively. The shear rate in atomizers can be extremely high, in these studies the shear rate calculated from Eq. (2) was in the range from 900 to 90000 [1/s]. The experiments were carried out with water at temperature of $T_L = 293 \pm 1$ K and air at temperature of $T_G = 293 \pm 1$ K.

3. Results and discussion

3.1. Resistance of flow

The results of the pressure drop and the analysis of discharge coefficient and the Euler number are presented below. The sample plots of pressure drops vs. w_G *and* w_L are shown in Fig. 2. The experiments for two-phase flow showed that the pressure drop values are dependent on flow rates of gas and liquid and dependent on the construction used. These results confirm previous data [1,10,28] which showed that the atomization process depend on the construction of the atomizer.

Table 1
The dimensions of the atomizers.

Atomizer	Diameter of chamber *D* [mm]	Height of chamber *H* [mm]	Outlet orifice diameter d_0 [mm]	Outlet orifice length l_0 [mm]	Diameters of the inlet ports $d_1 = d_2$ [mm]
A-1	20 ± 0.1	20 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
A-2	20 ± 0.1	40 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
A-3	20 ± 0.1	60 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
A-4	20 ± 0.1	80 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
B-1	40 ± 0.1	20 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
B-2	40 ± 0.1	40 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
B-3	40 ± 0.1	60 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05
B-4	40 ± 0.1	80 ± 0.1	2.5 ± 0.05	1.25 ± 0.05	2.5 ± 0.05