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Effervescent atomization of glycerol aqueous solutions

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Abstract

Paper presents the rheological characteristics of glycerol aqueous solutions and spray structures, droplets diameters, drop size histograms for effervescent atomizers. The study shows a nonlinear relation between the Sauter mean diameter and the gas to liquid mass flow ratio. By increasing the concentration of glycerol the solution viscosity tends also to increase. The experimental results show that the size of droplets depends on the liquid viscosity. The diameter of droplets increases with increase of liquid viscosity. Drops size histograms based on the number of drops showed the increase in number of large and the decrease in small droplets with increase of concentration of glycerol. Additionally, the characteristic stages of atomized liquid have been presented: the jet with built-in bubbles (slug flow), satellite bubbles and connected bubbles.

Keywords: Spray; Effervescent atomization; Viscosity; Drop size histogram; Sauter mean diameter

Nomenclature

c	–	concentration, % by mass
d	–	diameter, m
GLR	–	gas to liquid mass flow rate ratio
m	–	total number of size ranges of drops
$\dot{m}$	–	mass flow rate, kg/s
n	–	percentage of drops
SMD	–	Sauter mean diameter, m

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Greek symbols

η – viscosity, Pa s
ρ – density, kg/m^3

Subscripts

G – gas
L – liquid
0 – outlet

1 Introduction

The atomization process is often used in many branches of industry, for instance, in combustion engines, in medicine and in environmental protection [1,2]. The effervescent atomizers belong to types of twin-fluid atomization and fall into the category of internal mixing atomizers. In effervescent atomization the bubbling gas is ejected directly into the liquid stream inside the atomizer body [1–7]. This type of atomizers has many advantages, such as: lower pollutant emissions are produced, possibility to use smaller gas flow rate and velocities or reduction of clogging problems. Good atomization in effervescent atomizers can be achieved at injection pressure lower than that required by other types of atomizers. These devices are simple, rugged, reliable, little and cheap [6]. The smaller drop sizes are obtained than those produced by more conventional methods of atomization. Effervescent atomizers are very popular in many chemical engineering processes. They are applied for gas turbines, consumer products, process industry applications or Diesel engines [2–14].

The paper presents the results of experimental studies on atomization of the water and glycerol aqueous solutions flowing through effervescent atomizers. The analysis was realized by the use of the digital microphotography method. Using obtained photos the values of Sauter mean diameter (SMD) were determined.

2 Experimental setup and conditions

The experimental equipment consists of pump, rotameters, PC computer, digital camera and the atomizer (Fig. 1). The detail dimensions of the atomizer are given in Fig. 2. The atomizer used had diameters of outlet $d_0 = 2.7$ mm. The atomizer was mounted vertically on a stand. The investigated liquid was injected vertically downstream through an atomizer into the room temperature and atmospheric pressure. Rotameters VA-40 provided by Krohne Messtechnik GmbH&Co KG have been used. The rotameters have been scaled for each of tested liquids.

The photographs with 3888×2592 pixels were obtained using the Canon EOS 1D Mark III camera. The spray characteristics were obtained by averaging the values of several images for each experimental condition. The photographs were analyzed using the Image Pro-Plus by Media Cybernetics which enables in-depth and precise measurement analysis of droplets diameters.

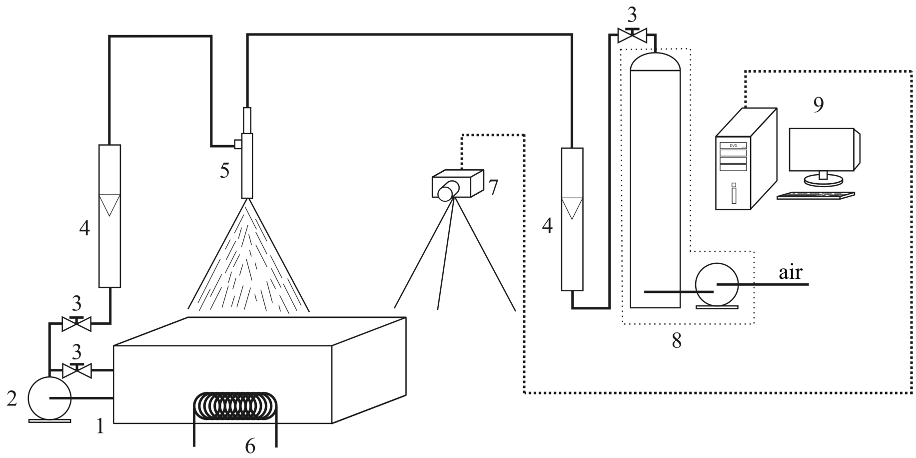

Figure 1. Schematic diagram of experimental setup: 1 – vessel, 2 – pump, 3 – valve, 4 – rotameter, 5 – atomizer, 6 – heat exchanger, 7 – digital camera, 8 – blower, 9 – PC computer.

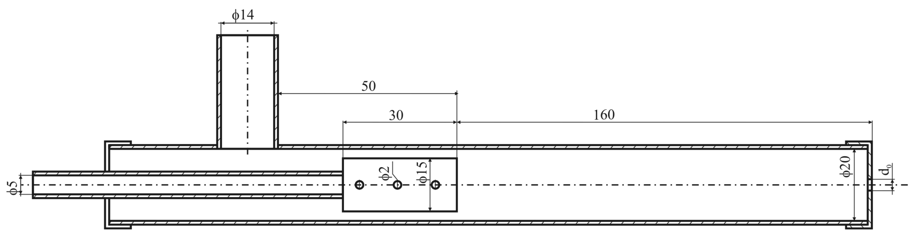

Figure 2. Effervescent atomizer used.

The studies were performed at flow rates of liquid phase varied from 0.0014 to 0.011 kg/s and of gas phase changed from 0.00017 to 0.0084 kg/s, respectively. It corresponded to the gas to liquid mass flow rate ratio (GLR) values ranging from 0.014 to 0.57, where GLR is defined as

$$GLR = \frac{\dot{m}_G}{\dot{m}_L}\,. \tag{1}$$

The process was conducted using the glycerol aqueous solutions at $35\pm2\,^{\circ}$C as a test liquid. The experiments temperature was regulated by a heat exchanger. The test fluids used in this study were water and glycerol aqueous solutions of concentration of 76, 80, 85, 90 and 92% of glycerol by mass. The value of the molecular weight of glycerol was 92.1 kg/kmol rended by POCh S.A. The viscosity was measured by two types of capillary viscometers, namely the ubbelohde type viscometer no. H 100, size no. 2 and no. H 22, size no. 2E. In the experiment, five aqueous solutions of different concentrations of the glycerol were used and their physical characteristics is given in Tab. 1.

Table 1. The physical characteristics of glycerol aqueous solutions.

Concentration of glycerol [%]	Density [kg/m^3]	Viscosity [mPa s]
92	1.189	182
90	1.189	80
85	1.168	37
80	1.158	25
76	1.142	14

3 Results and discussion

The analysis of photos shows that viscosity affects the atomization process. During atomization there can be distinguished several stages described by Lefebvre [1] such as dribble, distorted pencil (jet) and fully developed spray. The characteristic structure of atomized liquid has also been described by Broniarz-Press *et al.* [7]. During atomization of aqueous solutions of polyethylene oxide (PEO) the following stages were distinguished: the jet with built-in bubbles, satellite bubbles, connected bubbles and jet with slug flow. The filaments characteristics for polymers solutions were not observed. The observations suggest that the stages of spray development are determined by the physical properties of liquid atomized, especially by viscosity.

The Fig. 3 shows the structure of sample images for the atomization process of the glycerol aqueous solution containing 85% of glycerol by mass obtained at different flow rates of gas and liquid. At high concentrations of glycerol in solution effect of viscosity on the atomization process is clearly visible. The Fig. 3a shows fully developed spray, which is created at high flow rate of gas. When the flow rate of liquid was the highest the satellite bubbles were formed (Fig. 3b). In Fig. 3c the jet with built-in bubbles was observed, which is associated with an increase in viscosity of the atomization liquid. The Fig. 3d presents the stream of liquid, which is created at the lowest flow rate of gas and the highest flow rate of liquid. Bigger droplets resulting even in the liquid stream are formed, when concentration of glycerol increases.

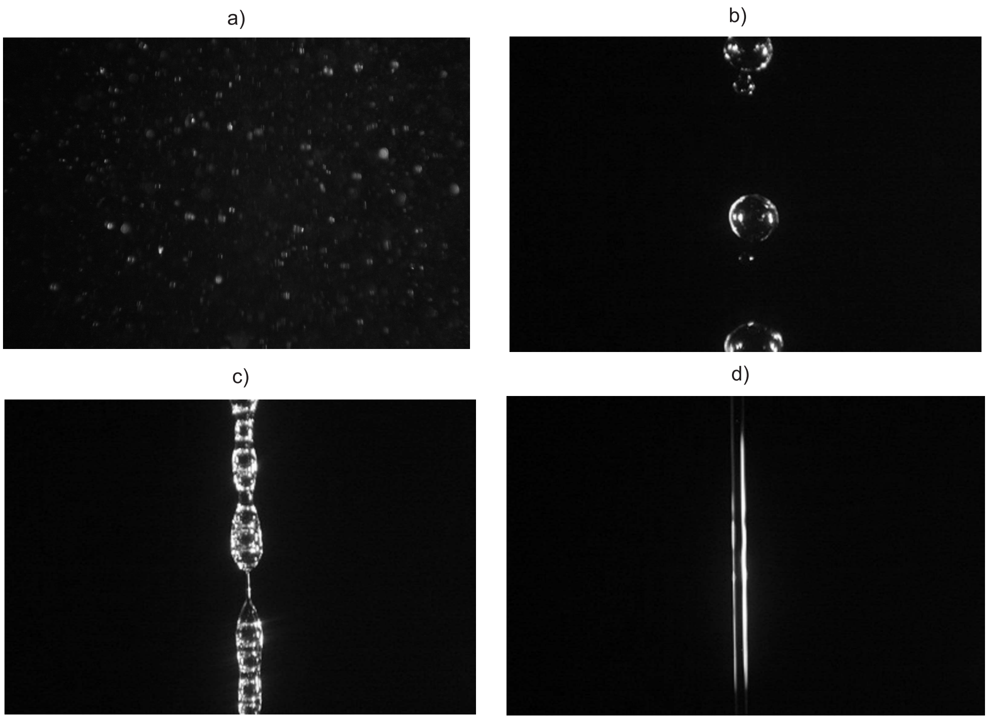

Figure 3. Photos of atomization of the aqueous solution of glycerol of concentration 85% by mass: a) $\dot{m}_L = 0.0083$ kg/s, $\dot{m}_G = 0.00048$ kg/s, b) $\dot{m}_L = 0.011$ kg/s, $\dot{m}_G = 0.00032$ kg/s, c) $\dot{m}_L = 0.0028$ kg/s, $\dot{m}_G = 0.00016$ kg/s, d) $\dot{m}_L = 0.011$ kg/s, $\dot{m}_G = 0.00016$ kg/s.

The droplets being formed during the atomization of water and glycerol aqueous solutions have very different sizes. The experimental results showed that the changes in viscosity of a liquid lead to significant changes in the spray characteristics. The analysis of the photos of liquids atomization process showed that the droplet sizes are dependent on gas and liquid flow rates. The differences between characteristics of atomization for water and glycerol aqueous solutions have been observed.

Figures 4–7 show the drops size histograms for glycerol aqueous solutions of concentration of 76, 80, 85 and 90 of glycerol by mass. The summary of individual droplets diameters exhibited that the increase in concentration of glycerol contributed to the expansion of the quantitative distribution of the droplets. The phenomena of formation a bigger droplets and disappearance of droplets of small diameters have been observed. The changes of drop size histograms are the effect of increase of viscosity of aqueous solution of glycerol.

For all tested solutions the Sauter mean diameter was determined described by

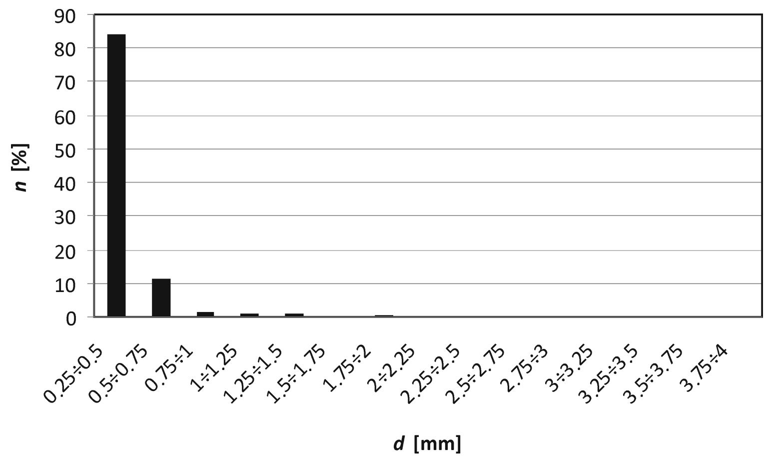

Figure 4. Drops size histograms for aqueous solution of glycerol 76% by mass at $\dot{m}_L$ = 0.0056 kg/s and $\dot{m}_G$ = 0.00064 kg/s.

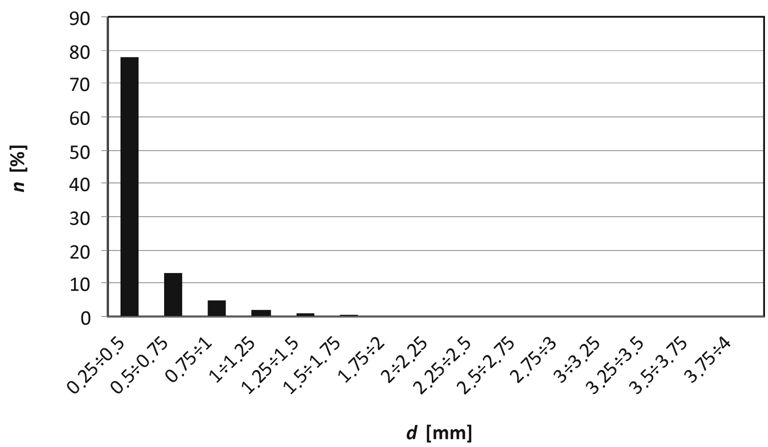

Figure 5. Drops size histograms for aqueous solution of glycerol 80% by mass at $\dot{m}_L$ = 0.0056 kg/s and $\dot{m}_G$ = 0.00064 kg/s.

the relationship

$$SMD = \frac{\sum_{i=1}^{i=m} n_i d_i^3}{\sum_{i=1}^{i=m} n_i d_i^2}\ , \tag{2}$$

where d_i denotes the middle diameter of size range i, and n_i is the number of drops in size range i.

Figure 8 presents the relationship between SMD and GLR for water and

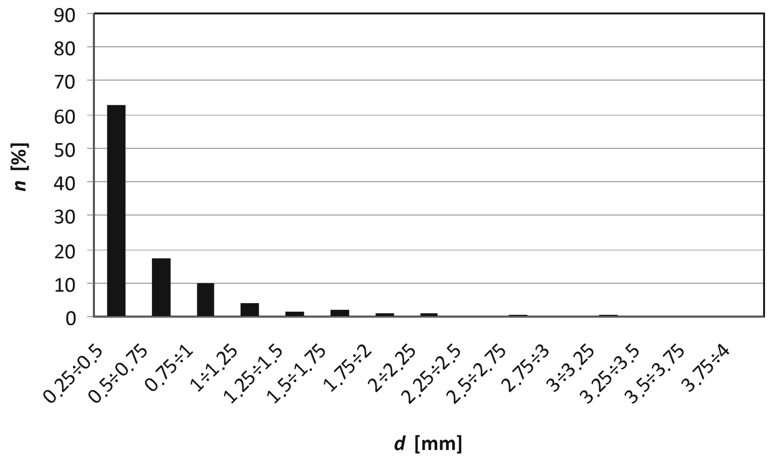

Figure 6. Drops size histograms for aqueous solution of glycerol 85% by mass at $\dot{m}_L$ = 0.0056 kg/s and $\dot{m}_G = 0.00064$ kg/s.

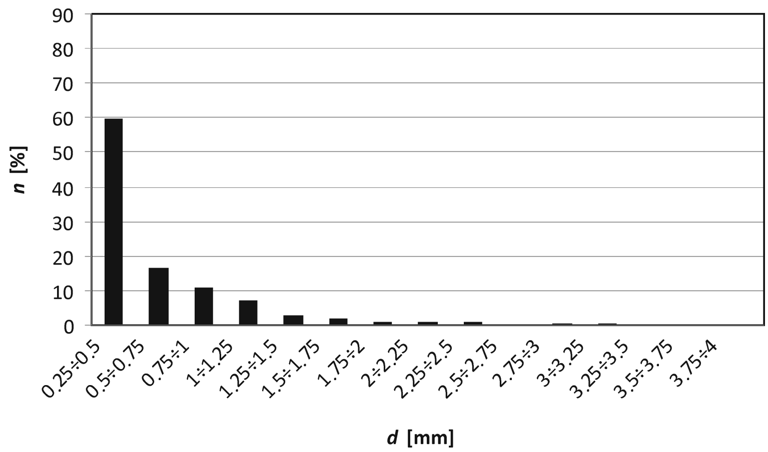

Figure 7. Drops size histograms for aqueous solution of glycerol 90% by mass at $\dot{m}_L$ = 0.0056 kg/s and $\dot{m}_G = 0.00064$ kg/s.

glycerol aqueous solutions. The smallest drop size diameter was observed for the atomization of water. Parameter SMD increases with the number of glycerol in solution. The smallest mean size diameter was observed during water atomization. Increasing the amount of glycerol in the solution, SMD value increases. The biggest the SMD value occurred in the glycerol aqueous solution with the highest concentration of glycerol.

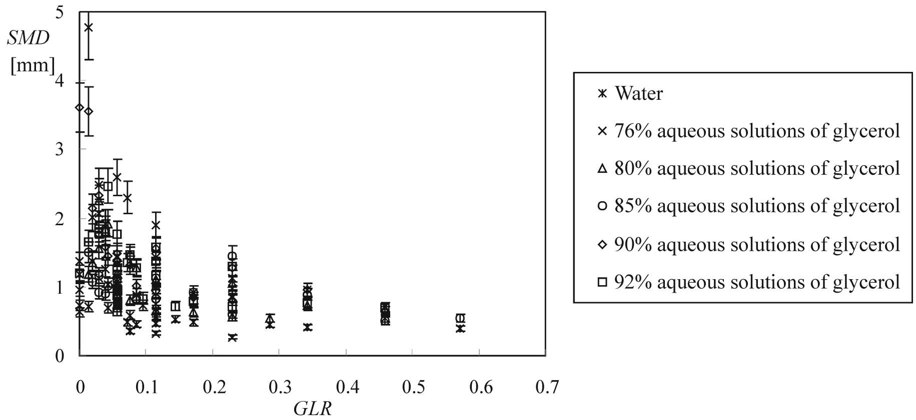

Figure 8. The nonlinear relation between SMD and GLR for different concentrations of glycerol in a solution.

4 Conclusion

The experimental study includes determination of spray structures and droplets diameters for liquids of different viscosities in effervescent atomizers. During the atomization process following stages were distinguished: the jet with built-in bubbles, satellite bubbles and connected bubbles. The observations suggest that the stages of atomized liquid depend on viscosity. With increasing solution concentration the number of droplets of larger diameter increases and the droplet size histogram is wider. The Sauter mean diameter of liquid atomized has been studied as a function of gas-to-liquid ratio. When GLR values increase, the decrease in mean size diameter was observed. Values SMD increases with the increase of aqueous glycerol solution viscosity. The results of experimental study may be used, for instance, to verify numeral models of effervescent atomization or at comparison with the simulations proposed for similar atomization processes.

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