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VISUALISATION AND IMAGE ANALYSIS OF EMULSIONS ATOMIZATION

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ABSTRACT
The paper presents the results of experimental studies on atomization of emulsions flowing through twin-fluid atomizers using the digital microphotography method. The photographs were analyzed using Image Pro-Plus by Media Cybernetics. Used oil was a mineral oil 20-90 (Institute of Petroleum Processing, Cracow) with density, surface tension, and viscosity of 868 [kg/m^3], 30 [mN/m], and 89.42 [mm^2/s], respectively. The studies were performed at flow rates of liquid phase changed from 0.0014 to 0.011 [dm^3/s] and of gas phase changed from 0.28 to 1.4 [dm^3/s], respectively. The analysis of the photos of water and emulsions atomization process showed that the spray angle and the droplet sizes are dependent on: gas and liquid flow rates, construction of nozzle and properties of liquid. The differences between characteristics of atomization for water and emulsions have been observed. The results showed that the spray angle is dependent on a content of oil in emulsions. Analysis of photos on forming the droplets in air-water and air-emulsions showed that droplets are bigger in air-emulsion system (at the same value of gas to liquid ratio). Probably it is the effect of viscosity surface tension of investigated liquids. The values of *SMD* increased with increase of volume fraction of oil in emulsion. The droplet size increased with emulsion viscosity. It is evident that the addition of water changes emulsions' properties which are the key parameters influencing the atomization of the spray.

INTRODUCTION

The emulsions atomization is a wide-spread operation in many branches of industry, for instance in power engineering and combustion engines, in engineering industry and in agriculture [1-3]. The cooling agent for machine elements, fuel oil, pesticides and milk can be emulsions. The studies of emulsions atomization were directed also to improve the combustion performances of emulsions as fuels in furnaces for local power generation. The spray characteristics are: spray angle, covering of surface, droplet size distribution, droplet velocity distribution, volume distribution pattern, spray structure, the structure of individual droplets. The flow and spray characteristics of most atomizers are strongly influenced by the liquid properties: density, viscosity, and surface tension. A typical spray includes a wide range of droplet sizes. Some knowledge of droplet size distribution is helpful in evaluating process applications in sprays, especially in calculations of heat or mass transfer between the dispersed liquid and the surrounding gas. The *SMD* is calculated as the ratio:

$$SMD = \frac{\sum_i n_i d_i^3}{\sum_i n_i d_i^2} \qquad (1)$$

Spray nozzles have many important applications and have been the subject of considerable research. Pneumatic nozzles are operated with comparatively low gas pressures and relatively high efficiencies. A wide variety of designs of this type have been produced for use in industrial gas turbines and oil-fired furnaces. Typical applications are: humidification, evaporative cooling, coating, moistening and greenhouse applications [4-7].

In the present paper the results of experimental observations on emulsions atomization process in pneumatic nozzles using the digital microphotography method have been presented. The experimental facility, nozzle geometry, measurement method and instruments are introduced.

EXPERIMENTAL APPARATUS

The paper presents the results of experimental studies on atomization of emulsions flowing through twin-fluid atomizers using the digital microphotography method. These basic parameters and the measuring technique are described by Lefebvere [1] and Orzechowski and Prywer [2]. The main elements of the test installation presented in Figure 1 were: nozzle (Figure 2), reservoir, pump and measurement units of liquid flow. The geometries of nozzles used in this study have been presented in Table 1. The photographs were obtained using a Canon 1D Mark III camera and an automatic flash that allowed exposure times of 1/8000 s. The photographs were analyzed using Image Pro-Plus by Media Cybernetics. Image-Pro Plus, image processing software, provides in-depth and precise measurement analysis of the parameters of spray characteristics (Figure 3). This one eliminates human error and maintains the highest quality standard possible.

Oil used was a mineral oil 20-90 delivered by Institute of Petroleum Processing of Cracow, (4) with density, surface tension, and viscosity of 868 [kg/m^3], 30 [mN/m], and 89.42 [mm^2/s], respectively. The emulsion was prepared by blending mixtures of oil, water, and surfactant within 20 minutes. The surfactant EMB - 2 was used. The emulsions had the mineral oil volume fraction in the range from 0.2 to 0.6.

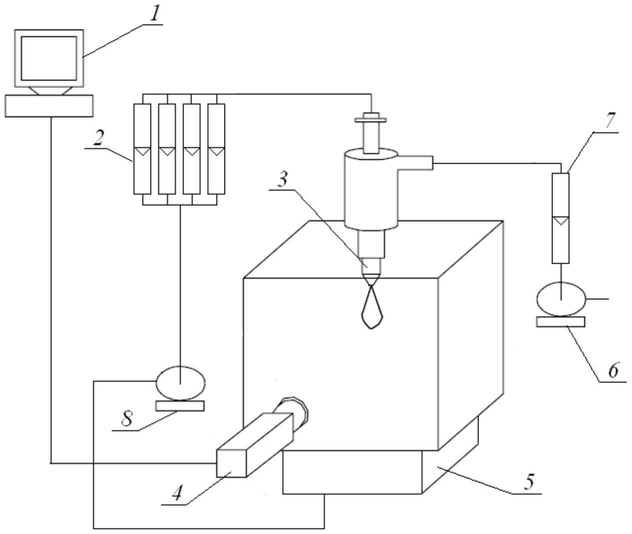

Figure 1. Test installation:
1 – PC computer, 2 – liquid rotameters, 3 – nozzle, 4 – digital camera, 5 – vessel, 6 – blower, 7 – gas rotameter, 8 – pump

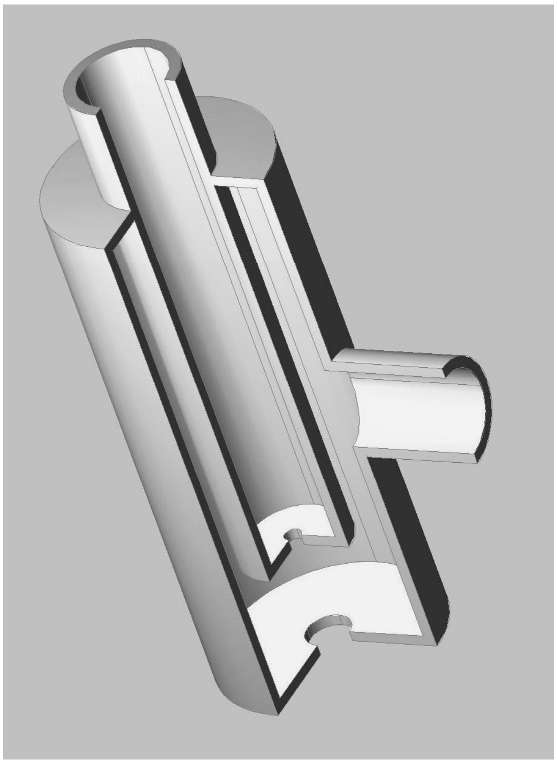

Figure 2. Investigated nozzles construction

Table 1. Geometry of investigated nozzles

Denotation	S	d_{in} = 1.5 mm d_{out} = 4 mm
	L	d_{in} = 3 mm d_{out} = 8 mm

The surface tensions were measured by tensiometer K9 delivered by Krüss GmbH. The characteristics of emulsions used are presented in Table 2. In this work the equivalent viscosity of emulsions was determined from Arrhenius-Kendall's equation [8]:

$$\log\mu_L = \Phi_D \log\mu_D + (1-\Phi_D)\log\mu_C \qquad (2)$$

Table 2. Characteristics of the emulsions studied

Quantity	Φ_{oil}	ρ_L [kg/m^3]	μ_L [mPa s]	σ_L [mN/m]
Emulsion	0.2	974	2,39	30.9
	0.4	947	5,70	30.8
	0.6	921	13,6	30.6
Pure oil	-	869	77,7	30.4

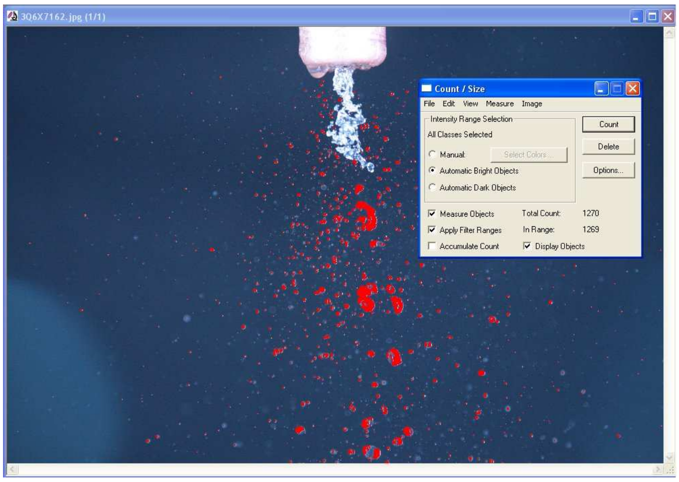

Figure 3. Analysis of photos in Image-Pro Plus program

The studies were performed at flow rates of liquid phase changed from 0.0014 to 0.011 [dm^3/s] and of gas phase changed from 0.28 to 1.4 [dm^3/s], respectively. It corresponded to gas to liquid mass ratio (*GLR*) values from 0.028 to 0.92. Reynolds number for gas and liquid flows was defined as follows:

$$Re = \frac{w d_{out} \rho}{\mu} \qquad (3)$$

RESULTS AND DISCUSSION

Exemplary results of the visualization of air- emulsions systems atomization are shown in Figure 4. The analysis of photos shows that the droplets which have been formed during the liquid atomization have very different sizes. The smallest droplets have diameters of the order of ten micrometers. The development of the spray passes through several stages such as dribble, distorted pencil and fully developed spray [1]. The observations suggest that the stage of spray development is strongly affected by the physical properties of liquid atomized. In this study onion and tulip stages characteristic for flow of smooth liquid film were not observed. In the pneumatic atomizers, atomizing gas is breaking the liquid film flow into droplets. In the result the stages are not observed.

Analysis of the photos showed that the spray angle is dependent on the liquid and gas flow rates, properties of liquid and geometry of nozzle. It has been shown that larger values of spray angle have been observed for geometry S. For both investigated geometries the values of spray angle do not exceed 60^o. The values of spray angle increased with increase of gas volume rates and decreased with liquid volume rates (Figure 5).

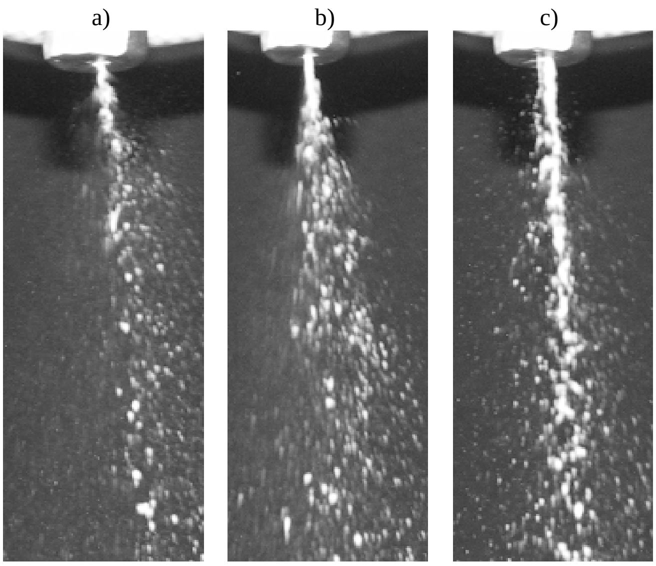

Figure 4. Air-emulsion (Φ_{oil} = 0.20) atomization in nozzle S for:
a) V_G = 3 [m^3/h], V_L = 10 [dm^3/h],
b) V_G = 3 [m^3/h], V_L = 20 [dm^3/h],
c) V_G = 3 [m^3/h], V_L = 30 [dm^3/h]

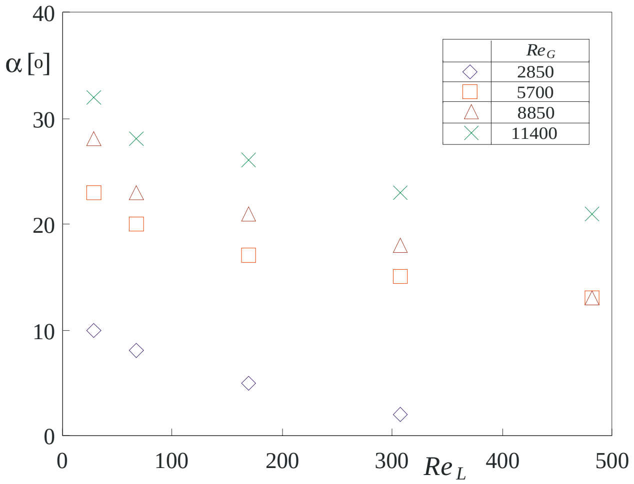

Figure 5. The relationship of spray angle vs. Re_L and Re_G obtained for air-emulsion (Φ_{oil} = 0.40) system in nozzle L

The main parameters that have been selected in the experimental characterization of nozzles are the Sauter Mean Diameter and gas to liquid mass flow ratio. In Figures 6 and 7 the relations between *SMD* and Reynolds numbers for gas Re_G and for liquid Re_L are shown. *SMD* for air-liquid systems investigated is decreasing with increase of Reynolds number for gas phase and is increasing with increase of Reynolds number for liquid phase. The values of Sauter mean diameters increased with increase of volume fraction of oil in emulsion (Figure 8). The droplet size increased with emulsion viscosity. The experimental results obtained show that the changes in physical properties of liquid phase lead to the significant changes in the spray characteristics. The analysis of the photos of water and emulsions atomization process showed that the spray angle and the droplet sizes are dependent on: gas and liquid flow rates, construction of nozzle and properties of liquid.

The final step of data analysis the empirical correlation for *SMD* has been proposed. The analysis has shown that *SMD* depends on *GLR*, nozzle geometry and liquid characteristics.

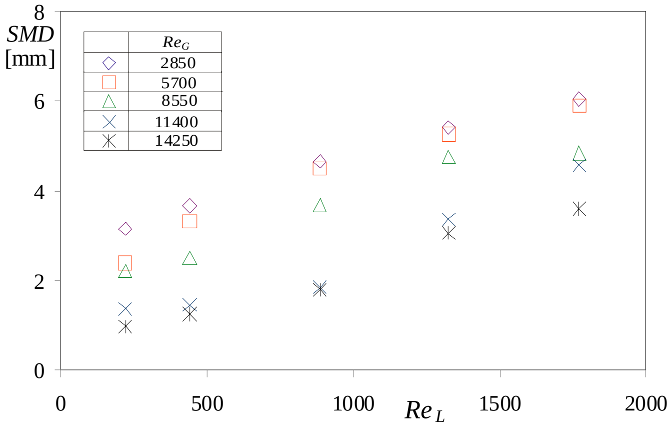

Figure 6. The relationship of *SMD* vs. Re_L and Re_G obtained for air-water system in nozzle L

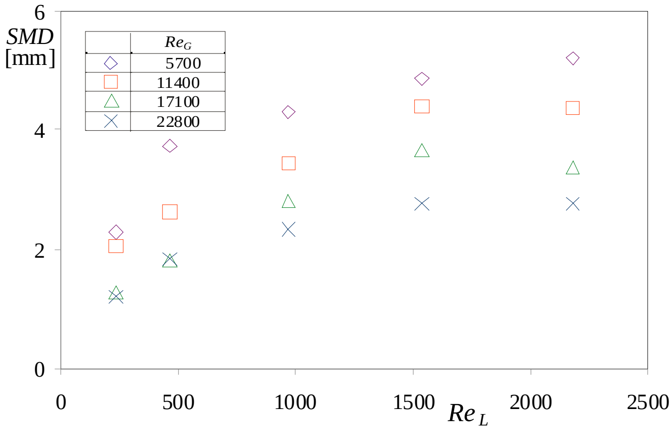

Figure 7. The relationship of *SMD* vs. Re_L and Re_G obtained for air-emulsion (Φ_{oil} = 0.20) system in nozzle S

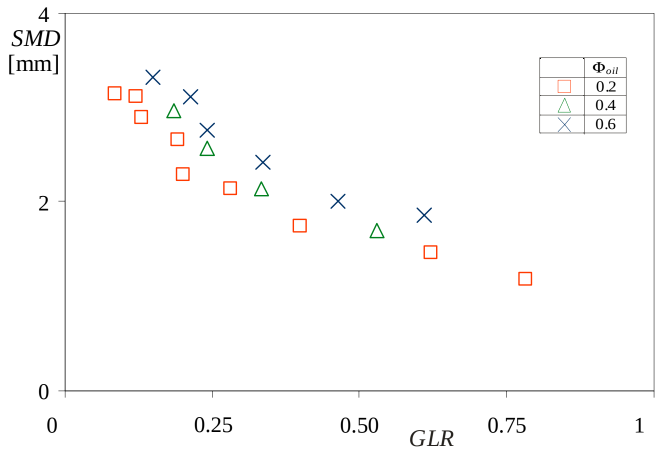

Figure 8. The relationship of *SMD* vs. *GLR* obtained for atomization in nozzle S

The empirical equation for *SMD* has been derived as follows:

$$SMD = A\frac{d_{out}^{1.14}}{d_{in}^{-0.56}}\frac{\mu_L^{0.12}}{\mu_G}GLR^{-0.30} \qquad 47)$$

where *A* is a function of nozzle internal geometry, surface tension and other parameters influencing on atomization process. In the equation Φ_{oil} is hiding inside the liquid viscosity.

The differences between characteristics of atomization for water and emulsions have been observed. The results showed that the spray angle is dependent on a content of oil in emulsions. The Sauter Mean Diameter of droplet increased with increase of liquid flow rate and decreased with increase of gas flow rate. The influence of emulsion composition on the droplet sizes has been observed too. It is evident that the addition of water changes the emulsions properties which are the key parameters influencing the atomization of the spray.

SUMMARY

The experimental results obtained showed that the changes in physical properties of a liquid phase lead to the significant changes in the spray characteristics. The analysis of the photos of water and emulsions atomization process showed that the spray angle and the droplet sizes are dependent on: gas and liquid flow rates, construction of nozzle and properties of liquid. The differences between characteristics of atomization for water and emulsions have been observed. The results showed that the spray angle is dependent on a content of oil in emulsions. Analysis of photos on forming the droplets in air-water and air-emulsions showed that droplets are bigger in air-emulsion system (at the same value of gas to liquid ratio). Probably it is the effect of viscosity surface tension of investigated liquids. The values of *SMD* increased with increase of volume fraction of oil in emulsion. The droplet size increased with emulsion viscosity. It is evident that the addition of water changes emulsions properties which are the key parameters influencing the atomization of the spray.

ACKNOWLEDGMENT

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NOMENCLATURE

A	surface area	m^2
GLR	gas-to-liquid ratio by mass	-
SMD	Sauter mean diameter	m
$\dot{V}$	volumetric flow rate	m^3/s
d	diameter	m
$\dot{m}$	mass flow rate	kg/s
Φ	volume fraction	m^3/m^3
α	spray angle	deg
σ	surface tension	N/m
ρ	density	kg/m^3
μ	viscosity	Pa s

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