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TWO-PHASE FLOW CHARACTERISTICS IN THE MIXING CHAMBER OF THE EFFERVESCENT ATOMIZER

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ABSTRACT

The article deals with the description of two-phase flow in the mixing chamber of an effervescent atomizer. The first observation has been carried out with the use of high-speed records of the flow inside the mixing tube. The flow in the mixing chamber is very fast and inhomogeneous thus the need to use a high-sampling frequency device has arisen in order to describe changes in the flow. Therefore, an experimental technique has been found which is able to describe the liquid-air distributions in small channels. As a two-phase flow measurement instrument, a miniature wire-mesh conductivity sensor to deal with cross-sections of 8 mm in diameter was designed and built. The frame rate of this sensor is 10 000 images per second. In this study, a special model of a transparent nozzle spraying deionized water that makes use of air as the atomizing medium was used. The effervescent nozzle is of "inside-out gas injection" configuration with the internal diameter of the mixing channel 8 mm. During the experiment, the effervescent atomizer was operated at different air pressure levels ranging from 0.1 to 0.5 MPa and mass GLR (Gas-to-liquid- ratio) from 0.1 to 25%. Mass flow rates of water ranged from 5 up to 65 $g\cdot s^{-1}$. The results reveal the unstable behavior of two-phase flow in the mixing chamber.

INTRODUCTION

The groundwork of the effervescent atomization research was laid in the late 80's of the previous century [1]. 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 atomization media is fed into a volume of a 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 behaviour of the two-phase flow inside the mixing chamber is affected by the operational conditions, geometrical arrangement of the mixing chamber and the properties of both the media [2]. To study flow patterns and associated spray quality different techniques have been used in the past. The internal-mixing in twin-fluid atomizers was studied by Chin and Lefebvre [3]. Lorcher at al. used an electrical tomography system to measure the void fraction profile. Visualization of the two-phase flow at the final orifice and its void fraction was done by Lorcher et al. using a special optical sensor with two photoelectric relays [4]. Another research work was carried out by means of holographic experiments of the spray generation in the near nozzle region [5]. Further, high-speed cameras have been used to study the oil-air and water-air flows in effervescent mixing chamber [6], [7]. Research of the effervescent atomization is connected with measurement of the pulsations in two-phase flow and in the spray cone [8], which cause flow instabilities and heterogeneity in the spray. All these mentioned phenomena are probably bound together in a complex behaviour of effervescent nozzles. Visualisation provides a qualitative view on the flow pattern and can help give coarse explanations how the mixture is produced. However, quantitative description of the flow based on the visualization images is quite difficult due to the complex spatial-temporal two-phase structure of the flow. Wire mesh sensors have been successfully used in the past to measure two-phase flows in pipes and vessels [9], [10], [11], [12]. Their decisive advantage is that they give high resolution images of the phase distribution both in space and time. Commercially available wire-mesh sensors can deliver cross-sectional images at up to 10 kHz frame rate and 2 mm spatial resolution. The data from such a sensor can be post processed to yield gas fraction profiles, bubble size distributions and interfacial area parameters. Thus, the wire-mesh sensor is a very versatile instrument. Of course, it is an intrusive instrument and produces some feedback on the flow structure. Therefore, care must be given to its use in flow measurement. However, as long as the wire electrodes are reasonably thin and the liquid phase is moving at moderate or high speed, the sensor has proven to give accurate instantaneous images of the undisturbed flow. Another technical problem that had to be solved was the miniaturization of the sensor. Commercial wire mesh sensors are typically designed for flow cross sections of a few centimeters in diameter. The mixing chamber of the effervescent atomizer is, however, just a few millimeters in diameter. Therefore, a new miniaturized sensor was manufactured which is described in more details below.

TEST EQUIPMENT

The test bench hydraulic circuit is sketched in Fig. 1. An effervescent nozzle (8) is mounted to a holder. The nozzle is connected to the liquid and air branches, both of them being equipped with sensors of pressure (3), temperature (7) and a 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·min^{-1} at the gauge pressure of 0.8 MPa. The air branch is connected to the compressor (1) with an air pressure tank (2) by means of a gas pressure regulator (5) and a filter (4). The maximal pressure in the air distribution system is about 1 MPa. The measuring program, which runs under LabVIEW environment, was used to control the measurement system and for data acquisition and its processing.

As a two-phase flow measurement instrument a miniature wire-mesh conductivity sensor for 8 mm diameter cross-section was designed and built. The sensor design is shown as a CAD drawing in Fig. 2.

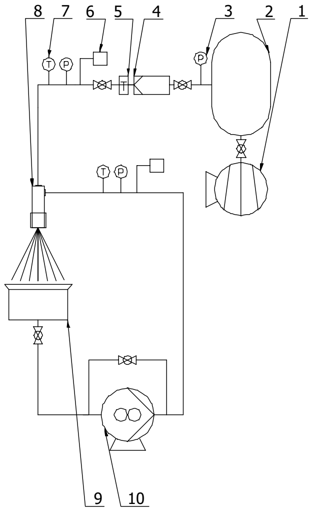

Fig. 1 Test circuit

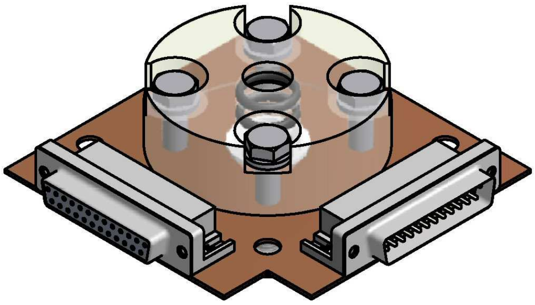

Fig. 2 Wire-mesh sensor

It consists of 50 µm diameter stainless steel wires stretched across the flow cross-section in two planes. Each plane comprises 16 wires running at a distance of 0.5 mm in parallel to each other. The wires of different planes run perpendicular to each other. The plane spacing is 0.5 mm. The wires are mounted on printed circuit board frame, which also contains the required copper leads and sockets for wire connection to the processing electronics. The printed circuit board frame is further inserted between two small Perspex flanges. These flanges make it easy to mount the sensor into the mixing channel (Fig. 4). The electronics scheme of the wire-mesh sensor is illustrated in Fig. 3. To measure the local conductivity in the gaps of all crossing points, a bipolar voltage pulse is applied consecutively to all of the sender electrodes in one wire plane while all other sender electrodes are kept at ground potential. At both states of the bipolar signal the current flowing to the receiver electrodes in the other wire plane is measured synchronously by a set of transimpedance amplifiers and analog-to-digital converters. The difference voltages resulting from the positive and negative excitation are subtracted and further processed as a quantitative measure of the electrical conductivity of each wire pair. The bipolar excitation scheme is used to avoid electrolysis at the wire electrodes. The frame rate for this sensor is 10 000 images per second.

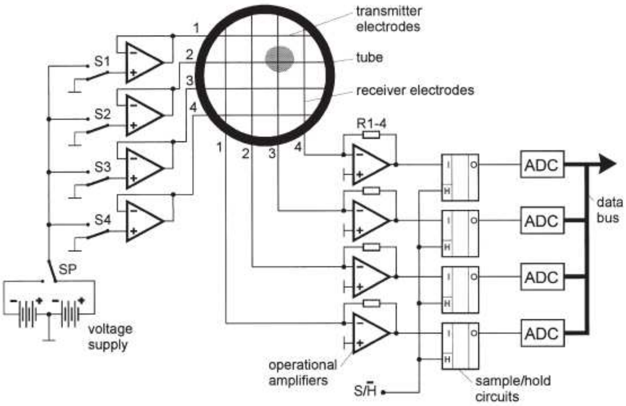

Fig. 3 Simplified scheme of a wire-mesh sensor

ATOMIZER DESCRIPTION

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 power up to 40 MW. The oil physical properties are not suitable for the conductive characteristics measurement hence water was applied.

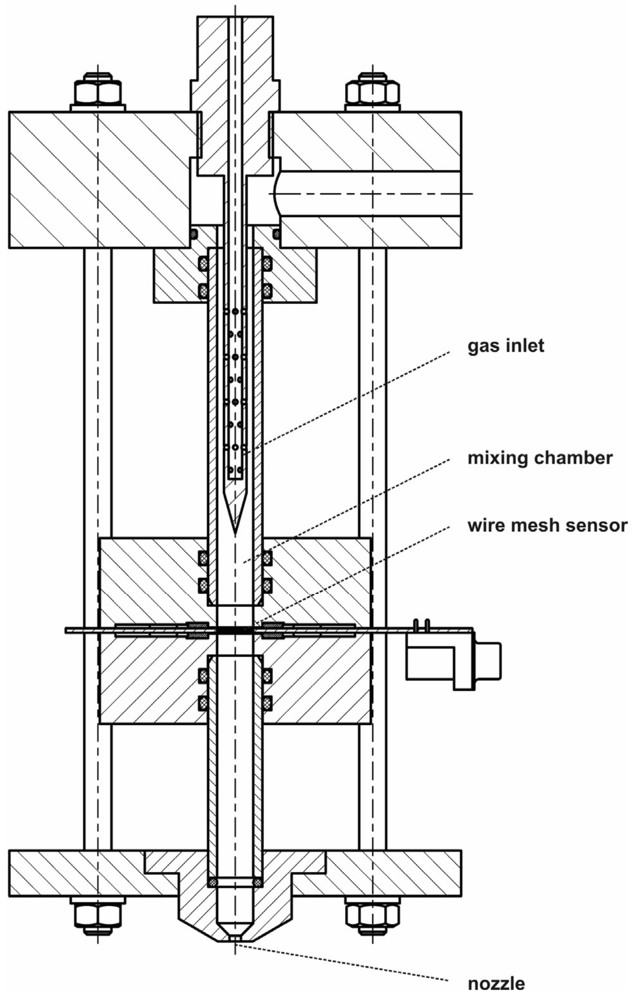

Fig. 4 Scheme of effervescent atomizer

The first of the transparent models was designed as the outside-in gas injection configuration [8]. 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.4), which is more flexible to geometry configurations. This model enables changing 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 air supply. 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 a 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 available for mixing of both media was 80 mm. The final discharge orifice was 2 mm in diameter.

RESULTS

High-speed recording was the first step of the study allowing visualization of the process in the mixing chamber [7]. For this purpose, a Redlake MotionPro X-4 camera was used. From a distance of 500 mm, image sequences were recorded with diffuse back illumination, a resolution of 192×992 pixels and at a frame rate of 5 kHz. The record of the two-phase flow in the mixture is shown in Fig. 5 at the operational point 0.1 MPa and 3 % GLR. The high-speed images show generation of non-homogeneous flow structures. The time shift between two consequent images is 4 ms.

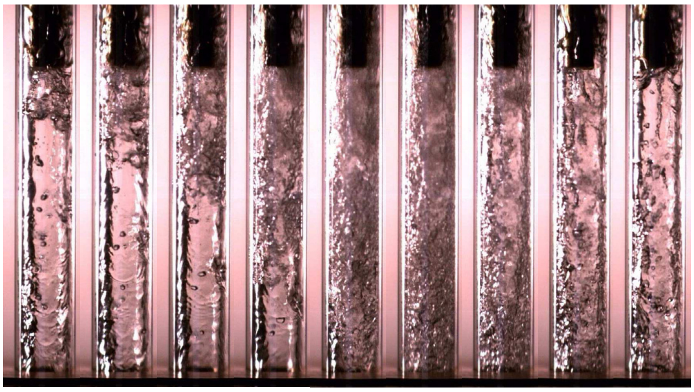

Fig. 5 High-speed images 0.1 MPa 3 % GLR

The wire-mesh sensor experiments were focused on operational conditions at pressure levels 0.1, 0.3 and 0.5 MPa. The mass GLR (Gas-to-liquid-ratio) was set to values 0,1 %, 1 %, 3 %, 5 %, 10 % and 25 %. Maximal and minimal flow rates are presented in Table 1.

Table 1. Atomizer operational conditions

p_a [MPa]	p_w [MPa]	m_w [$kg \cdot min^{-1}$]	m_a [$kg \cdot min^{-1}$]	GLR [%]
0.1	0.95	1.60	0.002	0.1
0.1	0.88	0.34	0.084	25
0.3	2.93	2.81	0.003	0.1
0.3	2.78	0.69	0.17	25
0.5	4.91	3.74	0.004	0.1
0.47	4.42	0.87	0.22	25

Experimental data from the wire mesh measurement were obtained at the maximal possible sampling frequency 10 kHz. The frequency is sufficient to record the changes in the two-phase flow continuously; the total observation time was set 2 s. Each record contains 20 000 integral values of the gas fraction in a cross section of the mixing chamber (see Fig. 6). Two types of flow patterns were observed. The first one was the annular flow with the air core and the liquid film streams down the tube wall. The second one was the wavy annular or the churn flow where the liquid layer is quite thick and the surface is not smooth. The air core was still present though. The classical slug regime at which the cross section is periodically filled up with liquid and the air core disappears occurred very rarely. Void fraction fluctuations may reach rather large magnitude depending on the case. The assessment of the two-phase flow was based on the void fraction histogram (see Fig. 7). The width of the histogram reflects on

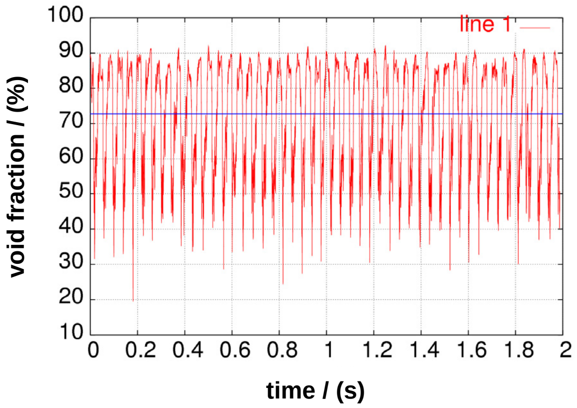

Fig. 6 Void fraction in the 2s sequence

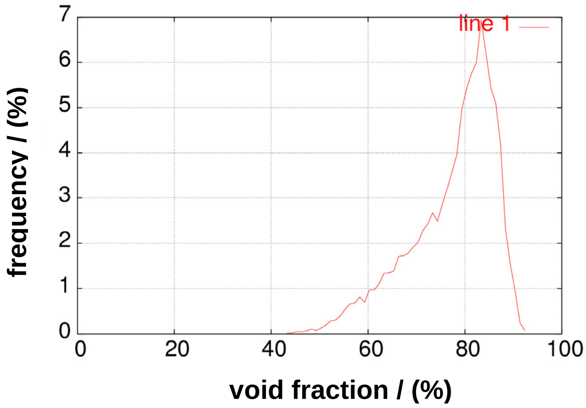

Fig. 7 Histogram of void fraction

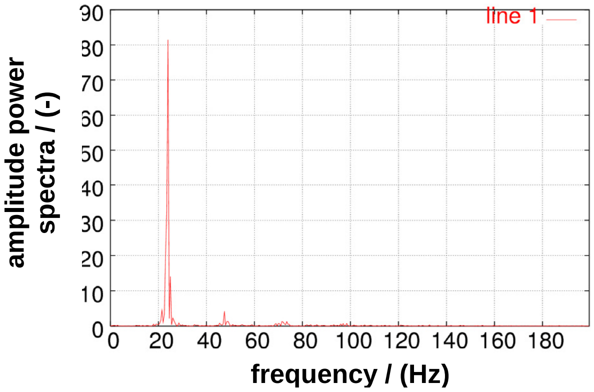

Fig. 8 Frequency of pulsation in the mixing chamber

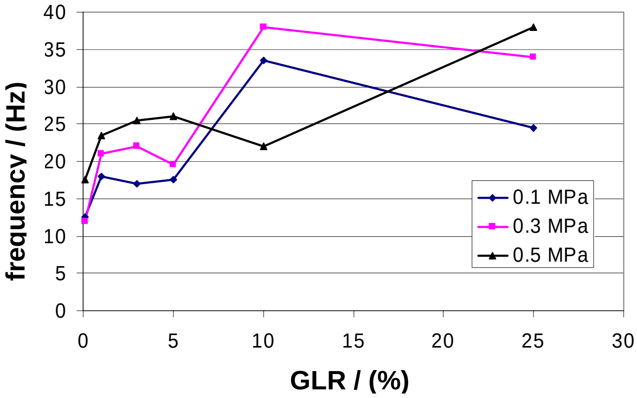

Fig. 9 Resultant frequency trends

the rate of void fraction fluctuation. If the characteristics of two-phase flow type changes are to be assessed a FFT (Fast Fourier Transform) analysis is useful. The results from the FFT analysis were focused on determination of low-frequency pulsations in terms of changes of two-phase flow type. One of the frequency spectra is shown in Fig. 8. Resultant frequencies of pulsations *f* in the mixing chamber are presented in Fig. 9. Trends for all pressure levels are similar and the pulsations reach high frequencies for conditions at high pressure. Unfortunately, clear dependency of the pulsation frequency on the GLR for various pressure levels was not found.

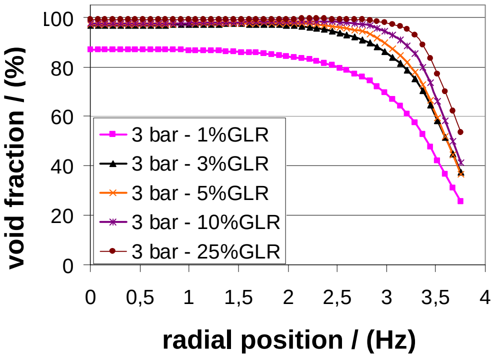

Fig. 10 Radial void fraction distribution

The radial profiles of void fraction were computed using the time averaged data. This was achieved by converting the data from the Cartesian grid onto a polar one using a spline interpolation method and then averaging over the angular coordinate. The calculations are easily performed in Matlab. The stream of water and air exhibits similar gas fraction distribution throughout the whole channel. Maximum values of gas fraction were reached in the centre of the channel whereas were diminished towards peripheral parts of the channel.

CONCLUSION

The experimental research in the two-phase flow mixture was carried out. A special transparent atomizer and a wire-mesh sensor for a small tube diameter (8 mm) were designed. Using this sensor, changes in the two-phase flow pattern in the mixing chamber of an effervescent atomizer were studied. The wire-mesh sensor results confirmed non-homogeneous behavior of two-phase flow in the mixing chamber. The wire mesh technique was used to obtain gas fraction characteristics and frequencies of changes in the two-phase flow type were determined. Radial profiles of the gas fraction in the mixing chamber were computed. The evaluation of instabilities was done by means of the FFT analysis. The frequency of two-phase flow pulsation reaches maximal values at maximal pressure level. Finally, the wire-mesh sensor is a very strong tool for two-phase flow visualization that provides quick view of the flow pattern. The wire mesh technique is presented as a high temporal resolution measurement technique and that can provide information about time evolution of the two-phase flow.

ACKNOWLEDGMENT

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NOMENCLATURE

Symbol	Quantity	SI Unit
p	pressure	MPa
m	Mass flow rate	$kg{\cdot}min^{-1}$
GLR	Mass gas to liquid ratio	-
f	frequency	Hz
Subscripts		
w	water	
a	air	

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