INFLUENCE OF SOME GEOMETRICAL PARAMETERS ON THE CHARACTERISTICS OF EFFERVESCENT ATOMIZATION

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Abstract

Experimental study of effervescent atomizers with different geometrical features is performed with the goal to obtain stable spray in the large turndown ratio with uniform flux distribution and very small SMD. Different flow characteristics were studied, i.e. dependence of flow rates of fuel and air on pressure of both, discharge coefficient, mass flux distribution and SMD using both PLIF technique and PDA system. The atomizers are intended to replace Y-jet atomizers commonly used in high power industrial burners that use the heating oil as a fuel. It is expected that effervescent atomizers may provide a more economical solution from the point of energy consumption and fuel preparation for the same inlet pressure and gas-to-liquid ratio (GLR).

Introduction

Currently, high power industrial burners for liquid fuels are mostly equipped with internal-mixing Y-jet atomizers or similar twin-fluid types. The principle of such atomization is based on the high shear stresses that develop at the interface between the liquid and gas. Such atomizers have one important feature in common: the bulk liquid to be atomized is first transformed into a jet or sheet before being exposed to high-velocity air. And this common feature forms main drawbacks of the pneumatic atomizers: high-energy consumption per atomization of a unit mass and a relatively complex structure of the atomizer that makes them more difficult and expensive to manufacture. Typical Y-jet atomizers in industrial burners use the air-to-liquid ratio mostly 5% to 10% and even higher and the fuel pressure mostly attains the maximum values of 1.6MPa. As a gas, superheated steam is mostly used with pressure above 0.8MPa. The SMD can be calculated from Wigg's empirical formula [1] and reaches values of about 100 μm for abovementioned parameters.

If a fuel with high viscosity is to be burned it must be preheated to temperatures up to 140°C. From this short description it follows that a significant amount of energy is needed to prepare the fuel prior to be sprayed into combustion chamber. Another important feature of atomizers is the size spectrum of the droplets and uniformity of the mass flux distribution since they significantly impact on the combustion and pollutants formation.

It is known that for the same GLR and inlet pressure, a well-designed effervescent atomizer may provide a more uniform spray having a much smaller Sauter mean diameter (SMD) than currently used Y-jet atomizers and/or similar twin-fluid atomizers.

The effect of some thermodynamic parameters of the liquid on e.g. SMD, spray cone and discharge coefficient has been studied in the past by several researchers [2,3,4]. It is generally agreed that SMD strongly depends on GLR and the pressure difference between the compressed fuel and ambient air. Less attention has been given to stability of the spray within the operational range of atomizers. Some qualitative information on stability can be acquired from [5] but there is still a lack of useful information for designers. Useful in the sense that once the atomizer is designed it should guarantee stability in the large turndown ratio needed for a burner. From our measurements it is obvious that some geometrical features of the atomizers play a very important role and that further studies are needed. The same can be concluded from [6].

In the present paper, several designs of effervescent atomizers are studied with different geometrical features. The main purpose of the study was to design an atomizer that would guarantee the following requirements:

- stable spray in a large turndown ratio
- as uniform as possible mass flux distribution
- small SMD

Basic flow characteristics were measured, i.e. dependence of flow rates of compressed fuel and air on pressure of both mediums, discharge coefficient, fuel pressure fluctuations, mass flux distribution and SMD. Studies were conducted on relationship between the characteristics of the spray, its stability, the operating conditions and the more important design parameters of the atomizer. It is shown that the geometry of the mixing system is an important parameter.

Experimental facility

Figure 1 shows a schematic layout of the experimental facility. It consists of a gear pump #14 that supplies light heating oil from a main fuel tank 16 through a set of filters, control valves and flowmeters into the atomizer #7. The compressed air is delivered either from the central plant or from a two stage compressor #1 depending on the required pressure through an air chamber #2 and set of filters and control valve into the atomizer. Spray is collected in a vessel #12 and returned to the main supply tank. The collector is connected to an oil mist separator that keeps the spray zone free of aerosol but doesn't distort the spray. The gear pump delivers the oil with a pressure up to 3MPa, pressure of the compressed air can reach 2MPa. The maximum flow rate of the oil can reach 1800 kg/hour. Pressures and temperatures readings are taken at the atomizer inlets for both the fuel and air. The pressure measurements are complemented by the pressure difference measurement. A special high frequency pressure gauge for pressure fluctuations is installed just upstream of the atomizer inlet. The fuel is injected vertically downwards into the ambient atmosphere. The sampling distance was set to 152mm from the atomizer orifice.

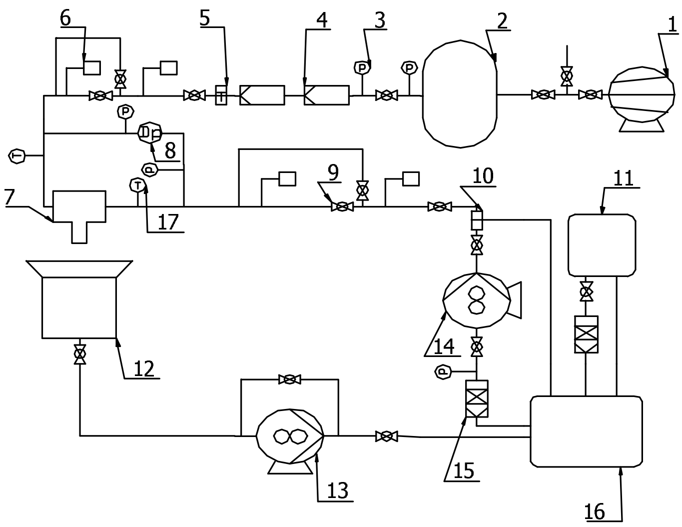

Figure 1. Schematic layout of the experimental facility

The spray measurement systems are a Planar Laser Induced Fluorescence imaging system (PLIF) and 1-component Phase-Doppler Analyzer (PDA). The PLIF system was used for the mass flux distribution and comparative SMD measurements and PDA system was used for detailed point SMD and correlation SMD-velocity measurements.

As a fluid, the heating oil was used with the flow rate in the range from approximately 0.6 l/min to 9 l/min, the GLR was adjusted to 1, 3, 5 and 10%, the pressure of the fuel was set to 0.2, 0.4, 0.6, 0.8 and 1.0 MPa.

Atomizers

Five types of atomizers have been studied. They were designed after the methodology [3] and [5] with the goal the atomizers work in the bubbly flow regime. The atomizers are labelled E1 to E5 (for E2, E3 and E4 see figure 2). The atomizer body has the inner diameter of 38.5mm, the length of the mixing chamber is 100mm and the orifice diameter is 2.5mm. In the variants E1, E2, E4 and E5 the fuel enters the aerator through a central cylindrical tube and the air flows through an annular passage from which it penetrates into the fuel through a set of small holes of the diameter of 1mm. The inner diameters of the aerators are 8mm and 5.5mm for variants E1 and E2, respectively. In the variant E3 a central shaft is inserted into the aerator tube to obtain an annular mixing chamber with a gap of 1mm. The central shaft has a conical tip and is adjustable in the axial direction to enable different settings of the conical orifice. The variants E4 and E5 have a special conical insert in the upstream part of the aerator that forms a short annular space that downstream gradually enlarges and smoothly adapts to the cylindrical mixing chamber. The purpose of the insert was to gradually enlarge the flow passage of the air/fuel mixture as the amount of air mixing with the fuel increases and to avoid formation of larger plugs of bubbles. The variant E5 differs in the length of the aerator chamber: it is half of the others, i.e. 50mm. In all variants, the set of total 30 holes of diameter of 1mm is made in always 3 rows spaced 5mm. In each row there are 5 holes turned through 72°. The last row is 86mm from the orifice for all variants except the variant E5 where the distance is 32mm.

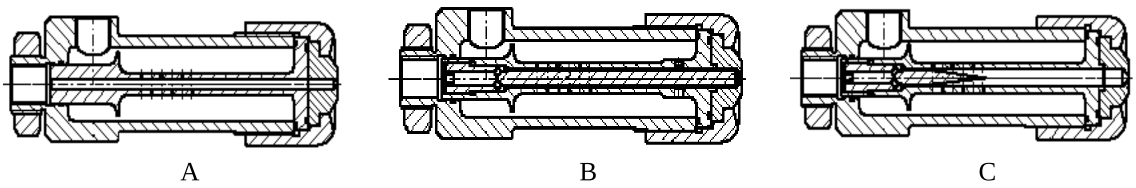

Figure 2 Internal-mixing plain-jet effervescent atomizers (A - E2, B - E3, C - E4)

Optical Patternator and PDA

An Optical Patternator system was used to measure the mass flux distribution in the spray. The system is a commercial one fabricated by Aerometrics, Inc. (now TSI). The patternator employs both elastic light scattering and fluorescence scattering from an ensemble of spherical droplets to compute both the fuel mass and SMD. In our tests only mass distribution was measured. A thorough explanation of the theory, applicability and assessment of the system is given by Sankar et al. in [7]. In principle, when a droplet containing fluorescence excitable molecules is illuminated by a laser light source, a portion of the incident light energy is absorbed by the excitable molecules that is then re-emitted as fluorescence (frequency shifted from the incident light wave). The remaining portion of the incident light experiences elastic light scattering (elastic means that the radiated light has the same frequency as the incident light). The fluorescence signal is used to infer the fuel mass and the information contained in both the fluorescing and nonfluorescing scattered light is used to directly measure the SMD. The patternator consists of a quadruplet Nd:YaG laser Surelite I from Continuum with the output of 266nm wavelength. The power used was 40mJ. The light goes through a light sheet projector. The Xybion intensified camera with 8-bit resolution was used. The fuel can be made to fluoresce at about 420nm. Appropriate filters were placed in front of the camera to filter out the scattered light at 266nm and the fluorescent light at 420nm.

1-component PDA (Dantec) system with standard optics was used to measure size spectrum of droplets. 300mW Argon-Ion laser was used as a source of light, receiving optics was set to refraction mode with the scattering angle of 68.8° with parallel polarization.

Results and their discussions

The results of the measurements have been assessed from the point of flow characteristics. The basic point of view was the operational behavior of the atomizers in the largest possible turndown ratio. The stability of the spray was the major concern. Comparison was made namely between atomizers E1, E2 and E4, E5 that are similar in the basic geometry of the aerator. Atomizer E2 has the smaller inner diameter of the aerator compared to E1 and atomizer E5 is shorter (half) than the E4.

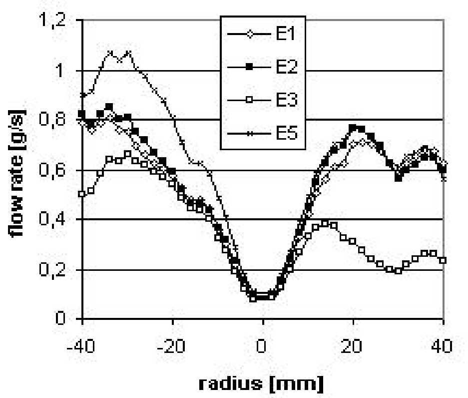

Figure 3 Mass flux distribution for fuel p_{fuel}= 6 bar and GLR=1%

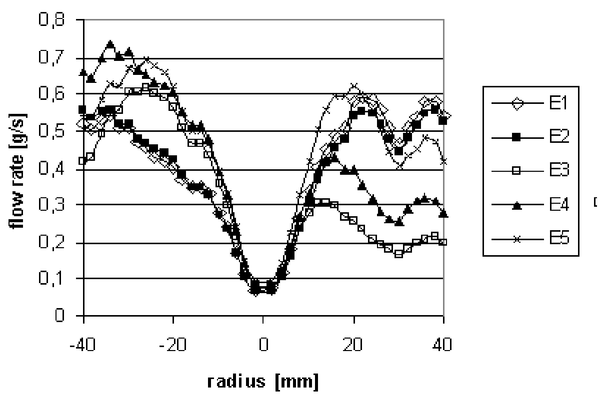

Figure 4 Mass flux distribution for p_{fuel}= 6 bar and GLR=3%

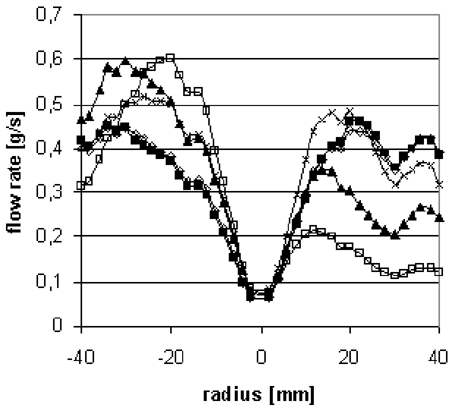

Figure 5 Mass flux distribution for fuel p_{fuel}= 6 bar and GLR=5%

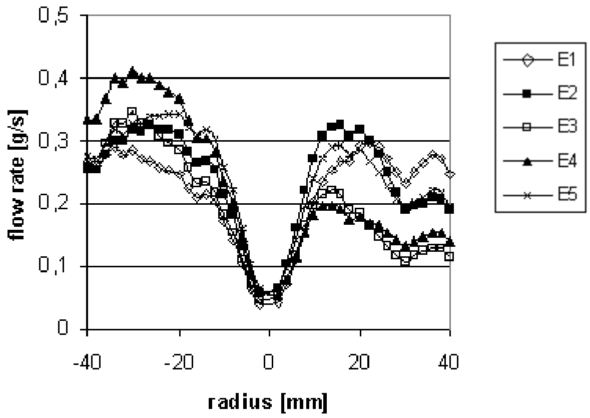

Figure 6 Mass flux distribution for p_{fuel}= 6 bar and GLR=10%

All atomizers E1 to E5 were first studied from the point of flow characteristics, i.e. discharge coefficient C_d, dependence of fuel flow rate on the air flow rate for the range of GLR and fuel pressures. Optical patternator was used to measure the mass distribution in the horizontal plane of the spray in the distance of 152mm from the atomizer orifice. Results obtained from the fluorescence signal were recalculated to obtain flow rate in individual position across the spray. The diameter perpendicular to the direction of incident light was analyzed. Resulting distribution can be seen in fig. 3 to 6 for the fuel pressure of 0.6 MPa and GLR 1%, 3%, 5% and 10%.

First we can see from Fig. 3 to 6 that the flow rate of fuel decreases as GLR increases (note the plotting scale of the flow rate) what means that with increasing GLR the air blocks a larger orifice area. The figures also show a certain non-uniformity of the flow rate distribution. The best uniformity show the atomizers E1, E2 and E5, the worst the atomizers E4 and E3. It could have been expected with the E3 as this atomizer has an annular orifice with an adjustable gap and it's very difficult to set up very precisely the same gap all around. For E4 the stability at GLR=1% was very poor and results of the flow distribution are not presented in fig.3. With increasing GLR the non-uniformity is slightly reduced (compare the ratio of both peaks for - and + radius and the minimum for + radius). It's not yet clear why there is the minimum for r=30mm. This will need further studies and a check with PDA flux measurements. From the same figures we can also conclude that the spray angle remains almost constant for the whole range of GLR showing the appropriate peaks in the flow rate in the same radial positions.

Instabilities of the spray were studied using a miniature pressure transducer Kistley mounted just upstream of the nozzle. Stability of the spray is predominant parameter for burners. The stability of the spray can significantly impact on the stability of the flame and on the formation of NOx. Amplitude and frequency of pressure oscillations were measured, compared and assessed. For this purpose also a video camera shooting was used and studied. The base frequency of the gear pump was filtered out using a 10m long coil of plastic hose placed downstream of the pump discharge. From the measurements of frequency and amplitude of oscillations it results that the most stable atomizers are E2 and E5. Both atomizers have approximately the same frequency (except for high GLR at lower pressures) but E5 shows significantly lower amplitude of oscillations (Tables 1,2).

Amplitude E5/E2 [mbar/mbar]					
GLR	Pressure [MPa]				
[%]	0.2	0.4	0.6	0.8	1.0
1		0.12	0.29	0.46	
3	0.40	0.53	0.57	0.61	0.56
5	0.56	0.29	0.71	0.63	0.77
10	0.75	0.70	0.50	0.67	0.86

Table 1 Dimensionless amplitude

Frequency E5/E2 [Hz/Hz]					
GLR	Pressure [MPa]				
	0.2	0.4	0.6	0.8	1.0
1		3.65	1.11	1.12	
3	1.08	0.95	1.04	0.97	1.03
5	0.75	1.12	1.10	0.97	1.03
10	0.67	0.68	0.53	1.00	1.00

Table 2 Dimensionless frequency

After the evaluation of atomizers from the point of stability, atomizers E2 and E5 were selected for further studies using PDA system. We limited the GLR for 3% to 10%. Results of the SMD measurements are presented in the Fig. 7. From this figure we see that there is a slight difference between E2 and E5 (we remind that E2 has a simple cylindrical aerator with the inner diameter of 5.5mm, the E5 has a special conical insert and is half-long compared to E2). The E5 shows a somewhat more flat radial distribution with a little higher SMD in the centre. The flatness is more remarkable for higher GLR (here ALR). The GLR does not have very much impact on the

SMD. For E2 at all GLR the distribution is almost identical. For E5 at GLR=3% and 5% is also almost identical, for GLR=10% we can observe a moderate decrease of SMD in the core region for higher pressure of 1 MPa.

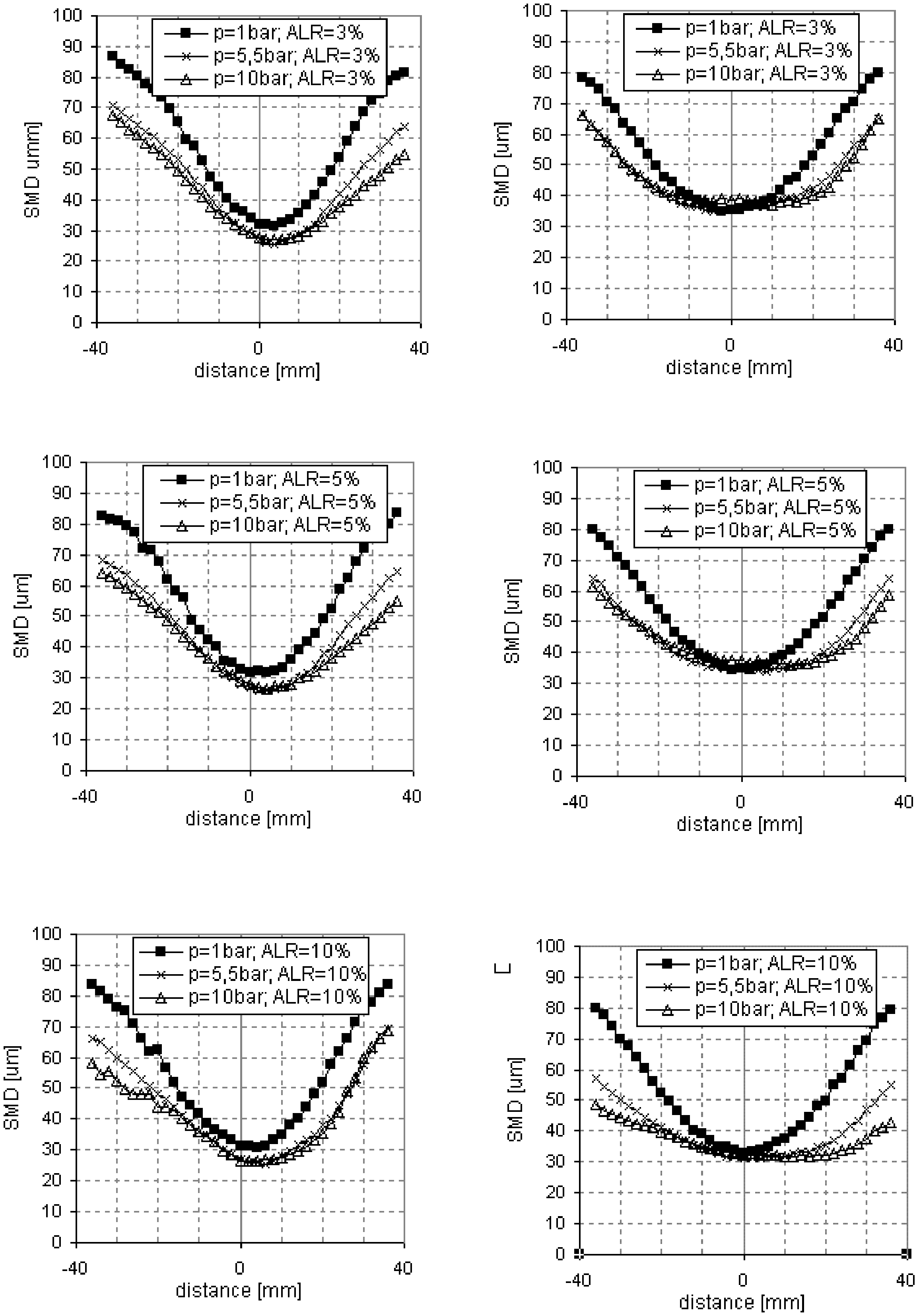

Figure 7 Radial SMD distribution for E2 (left) and E5 (right) for the range of fuel pressures and GLR

Conclusions

Experimental study was conducted with several geometrical variants of internal-mixing effervescent atomizers. The atomizers were designed according the methodology [3, 5]. The main goal of the research was to find a design of the atomizer that would guarantee a stable spray in a large turn-down ratio and in the same time guarantee a very fine spray. The reported research was performed with single-hole atomizers, but the final goal is to develop a multi-hole atomizer for industrial burners.

Results of the research show that there is a strong dependency on the design of the atomizers. The stability of the spray was judged optically from video shootings and by measurements of pressure oscillations - both amplitude and frequency. Based on this assessment, only atomizers E2 and E5 "qualified" for the final tests. The E5 shows a little better behaviour from the point of stability. From the point of size spectrum, the E2 has a less flat radial distribution with smaller SMD in the centre of the spray. The E5 has a more flat distribution with negligibly larger SMD in the centre. Generally, SMD in the centre is in the range from 25μm to 35μm.

The mass flow distribution, measured with PLIF system show a large non-uniformity for some of the atomizers (mainly E1, E3 and E4). It's not yet clear what's the reason for this non-uniformity. One reason may be a manufacturing inaccuracy or difficulties in adjusting the uniform gap, this latter mainly for the annular gap atomizer E3. Another reason may lie in the non-homogeneity of the two-phase flow regime that is developing inside the aerator.

When comparing E1with E2 (similar geometry, E2 has a smaller inner diameter of the aerator than E1) we can conclude that the smaller diameter contributes to a more stable spray, because E2 generates a more stable spray. When comparing atomizers E4 and E5 (the same geometry with a special insert, E5 is half-long) we can conclude that a shorter aerator tends to stabilize the spray because E5 shows smaller oscillations. When comparing E2 and E5 from the point of stability, E5 shows a little better stability - the same frequency but smaller amplitude.

Both, the poor stability and non-uniform mass flow distribution in the horizontal plane can result from the two-phase flow regime inside the mixing chamber (aerator). Though the atomizers were designed to ensure two-phase bubbly flow in the mixing chamber at nominal parameters, which was checked in Baker's horizontal two-phase flow map, however the working point can move to slug flow pattern at higher GLR and low pressure.

Acknowledgement

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