Flow blurring atomization for combustion of viscous (bio)fuels

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Abstract: In order to achieve efficient combustion of liquid fuel a proper atomization of the fuel is needed. In case of many biomass fuels the atomization process is obstructed and hindered by high viscosity of the fuel. Preheating to reduce the viscosity in many cases is not possible because of fuel polymerization processes and secondary cracking reactions which finally result in fuel flow restriction. In this work, a novel flow blurring atomizer is presented and discussed in view to atomization and combustion of regular and highly viscous fuels. A detailed results regarding droplets SMD and distributions are presented followed by the combustion experiments in 50kWe full scale gas turbine. The outcome of the research shows that flow blurring atomizer is not sensitive for changes in the fuel viscosity and can be efficiently used for combustion applications.

Introduction: Conventional atomizers, like pressure swirl, air-assisted or air-blast nozzles cannot produce high-quality sprays from viscous biofuels without their excessive preheating. Unfortunately in many applications such preheating is prohibited. A solution for that problem may be an application of new type of twin-fluid atomizer called flow blurring. The principles of the process were first described by Ganan-Calvo [1]. The flow blurring atomizer disintegrates liquid flow with utilization of air bubbles which enter the fuel passage via fuel outlet, as schematically presented in Fig. 1. Because of the decreasing of the effective nozzle area, expansion of the air bubbles at the nozzle outlet and immediate ligament formation, the atomization process is very prompt leading to small droplets size. Further laboratory scale research conducted by Rosell-Llompart and Ganan-Calvo [2], Azevedo et al. [3,4] and Agrawal et al. [5] confirmed low sensitivity of the atomizer for changes in the viscosity for very low mass flows. However, in 2015 was concluded [6] that more knowledge is required regarding mechanisms standing behind the flow blurring phenomena to be able to operate the atomizer efficiently at high mass flow rates needed for commercial power generation applications.

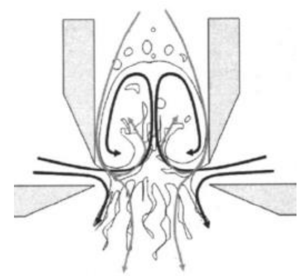

Fig. 1. Flow blurring atomization [1]

Experimental research: In order to investigate the behavior of the atomizer at full scale conditions, a set of atomizers having modular construction and possibility to adjust characteristics dimensions like orifice diameter (D) and height of the air passage (H) were investigated at different operating conditions and for liquids with dynamic viscosity varying between 0.8 – 64 cP. The surface tension and density were kept relatively constant at level of 65-70 mN/m and 1-1.2 kg/l, respectively. The investigations were performed with application of state of art atomization test rig working on PDIA principle, see [7], and 50 kWe gas turbine, as presented in details in [8]. For the SMD measurements, the droplets were assessed at three different locations, i.e. 18, 50 and 80mm from the nozzle exit to account for primary and secondary break up phenomena. The studied orifice diameter was equal to 4 and 7 mm, and the ratio between orifice diameter and air passage height, i.e. $\psi = H/D$, was fixed to 0.15 and 0.25, depending on the investigated conditions. For the gas turbine experiments a nozzle with D=7mm and $\psi = 0.15$ was selected and manufactured. During the combustion measurements the gas turbine was operating steadily in an idle mode. The experiments were performed with flow blurring nozzle and regular pressure swirl nozzle (D=1.4mm). As the output parameter for assessment of combustion performance the CO emissions were selected.

Results: The atomization results presented in Fig. 2 show that the flow blurring atomizer can deliver droplets with very small SMD. It can be noted that the final droplets size is only a weak function of the viscosity. However, the SMD may depends on the mass flow rate and air to liquid ratio (not presented in Fig. 2.). Nevertheless, it could be concluded that for flows of 50kg/h with viscosity of approx. 50 cP, the droplets size of 50 µm is acceptable for most of combustion applications.

Comparison of data regarding CO emission for regular pressure swirl and flow blurring nozzles revealed that for the same fuel (diesel #2) when the flow blurring conditions are achieved (i.e. $ALR_{rel}>1$ [9]; and

$ALR_{rel}=ALR/ALR_{min\_flow\_blurring}$) the flow blurring nozzle performs similar to the pressure nozzle, despite about 5 times bigger orifice diameter. This is especially visible when the air to liquid ratio is increased towards value of 1.2. According to Bouma [10] the high ALR_{ref} ratio is also beneficial for spray quality.

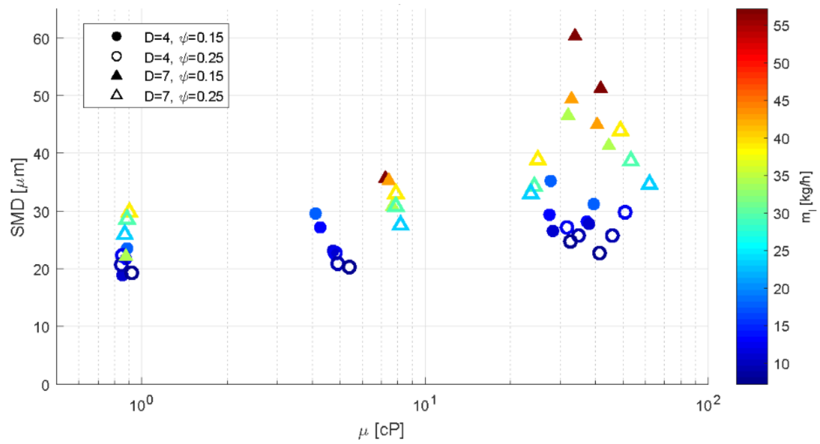

Fig. 2. SMD as a function of viscosity, flow rate and orifice geometrical parameters.

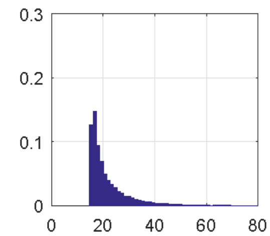

Fig. 3. Droplet size distribution; (x) SMD in μm; (y) normalized count

Conclusions: Experimental research was performed on application of flow blurring principle for atomization of viscous fluids up to viscosity of 60 cP. The results show that the viscosity has only minor effect on the droplet size and nozzle can deliver very small droplets. However, for the high mass flow rates (~50 kg/h) the air to liquid ratio should be increased to provide enough atomization energy. This was also observed during the combustion tests.

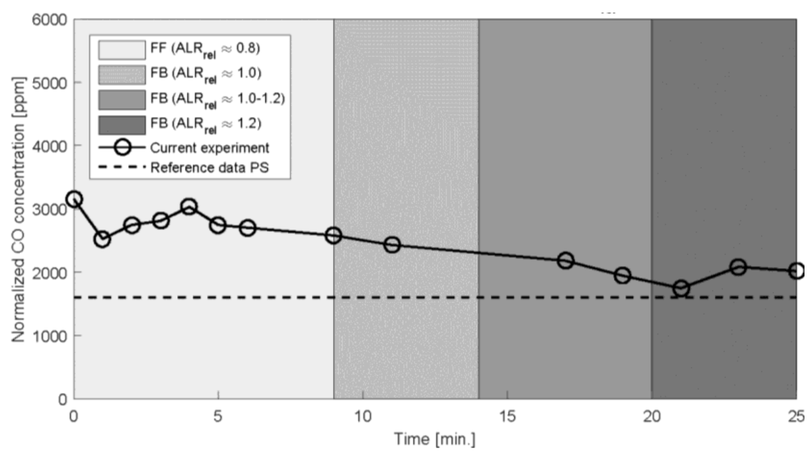

Fig. 4. Normalized (15% O_2) CO emissions in function of atomization regime

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