A novel atomization approach for low power liquid fueled burners

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Motivation

Due to the reduction of energy consumption in the domestic heating sector (Energy Saving Directive, Germany) there is an increasing demand for low load oil burners. As current oil burners are limited in load and modulation range due to characteristics of common pressure atomizers used for the fuel preparation, a novel atomization approach is needed for low liquid fuel mass flows.

In the course of the reduction of CO_2 emissions, energy-oriented modernization of buildings is of major importance. As an example, in Germany the Energy Saving Directive limits the allowed heat demand of newly build or renovated buildings and such limits are successively reduced. In this respect, heating boilers at very low burner loads (< 5kW) and with a wide adjustable power range are required, in order to minimize the amount of start-up and shutdown procedures. Commercially available burners at the low load segment are dominated by gas burners, which have no principal lower limitation in the fuel supply. On the contrary, oil burners usually utilize pressure atomizers, which have a minimum liquid flow rate at low modulation range.

A novel atomizer concept for low liquid mass flows

To close this gap, a novel atomization concept for low load oil burners with a wide adjustable power range has been proposed in a previous study [1]. The main working principle of this novel atomization concept is based on piezo-driven spray generator which either creates a liquid jet or a monodisperse droplet chain. When the liquid jet impinges on a pin in a certain range of operating conditions, it does not splash and the fuel can be collected and recirculated, while the droplet chain impinging on the pin produces a fine spray. Trough triggering of the Plateau-Rayleigh instability via piezo actuator, and hence the disintegration of the liquid jet into a drop chain, the spray generation can be switched-on and -off, and therefore a wide range of spray flow rates can be realized by pulse-width modulation. The schematic operation modes are shown in Fig. 1.

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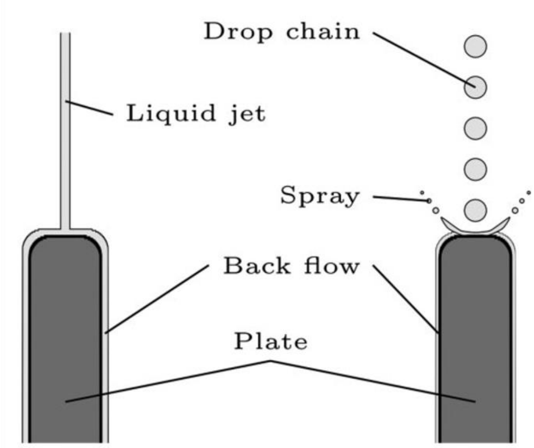

Fig. 1 Impinging jet on the pin with no atomization (left) and impinging droplet chain with spray formation (right) [1].

Through pulse-width modulation (PWM) of the piezo actuator triggering the disintegration of the jet a wide down modulation of generated spray volume flow can be achieved (see also Fig. 2). The novel atomization concept holds significant advantages in comparison with pressure atomizers. Sufficient atomization characteristics at low mass flow rates are obtained. Additionally, a wide modulation range without major deterioration of spray quality is achieved.

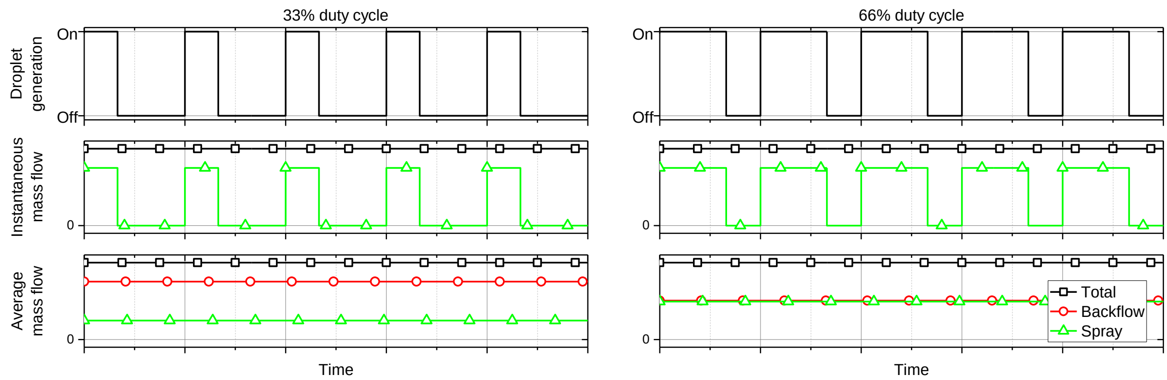

Fig. 2 Exemplary representation of the mass flow control at 33% (left) and 66% (right) duty cycle of the PWM.

Investigation of the atomizer concept

The atomization process was preliminary investigated in non-reactive conditions. Different model liquids have been selected in order to investigated impact of the liquid properties on the atomization process: water, a binary mixture of glycerine (40 wt%) and water and a binary mixture of glycerine (40 wt%) and ethanol. A rheometer with cylindrical measuring system in Searle-type arrangement [2] was used to determine the dynamic viscosity η, with an uncertainty lower than 5%. The density ρ was measured via Archimedean principle. The Du Noüy ring method [3] was applied to determine the surface tension σ with an uncertainty lower than 2%. All experiments were conducted at 20°C and under atmospheric pressure.
The droplet size distribution and drop velocity in the secondary spray along the radial axis from the pin was measured for various operating conditions and different heights above the impingment point using Phase-Doppler-Anemometry (PDA). The obtained results and the

correlation of the expected SMD of the secondary spray depending on Weber-number [1] are in good agreement. The secondary spray shows an SMD of approximately 10% of impinging droplet chain. While operation the atomizer in PWM-mode, no significant influence on the spray characteristics were observed.
Additionally, the back flow rate of the non-atomized liquid depending on the jet velocity and on the orifice diameter was measured for the three different model fluids. The results show that the back-flow ratio decreases with increase jet velocity and tend to stabilize at high rates for continuous operation. In case of controlling the atomization time via PWM, the back-flow rate shows no impact at low trigger frequency. When increasing the PWM frequency to the order of the droplet chain frequency (several kHz), the back-flow decreases.

Burner concept

The burner was designed with an atomization and combustion section, which are spatially separated. The droplet chain is vertically aligned with the pin, where the minor part of the combustion air is used in horizontal arrangement to drag the fine part of the spray to the combustion zone. The oil from the backflow at the impact element and wall film is recollected and reused. The remaining combustion air is fed after the atomizer section. The schematic of the burner is shown in Fig. 3.

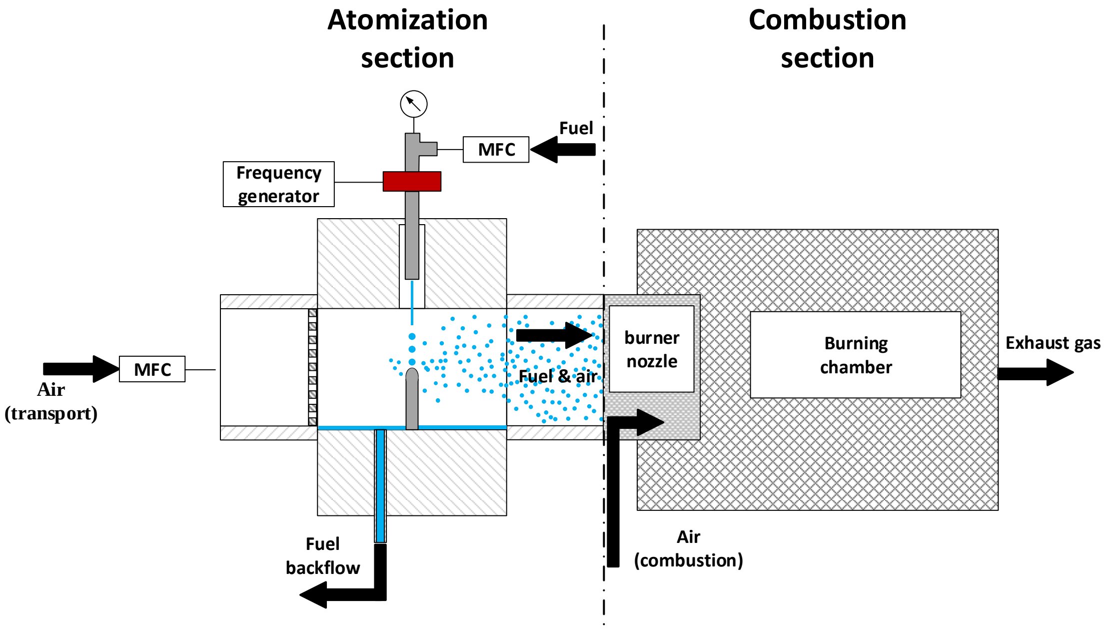

Fig. 3 Schematic of the burner concept.

The maximum thermal load is defined by the inlet pressure and the used orifice in the droplet generator with continuous droplet chain. Flexible down scaling of the thermal load is achieved by applying PWM. Here, constant operating conditions of the atomizer unit (total mass flow, exit velocity) resulting in constant spray properties

Burner test

A first burner prototype was operated in reactive conditions with light fuel oil. In focus were set the flame stabilization, the power modulation via PWM and the exhaust emissions. The total mass flow of the fuel was monitored by a Coriolis flow meter. Additionally, the pressure before the nozzle was measured. The characterisation of the exhaust stream included the measurement of CO and NO_X (emissions) as well O_2 and CO_2

(controlling parameter). Additionally, the back-flow was simultaneously measured with a balance.
The prototype was operated with a maximum thermal load of 5.5kW where a modulation range of 1:5 (to 1.1 kW) was achieved via PWM modulation. The emissions were within the current legislative regulations: the CO- and the NO_X-emissions showed on average 3 ppm and 50 ppm, respectively.

Conclusion and outlook

A novel atomization concept for low liquid mass flows was studied under non-reactive and reactive conditions. The control of the mass flow is based on a backflow and using PWM of the piezo element. In the presented study, the backflow and atomization process was investigated for three different model fluids. It was shown that the spray quality stays constant over a wide modulation range. The SMD of the secondary spray is approximately 10% of the size of the monodisperse droplet chain. A first burner prototype was operated with thermal loads in a range of 1 to 5.5 kW. The measured emissions were within the current legislative regulations.

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