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INVESTIGATION OF VELOCITY DISTRIBUTION OVER A PERFORATED BURNER PLATE

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Abstract

One of the typical surface designs of metallic surface burners is a mulitport design, with many different port configurations. Increased flame stability toward blow-off in multiport burners compared to a single port burner is achieved through interaction between the flames formed over the adjacent ports. Flame’s tendency toward blow-off depends on port size (influencing air/fuel mixture velocity), port shape (influencing the fluid flow pattern), and the interport spacing (influencing the interaction between the flames).

In the scope of optimizing the operation of a slit-and-holes burner pattern, the cold flow velocity distribution over one multiport burner plate was investigated, by means of LDA measurement technique. The LDA measurements were conducted in the enlarged geometry, due to better spatial resolution. The same geometry was numerically simulated in order to compare the obtained velocity distributions over the perforated burner plate.

Analysis showed that the LDA-measurements of the velocity field in the cold flow are in a very good agreement with the numerical calculations, indicating that the shear-stress turbulence model used for the numerical simulations as well as the geometrical resolution was well chosen.

Introduction

Combustion process, in the case of surface burners, is stabilized at the burner surface. Present work is focused on burners, whose surface is made of a metallic sheet, on which a pattern (usually consisting of slits and/or holes) is punched.

Depending on the degree of mixing of oxidizer (usually air) and fuel prior to the combustion zone three main flame types can be distinguished: 1) diffusion flame, i.e. no premixing, 2) partially premixed flame, i.e. amount of premixed air is not enough for a complete combustion, and 3) fully premixed flame, i.e. the amount of premixed air is enough for a complete combustion. One of the main demands for modern burners is low emission of pollutant gases, especially NO_x. In order to meet this demand modern burners increasingly use lean, overstoichiometric fuel-air mixtures. This results in a complete combustion (leading to low CO emissions) at a relatively low flame temperature (leading to low NO_x emissions). On the other hand, fully premixed flames have a higher sensitivity toward flame instabilities, i.e.

flame blow-off ,flash-back and acoustic instabilities, due to higher burning rates compared to partially premixed flames. These instabilities limit the power modulation range of a burner, thus decreasing its application range and potentials on the gas appliances market.

One of the typical surface designs of metallic surface burners is a mulitport design due to increase flame stability in comparison to a single port burner (Harris und South 1978). Flame's tendency toward blow-off depends on port size (influencing air/fuel mixture velocity), port shape (influencing the fluid flow pattern), and the interport spacing (influencing the interaction between the flames). Port size and shape directly influence the velocity distribution through the flame port and over the burner plate.

Figure 1 shows one triple-slit pattern (left), and a flame shape formed over it (right), at high power loads. Among other parameters, the flame stabilization is influenced by flow recirculation originating from the air/fuel jets that emerge from the burner ports (Jones 1990).

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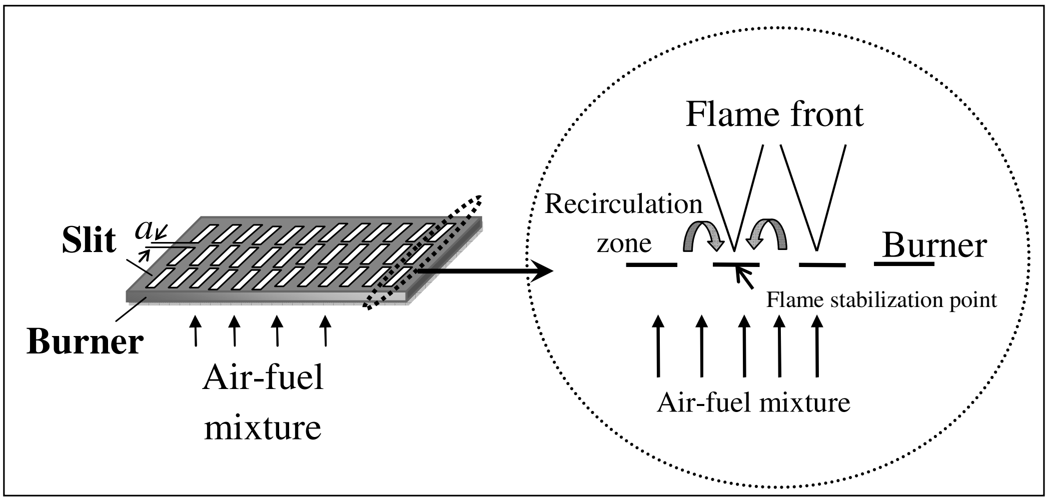

Figure 1: Sketch of a triple-slit burner pattern, and a flame formed over one row of slits

The aim of this study was to validate the existing burner construction, i.e. combination of slits-and-holes pattern in combination with the pressure distribution plate (placed below the burner pattern plate), and to provide guidelines for optimization of the slits and holes pattern. In the present work the cold flow through a slits-and-holes pattern was characterized by means of velocity measurements using the LDA measuring technique. The obtained results were compared with the numerical simulation of the cold flow, in order to be able to validate the numerical results for the future use in the burner pattern optimization.

Experimental set-up

In the scope of optimizing the operation of a slit-and-holes burner pattern, the velocity distribution over one multiport burner plate was investigated, by means of LDA measurement technique. The goal of the experimental analysis was to investigate the isothermal flow field over a flat burner plate. Velocity distribution was determined under the cold flow conditions, i.e. without combustion, at the position h = 1 mm above the model burner plate. Experimental set-up is shown in Figure 2.

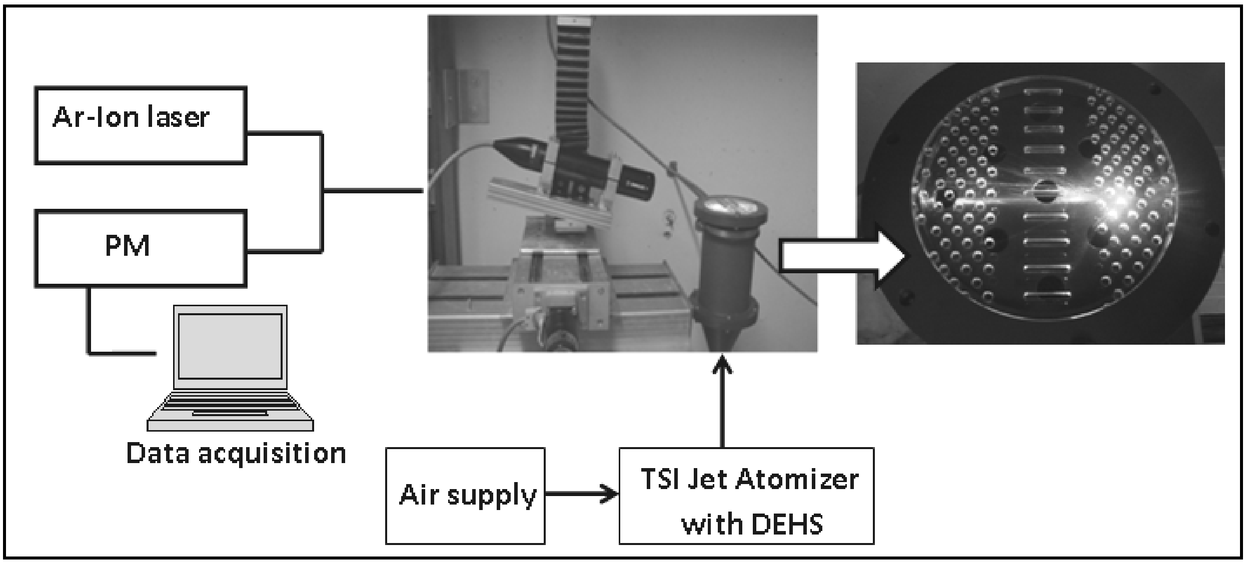

Figure 2: Experimental set-up with the test model of the perforated burner plate model

The LDA measurements were conducted using the enlarged burner plate model (with scaling factor 5), due to a better spatial resolution, since the holes of the burner plate have roughly the same dimensions as the measuring volume of the LDA system (600 µm). The enlarged model, shown in Figure 2 (far right), was produced based on the Reynolds similarity, calculated for a fluid velocity corresponding to a power load of 380 kW/m².

In the performed LDA measurements a multiline 4 W Ar-Ion laser was used, with the Dantec-Fiber Flow backscatter configuration. Measurement grid was 1 mm x 1 mm, with 18 x 109 points measured, i.e. total of 1962 measurement points, as is shown in Figure 3. Measuring time for one point was over 60 s, with min. 1000 data points, up to 100.000 and the integral time scale of 3 ms. Mean measured value was calculated with transient time averaging. LDA measurements were performed with a mixture of air and DEHS (Di-Ethyl-Hexyl-Sebacat). DEHS was atomized into droplets of dp= 4–5 µm, using a jet atomizer.

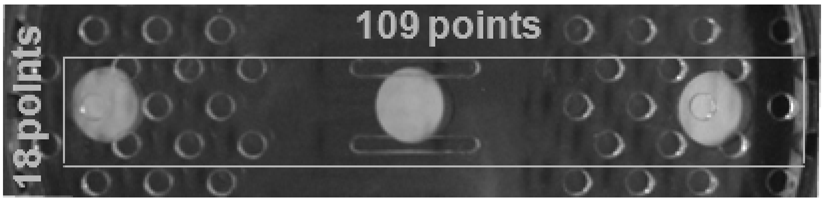

Figure 3: Measuring area of the enlarged burner plate model

Numerical simulation

The flow field through the slits-and-holes pattern integrated with the pressure distribution plate, showed in Figure 4a, was numerically simulated. The burner geometry was set according to the LDA experimental setup, in order to validate the simulation results with the experiments.

A commercial software ANSYS CFX was used for numerical simulation. Mesh consisted of 2.7 million hexahedral cells. Inlet was defined as the mass flow rate of mixture of air and methane, keeping the same Re number as in the LDA measurements, i.e. Re = 2600 (inlet gas

velocity v = 0.25 m/s). An outlet boundary condition was used on the downstream side. Since the characteristic area section of the pattern is periodic in x- and y- direction, the periodic boundary conditions perpendicular to the main flow direction were used.
For the turbulence modeling the Shear Stress Transport model (SST) with scalable wall function was used. This model combines several desirable elements of existing two-equation models, i.e. it uses k-ω model near solid walls and k-ε model near boundary layer edges and in free shear layers (Cebeci 2004).

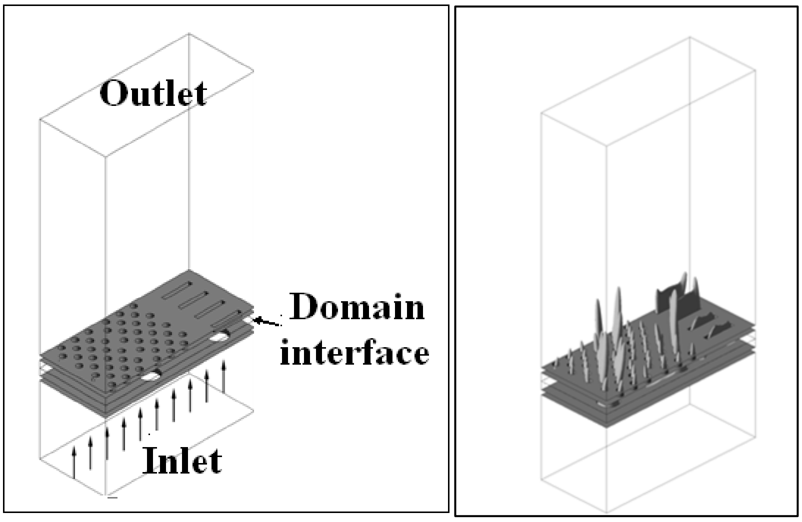

Figure 4. Numerical model of the perforated plate (a) and the obtained velocity field in the form of the isosurface plot of velocity magnitude (b)

Figure 4b shows the numerical simulation of the cold flow through the slits-and-holes pattern. Numerical simulation showed that the velocity field over the perforated plate is inhomogeneous, with velocity peaks formed over the distributor holes. At locations where no hole of the pressure distributor plate is below the burner plate, the velocity magnitude distribution is quite homogeneous. Regarding the time dependency of the flow, numerical simulation showed that the velocity field is almost stationary.

Discussion

Figure 5 shows the qualitative comparison between the experimentally investigated axial velocity component over the characteristic burner area, and the velocity distribution obtained by numerical simulation for the corresponding area. The velocities are measured/simulated 1 mm above the burner plate. The contours of the experimentally and the numerically obtained axial velocity component, shown in Figure 5, indicate a very similar distribution of the axial velocity, i.e. a very good agreement was obtained.

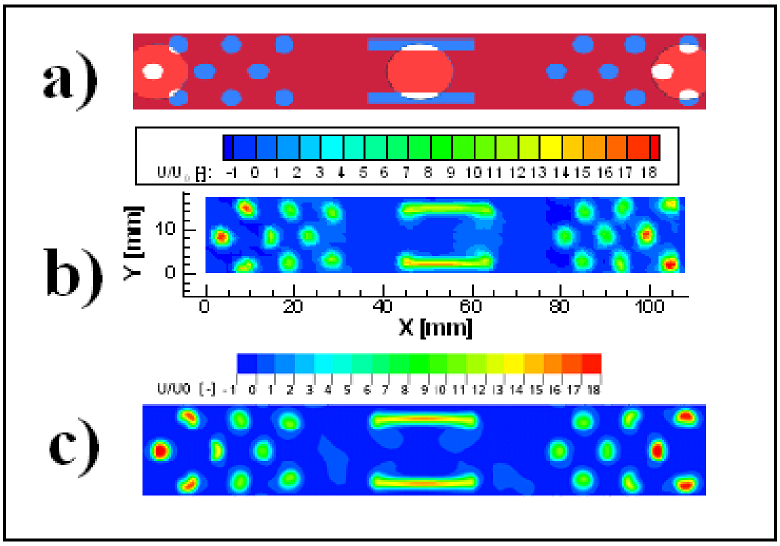

Figure 5. Qualitative comparison between the vertical velocity components 1 mm above the burner perforated plate (a) obtained by LDA measurements (b) and numerical simulation (c)

Figure 6 shows the quantitative comparison between the experimentally investigated two lines of velocity data at the centre of the rows of holes, and the velocity distribution obtained by numerical simulation for the corresponding lines.

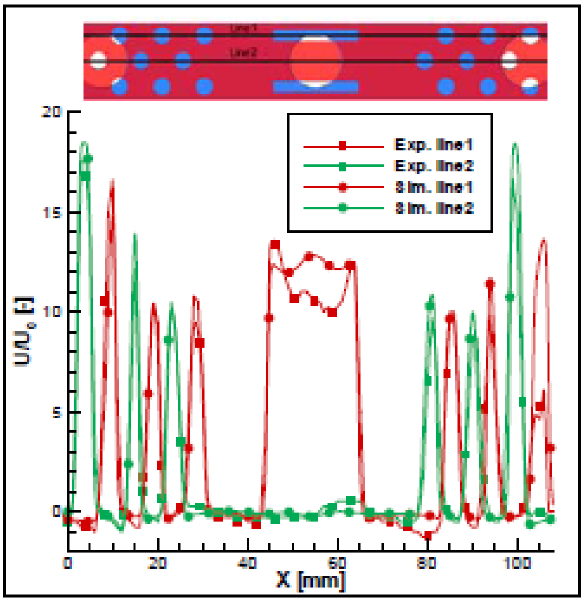

Figure 6. Quantitative comparison between LDA-measurements and numerical simulations of two

The LDA-measurements of the cold flow are in a very good agreement with the numerical calculations, indicating that the shear-stress turbulence model used for the numerical simulations as well as the geometrical resolution was well chosen. One difference can be seen at the axial velocity profile at the slit. This discrepancy can be caused by some minor deviation of the position of the measuring control volume above the burner plate, i.e. most probably the axis of the laser beams and the axis of the slit were not completely parallel. Already small deviations (e. g. 0.5 mm) in the assembly of the experimental setup can cause large differences.

Conclusion

The aim of this study was to validate the existing burner construction, i.e. combination of slits-and-holes pattern and the pressure distribution plate, placed below it, and to provide guidelines for optimization of the slits and holes pattern. The cold flow through a slits-and-holes pattern was characterized by means of velocity measurements using LDA. The obtained results were compared to the numerical simulation of the cold flow, in order to be able to validate the numerical results for future use in the burner pattern optimization.

Quantitative comparison between the obtained axial velocity components showed a very good agreement between measured and numerically simulated velocity profiles. Good agreement was confirmed with the quantitative comparison of results, indicating that the shear-stress turbulence model used for the numerical simulations as well as the geometrical resolution was well chosen.

Acknowledgment

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