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ENERGY TRANSFORMATION IN TURBULENT FLOW INSIDE REVERSING CHAMBER

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Abstract: *This paper presents results of measurements of static pressure distribution and pressure fluctuation on inner surfaces of the reverse chamber. Analyzed geometry is a geometrical model of the combustion chamber occurring, inter alia, in solid fuel boilers. An important aspect of the analysis is identification of reversing phenomena occurring inside the chamber. Due to the analyzed geometry shape, the flowing jet flow changes twice the direction of the jet impingement on the wall. As a result, on the walls of the chamber there is a transformation of medium kinetic energy into potential energy pressure. The test results describing the distribution of pressure on the impinged wall of the reverse chamber and pressure changes and fluctuations for various inflow velocities and various distances between the pipe outlet and the impinged surface have been presented. Characteristics of turbulent flow in chamber were measured with the use of constant temperature anemometer. The purpose of the paper is to indicate differences between different flows: an axisymmetrical free jet outflowing to the stationary surroundings, a jet impinging a stationary flat surface, and a jet flow impinging flat surface in close round chamber, which generates axisymetrical return flow. Efficiency being a part of the conducted analysis of the flow in the combustion chamber, was also used to prepare a mathematical model for numerical analysis. This analysis shows also that there is a need to validate CFD calculations due to limited possibilities of turbulence models to visualize the transformation of energy at the stagnation points.*

Keywords: Impinging jet, Reverse chamber, Combustion chamber, Energy transformation, Turbulent flow.

1. Introduction

Different kinds of free and impinging jets analyses have been described in world literature over years. That is because many authors try to find solutions for problems with flows of this type. One of main problems with these flows occurs when any author tries to use the results obtained for free unstimulated jets to describe other flows of similar type. This kind flow geometry influences on momentum, mass and energy transport inside thermal flow machines. In such situations, despite of the frequently apparent likeness to free jets, we deal with different class of flows, the restricted flows. One of the purposes of this paper is to indicate the differences between the above mentioned flow geometries.

With comparison to the free jet flowing into stationary surroundings, in case of the impinging jet only part of the area should be deemed free. The appearance of the wall changes the flow structure, i.e. restricts the propagation of the free jet. Fig. 1 presents the schematic areas of the impinging jet. The impinging jet's case, however, is considered to be the boundary case of free jets, because it only requires the change of the boundary conditions in the axial direction related to the axial velocity component and the parameter describing the turbulence model, e.g. kinetic energy of turbulence. This opinion shared in particular by researchers involved in the numerical description. Fig. 2 and 3 show profiles of normalized velocity and kinetic energy in impinging jet flow (Bartoszewicz 2009, 2012). The presented results shall be used for comparisons with the results obtained in the reverse chamber.

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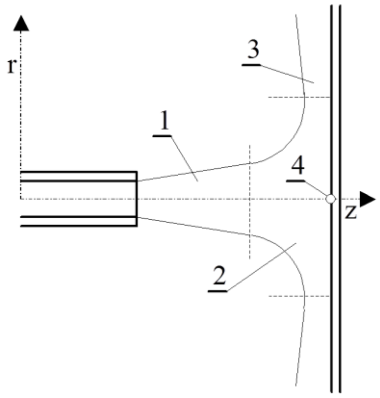

Fig. 1: Schema of impinging jet flow 1 – region of free jet, 2 – region of stagnation, 3 – region of wall jet, 4 – stagnation point.

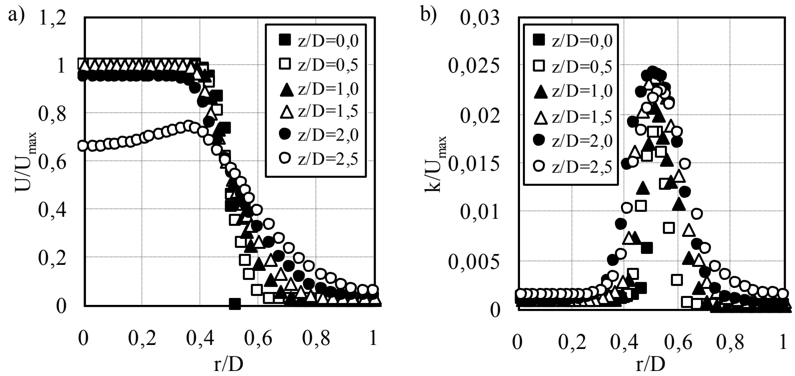

Fig. 2: Radial profiles of normalized velocity (a) and kinetic energy of turbulence in impinging jet (b) (Bartoszewicz 2012) at the distance between pipe outlet and impinging wall 3D.

2. Geometric model and test methods

An object of tests is the axisymmetrical reverse chamber shown in Fig. 3. The main flow direction changes twice in reverse chambers. The jets flowing out of the internal pipe, in its initial run, is of free jet nature, then it impinges the flat surface of the chamber bottom, where the flow direction changes by 90 ^{o} for the first time. Within the inflowing jet's axis, at the so-called stagnation point, the maximum pressure occurs. Such flow can be given as a simplified definition of the impinging jet. Upon change of direction, the wall jet heads towards the radial direction. Before it reaches the flow wall, however, it separates from the impinged wall and thus the second stagnation point is located on the side wall near the reverse chamber corner. The jet again changes its flow direction by 90^{o} angle. From this point, as the counter-flow jet in relation to the basic one, flowing out of the internal pipe, it heads towards the reverse chamber outlet. As the distance from the outlet wall increases, the wall jet may tear apart from the flow wall in the point depending on the jet's kinetic energy. The test chamber reflecting the nature of such flow is built of a steel sharp-edged pipe of the internal diameter D = 0.04 m and of thickness of 0.005 m. The chamber casing was made of plexiglas of the internal diameter R = 0.475 m and length of 0.7 m. The test chamber was mounted on an open aerodynamic tunnel shown in Fig. 4. The air in the tunnel is forced through a fan connected to the tunnel by means of two elastic couplers. A filter reducing particles contaminating the air was installed in the initial section, while the straightening vanes unify the velocity and turbulence fields in the channel. The whole reverse chamber with the internal pipe is positioned with the use of a laser situated behind the impinged surface.

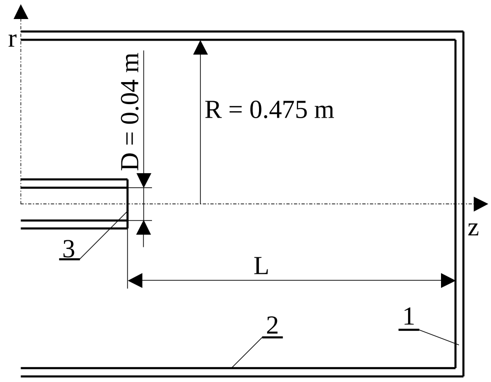

Fig. 3: Schema of reverse chamber: 1 – impinging wall, 2 – side wall, 3 – outlet of pipe.

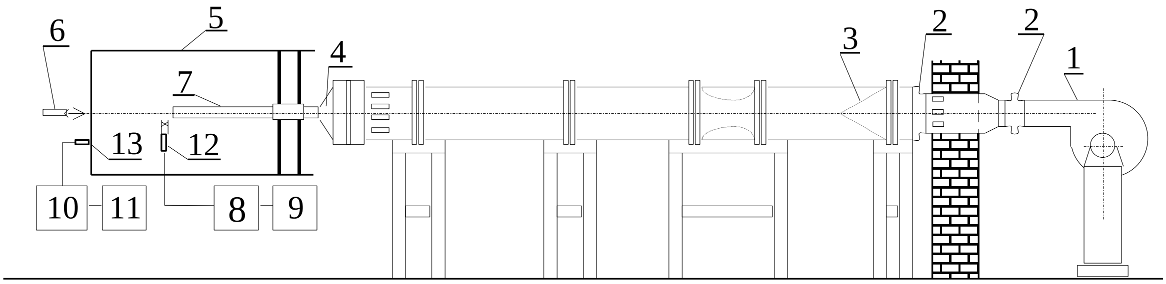

Fig. 4: Schema of measurements: 1 – fan, 2 – elastic coupler, 3 – filter, 4 – nozzle, 5 – reverse chamber, 6 – calibration laser, 7 – steel pipe, 8 – CTA module, 9 – computer, 10 – digitizer of pressure and its fluctuation, 11 – millimeter, 12 – CTA probes, 13 – phone.

Measurement of velocity and its fluctuation was carried out by the CTA anemometer. Standard X probe TSI-1241 was used to measure two components of velocity. Position of the jet axis was indicated by the laser beam. Probes were connected to the TSI-1050 constant temperature anemometer bridge. CTA signal was recorded by IOtech ADC488/8SA A/D converter which was controlled by TurboLab 4.0. Auto trigger option was selected. Subsequently, the recorded signal was processed and analyzed by means of the same program.

3. Numerical analysis

SST turbulence model combines the advantages of both, the standard model of the k-ε and k-ω model. As compared to the equations in the k-ω model, SST turbulence model changes the concept of production of turbulence in the equation for kinetic energy turbulence.

4. Boundary condition

Measurements were made on an axisymmetrical jet, not swirled and unstimulated, flowing out from the sharp-edged round channel of diameter of 0.04 m to the reverse chamber of 0.39 m diameter. The geometrical conditions corresponded to the pipe outlet position in relation to the impinged surface, varying from z/D = 10 to z/D = 0.2. Measurements were made for three velocities at pipe outlet: 10, 30 and 50 m/s, which corresponds to Reynolds numbers: 26000, 78000 and 130000, respectively. Air temperature was maintained at the level of 20 ^{o}C. Measurements of mean values in time: pressure, axial component and their fluctuations were carried out.

5. Results and conclusion

Results of modeling the flow in the reverse chamber were very promising. Possibility to simulate flow brought new information on the turbulence and energy transformation inside the chamber. During simulations, one can presume the established formation of turbulence by velocity fields observation. However, in case of the wall impingement, velocity gradient does not suggest the formation of such a thick layer of vortices. Flow modeling shows the mechanism of vortices formation. Moreover, it enables determining the vortex metrology and analysis construction. Such data are essential to determine the Strouhal number describing the simultaneity of the flow. The simulation results are consistent with transient flow in steady-flow simulations and experiments.

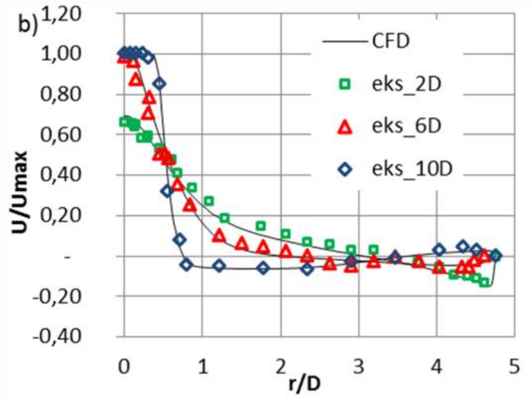

Fig. 5: Comparison of experimental measurements.

a) b)

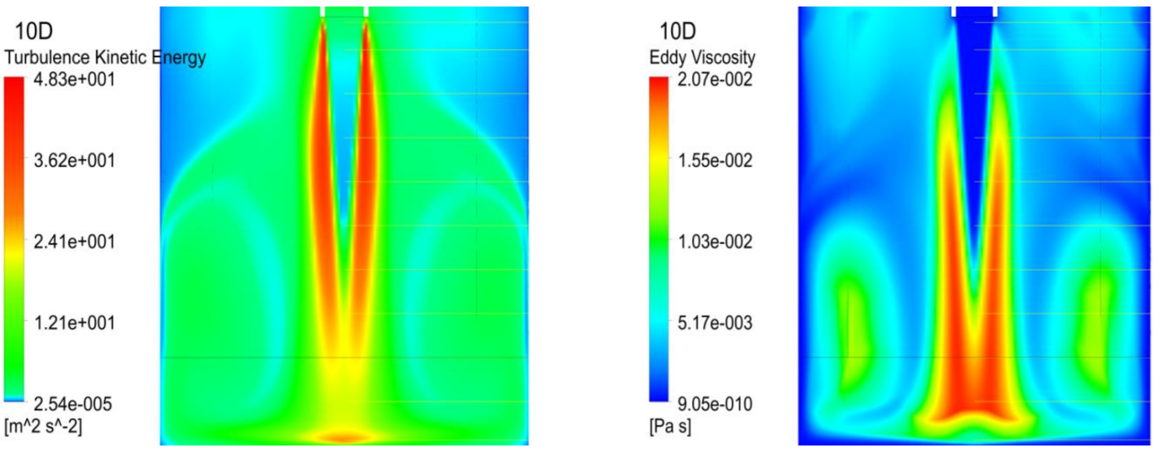

Fig. 6: Results of numerical analysis, a) distribution of turbulence kinetic energy; b) distribution of eddy viscosity.

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