

Investigation of flow kinematics in the structured multibed catalytic cartridge

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Abstract. The reduction of harmful substances emission into the atmosphere is very important to create compact, energy-efficient catalytic units for afterburning volatile organic compounds. A key component of such units is the catalyst cartridge. The efficiency of its operation is provided by the supply of a gas flow with a uniform velocity field. To solve the problem, the gas flow distributor and an aerodynamic stand for its testing were created. A set of air-flow blades was used to align the velocity profile before the catalyst cartridge. Also flow kinematics inside the cartridge was investigated via laser Doppler anemometry method.

1 Introduction

Catalytic afterburning of volatile organic compounds is the most effective way of reduction of harmful substances emissions into the atmosphere. Developing the gas treatment plants is often more expensive than paying environmental fines [1]. The creation of compact, energy-efficient catalytic units for the neutralization of gas emissions from harmful volatile organic compounds are very urgent task. Recently, a highly active afterburning catalyst with extremely low platinum content (0.01-0.02%) [2] have been developed on the basis of fiberglass material[3]. The efficiency of the catalyst depends on the uniformity of the flow at its supply into the cartridge. To develop technical solutions for uniform air supply the gas flow distributor and an aerodynamic measuring stand for its study have been created (Fig. 1). The model consists of the following functional blocks: section of the mixer, the control section and rotary device, the catalyst's section, and the node of the nozzle. Air is supplied to the model through the fan 1 and compressor 2. Then gas flows pass through the flow meters 3 and 4. The temperature in the flow is measured by thermal transducers 5, and the overpressure P is measured by pressure sensors 6. The hydraulic resistance of the flow is measured by the differential pressure value ΔP on a rotary device 10 and on the catalyst's section 11 using the differential pressure transmitters 7. The experimental stand model geometry is shown in Fig. 2. The working fluid was air. The flow rate changed up to 250 n.m³/h. The maximum overpressure was 0.03 MPa. The working temperature took values in the range 23-26 ° C. The Reynolds number was varied in the range 10000 to 50000.

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Two catalytic cartridges with different geometric structures are used in our experiments. In the first case, the cartridge's structure consists of corrugated structuring meshes with 1 mm cell width. The distance between fiberglass layers is 10 mm. In the second case, the cartridge's structure is based on corrugated structuring plates with holes about 1 mm in diameter. The length of both cartridges is 250 mm.

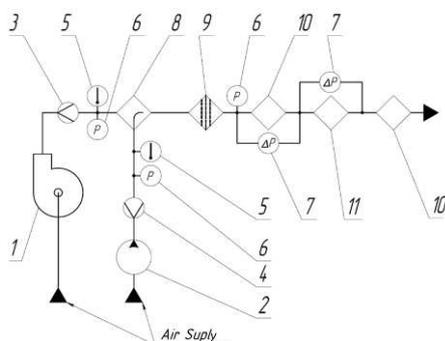


Fig. 1. Structural scheme of the stand for the study of the model of the gas flow distributor.

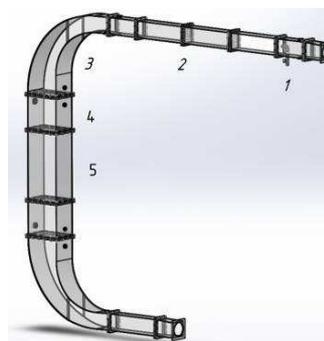


Fig. 2. 3D geometry the gas flow distributor. 1- the nozzle section; 2- the mixer, 3 - rotary device, 4- control section, 5 - catalyst's section.

2 Experimental techniques

Flow visualizations allow obtaining the qualitative information about the flow and its characteristics in a model of the gas flow distributor. The current air flow is visualized using smoke particles. Tracers are added to the gas flow with the use of a smoke generator. The illumination beam is produced by a solid-state Nd: YAG laser (a wavelength 532 nm, pulse energy of 120 mJ) whose beam is spread to a 1 mm thick laser sheet via cylindrical lens. The laser system operating frequency is 15 Hz. A laser sheet passes through the central plane of the flow and illuminates the target area. Image registration is carried out by using CCD camera with a wide-angle Nikon AF 28 mm f/2.8D Nikkor lens. The camera focuses on the target flow area. The exposure of the camera and the laser power are adjusted to obtain accurate brightness and contrast characteristics. Digitized images have an active area of 1280 pixels horizontally by 768 pixels vertically. Images processing is carried out via Matlab software in order to correct the brightness, contrast and sharpness of images. Digital image processing allows detect turbulent structures in the flow.

Measuring the two-dimensional kinematic characteristics of the flow requires a modern non-contact optical method for aerodynamic flow diagnostics like laser Doppler anemometry (LDA). The LAD-05 meter based on LDA method is designed and manufactured at the Institute of Thermophysics SB RAS. The meter allows measuring two projections of the velocity vector in the range 0.001...400 m/s with relative error not exceeding 0.1 %. The size of the measuring zone is 0.1x0.1x0.5 mm. The positioning device allows moving the measuring unit in the area of 250 x 250 x 250 mm with an accuracy of 0.1 mm.

3 Results and discussion

The results of visualization were obtained in two sections of the gas flow distributor in a rotary section and in a control section (Fig. 3). The visualization shows a turbulent flow regime with the large-scale vortex structures. Figure 3b illustrates the formation of

recirculation zones with boundary-layer separation. Such reverse flow zones are caused by the non-stationary Karman vortex streets.

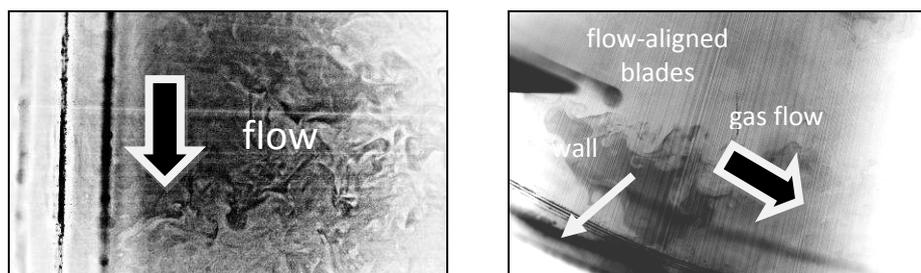


Fig. 3. Photos of flow visualization: control section (left), rotary section (right).

The Reynolds number is based on the average velocity, a characteristic length in a 0,25 m - diameter of pipe and the kinematic viscosity and it is equal to 50 000. The turbulence intensity $I = \Delta U / U$ is 23%. It is obtained with laser dopler anemometer measurements. The characteristic vortex sizes are calculated via flow visualization technique.

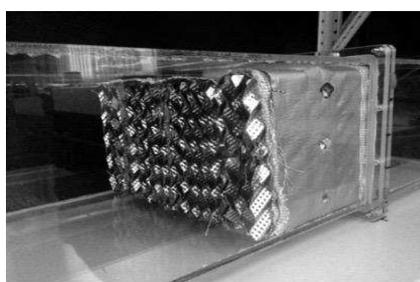


Fig. 4. Photo of catalytic cartridge with corrugated structuring plates.

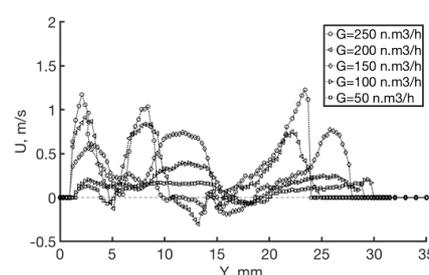


Fig. 5a. Cartridge with corrugated structuring plates.

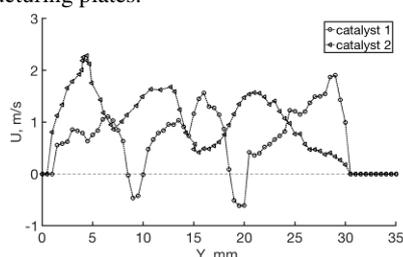


Fig. 5b. Velocity profiles inside the catalyst cartridge with structuring plates (1) and structuring meshes (2).

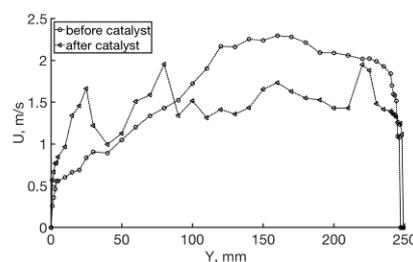


Fig. 5c. Velocity profiles before and after the catalyst cartridge at 250 n.m3/h of mass flow rate. Blade position 1.

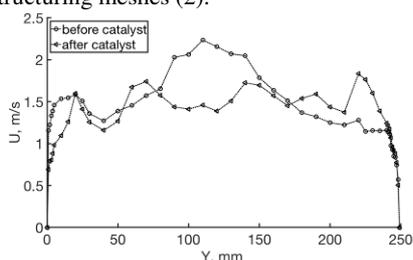


Fig. 5d. Velocity profiles before and after the catalyst cartridge at 250 n.m3/h of mass flow rate. Blade position 2.

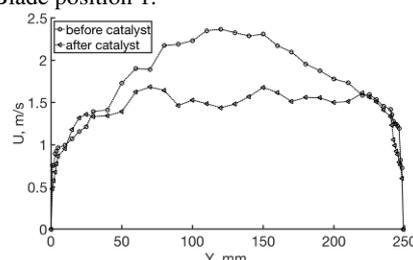


Fig. 5e. Velocity profiles before and after the catalyst cartridge at 250 n.m3/h of mass flow rate. Blade position 3.

The captured images are processed on personal computer. The contrast and brightness normalization are used. The inversed images are presented for better understanding of vortex flow structure. The obtained vortexes size is about 5-9 mm. The large-scale vortex structures formation affects the mass transfer process and the catalytic cartridge efficiency.

For understanding flow kinematics in catalyst, initial experiment is made without any blades. Velocity measurements were carried out in the cross section of catalytic cartridge (Fig. 4) at a distance of 45 mm from the edge of the closest to observation wall at different mass flow rates (50-250 n.m³/h). The results showed (fig. 5a) velocity profiles, which manifests itself mainly in three sections with an average velocity, varying in the range of 0.1-1.2 m/s depending on the change in mass flow. There are intense reverse currents. At a distance of 35 mm from the inner wall the zero velocity zones appear.

Additional velocity measurements inside the catalyst cartridge with structuring meshes are made at the maximum mass flow rate of 250 n.m³/h. A graph of the velocity profiles of two catalytic devices with the maximum air flow is presented in Fig. 5b. In the catalyst cartridge with grid guides, no reverse current zones are observed the same as in a cartridge with a frame made of profiled plates. Nevertheless, zones of a sharp decrease in the speed are also observed. Also velocity profiles before and after the cartridge were compared for the different positions of flow-aligned blades (Fig. 5c,5d,5e). Such blades are made on a 3D printer from PLA plastic. The choice of blades form and dimensions is based on the rotary device geometry. The location of the profiles is selected and corrected experimentally. The wing-shaped profiles are installed in the rotary device. The comparison has shown that blade position 3 is the most sufficient location for incoming flow correction.

3 Conclusion

The results of the measurements showed that the distribution of the velocity fields inside the cartridge is non-uniform, although a stream with an equalized velocity profile runs in the cartridge. The presence of a non-uniform velocity profile intensifies mass-transfer inside the catalyst cartridge, especially in a cartridge with the frame of structured plates, where reverse currents are formed. Also velocity profiles before and after the cartridge were compared for the different positions of flow-aligned blades (fig 5c,5d,5e). The comparison has shown that blade position 3 is the most sufficient location to align incoming flow.

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