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Experimental research on the dynamics of airflow parameters in a six-channel cyclone-separator

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The dynamics of airflow parameters were researched in a six-channel cyclone (separator with a tangential flow). The dependencies of dynamic pressures in cyclone's channels and of cleaning efficiency on an airflow inlet velocity were analyzed. Standard and upgraded semi-rings were used in the cyclone's internal structure. Changes in cleaning efficiency at different inlet concentrations of glass and technical salt particles were analyzed. Research results were obtained at inflow velocities of 10.9 m/s to 21.9 m/s. The highest cleaning efficiency was 97.3%.

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1. Introduction

Cyclone-separators are unrivaled leaders among devices used to remove particulate matters (PMs) from a dirty airflow. In terms of their price, simplicity and operation, cyclone devices have been unparalleled. Cyclones will stay competitive in the market for a long time due to their unique structure, absence of any moving parts and filtering surfaces that require regular service, comparatively low aerodynamic resistance and high efficiency [2,4,14,25].

Air cleaning devices of the cyclone type are most often used in industries which are characterized by high volumes of polluted air emissions. Most devices are suitable for the separation of PM of large-scale dispersion in multi-phase flows. The work of the common hollow filter is based on the widespread principle of separation of PM with the appearance of centrifugal forces that are influenced by the turbulent airflow inside the body of the equipment. The effectiveness of the mentioned cyclone-separator is from 75 to 85%; the air is cleaned from the PMs that are more than 20 μm in diameter. The structure of the upgraded six-channel cyclone is designed for the separation of dispersed fine PM, up to 10 μm in size [1,9,10,24].

Although cyclone-separators operate under the influence of centrifugal and gravitational forces, their cleaning efficiency depends on the characteristics of inlet airflow [11]. When airflow parameters – velocity and pressure – change, aerodynamic forces in the cyclone's system also change. The aim of this research is to evaluate changes in airflow pressure and cleaning efficiency at different airflow inlet velocities in a six-channel cyclone.

The cyclone's basic structure has remained unchanged for more than a hundred years. There are two main types of cyclone structures: a direct cyclone and a reverse-flow cyclone [21,22]. However, the most frequently used are reverse-flow cyclones, which are also divided into axial flow and rotational flow cyclones with a tangential gas inlet [3,4,10,15].

Patterson and Munz [18] studied the effect of PM concentration (of up to 235.2 g/m), fluid temperature (from 300 K to 2000 K) and gas inlet velocity (from 3 m/s to 42 m/s) on cyclone's collection efficiency and determined that an increase in PM concentration had improved the efficiency of collection, in particular at a high temperature [8,23].

Turbulent mixing of the flow may be associated by a free flow of gas kinetic theory. By this case the velocity of air molecules distributed by the normal law. According to this law, in the distribution of velocities in the gaps between the curved half-rings is defined by dependence [10]:

$$\sigma = \frac{2\rho a \vartheta_{\phi}^{2}}{\delta_{r}^{3}} = \frac{2\rho a k^{2}}{\delta^{2} r^{2}} \tag{1}$$

where: σ — standard deviation of velocity variation, $\sigma = \frac{6k\rho a\vartheta^2}{\delta^3 r^2}$, ϑ — velocity of airflow, m/s, ρ — air density, kg/m^3, a — distance between the aspects of half-rings, m, δ — diameter of air molecules, m, r — channel of cyclone radius, also $f(\nu) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{\vartheta^2}{2\sigma^2}\right)$.

Cyclone-separators are used as drying machines, reactors and catalysts [5,12,19]. Although recent patented cyclones differ by

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their originality, they still retain the main distinguishing feature of these devices — a turbulent flow [7,20]. Highly efficient cyclones and filters are used to reduce dustiness in industry [17]. Cyclone's two most important working parameters, collection efficiency and pressure drop, largely depend on the concentration of dispersed PM [6,23].

The work of channel cyclone-separator is based on centrifugal forces and additionally occurring filtration process. Due to the interaction between inlet flow from the (peripheral) channel coming next and the flow following the direction towards the axis of the cyclone along the channel (transit), additional filtration takes place. Air flow is filtered through the peripheral flow — a curtain appearing behind the separation zone of curved half-rings (quarter-rings), which raises cleaning efficiency up to 15%.

The aim of this work is to determine six-channel cyclone's airflow parameters and analyze air cleaning efficiency at different dispersities of PM.

2. Materials and methods

Experiments were carried out on an upgraded six-channel cyclone located at the Environmental Technologies Laboratory of Vilnius Gediminas Technical University (VGTU). A schematic diagram of the cyclone's basic design is presented in Fig. 1. The cyclone's air cleaning efficiency was determined by introducing into it ground PM of glass and technical salt of up to 50 μm and 20 μm. The standard dynamic pressure ($1/2\rho V^2$) of the airflow was measured in the respective channels of the cyclone's structure using a Pitot (Prandtl) dynamic tube connected to a multifunctional measurement instrument Testo-400. Measurements were made at the following characteristic points (Fig. 1) of the separation chamber inside the structure: at the beginning, in the middle and at the end of the channel, and also at the intermediate points (between the beginning and the middle, and between the middle and the end of the channel). The dynamic tube was inserted at the points directly through special holes made in the separation chamber cover plate. The pressure setting for the reliability of results was performed over all cross-sections of each cyclone-separator channel, by making a 9-point network (on the periphery boundary layer, in the middle of each channel cross-section, and on the inner wall of the channel).

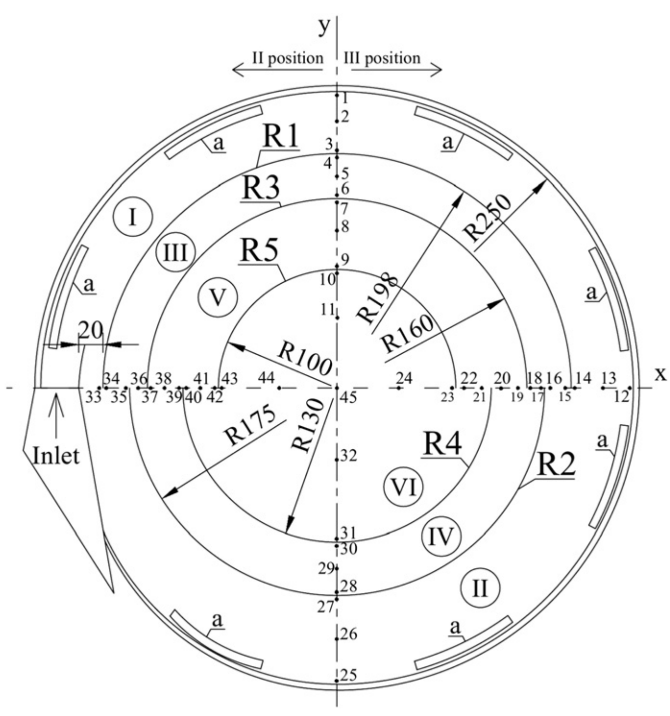

Fig. 1. Cyclone cross-section with semi-ring at position I: I–VI — cyclone channels; R1–R5 — semi-rings; 1–45 — dynamic pressure measurement points; a — segment circular spacings.

Dynamic pressures were measured by using standard curvilinear semi-rings and upgraded semi-rings with windows. All pressures were measured by changing the airflow yield supplied by the channel ventilator. The supplied airflow was changed with a lever of the ventilator's control unit. The aim of this regulation was to achieve the optimum pressure for the cyclone's highest cleaning efficiency.

Fig. 1 shows the cyclone's internal structure and the location of semi-rings. The positions of semi-rings (only R1, R3, R5) are regulated as follows: the rings are shifted by 10 mm to the left in position II and by 10 mm to the right in position III, but other semi-rings remain in the same places. Regulation was made only in the x-axis direction.

In order to determine the best application of the air cleaning device concerned in a particular industry, PMs of different density, bulkiness and dispersity were selected. The physical density of glass (SiO_2) PM was 2670 kg/m^3 and that of technical salt (NaCl) was 2210 kg/m^3.

For determining the cyclone's efficiency a high-pressure compressor producing an air pressure of up to 6 bars was used during experiments. The compressor was connected to a feeding nozzle which sucks in and delivers dust PM directly to the cyclone's air inlet, 200 mm in diameter, thus forming a dispersed two-phase flow. An airflow supply ventilator (RUCK RS200L, power 190 W) was installed in front of the six-channel cyclone and connected to an air duct, 2 m long. Pressure changes in the system were registered with a differential pressure meter (PCE Instruments DSM-1). A possible error for stream unevenness that might occur due to a non-uniform distribution of PM within the entire stream of the inlet air was eliminated. Glass vessels for specimens, scales for weighing specimens (error $\pm$ 0.1 g), and a second meter *Sekonda* for registering air inlet time (error $\pm$ 0.2 s) were used during tests.

Experimental research on the cleaning efficiency of the six-channel cyclone was carried out according to the Methodology "LAND 28-98/M-08 Determination of the concentration of dust (PM). Weighted method." [13]. Before being tested, the specimens of glass and technical salt PM were dried up to a constant weight in a laboratory electric stove at a temperature of 100 °C. PMs were ground with the grinder Retsch RM200. Only PMs of up to 20 and up to 50 μm fraction were used for the experiments. Studies using these PM sizes allow us to investigate the multi-cyclone cleaning efficiency of fine PM and compared with conventional centrifugal cyclone efficiency. The remaining portion was sieved once again. During experiments the ambient air temperature varied from 20.1 °C to 22.2 °C, while relative humidity reached 52%.

A two-phase airflow tangentially enters the first channel through the inlet (1) in the separation chamber. The channel is delimited by a peripheral wall and the first curvilinear semi-ring. The airflow is thus distributed within channels of different curvature and is filtered through spacings between semi-rings. PMs are precipitated on the bottom of the six-channel cyclone by a turbulent flow created by centrifugal forces. On entering segment circular spacings (9) they fall down and accumulate in the cyclone's hopper (10). After passing through all six channels clean air leaves the system through the airflow outlet (8). Dusty air is filtered in the active zone of channel spacings. Filtration also takes place during the interaction of PM when they coagulate and separate from the airflow (Fig. 1, Fig. 2).

Experiments were carried out by using the standard (without a window) and upgraded (with a window) structure of curvilinear semi-rings. In the case of upgraded structure a polluted airflow can be returned to the previous channels. Thus, this structural solution has extended the time of filtration of a dirty airflow in cyclone's channels. The experimental research on dynamic pressures analyzes cases involving the first three external semi-rings with cut windows of 10 mm curved width. Tests on air cleaning efficiency were carried out by using upgraded semi-rings: only the first (R1) upgraded semi-ring; the first two (R1 and R2) upgraded semi-rings, and the first three (R1, R2 and R3) upgraded semi-rings (Fig. 2).

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