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RESEARCH ON PARAMETERS CHANGES OF THE TWO-LEVEL MULTICHANNEL CYCLONE

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Abstract

The conducted research has proved the dependence of gas flow rate in the separate channels of the two-level multichannel cyclone at a different inflow velocity and the number of channels. The carried out investigation demonstrates the dependence of changes in velocity in the channels under varying relations between peripheral and transitional flows. The work of a cyclone of the channel is based on centrifugal forces and an additionally occurring filtration process caused by the interaction between the flow coming from the later channel (peripheral) and the other floating towards the axis of the cyclone (transitional). The structure of the two-level cyclone allows reaching higher gas (air) flow efficiency performing similar measurements of the applied equipment. New cyclones are designed upon the establishment of the tangential airflow and using the aerodynamic characteristics of the cyclones that have better efficiency than the ordinary ones. The aim of this research is to investigate changes in airflow rate at different levels of the cylindrical casing and their channels by regulating the half-rings of the multichannel cyclone, and changing relations of peripheral and transitional flows that get into the channels when the speed of the inflow/capacity of the cyclone varies. The maximum aerodynamic resistance is 1562 Pa when flow distribution ratio is 50/50 and inflow velocity is 15.3 m/s. According to the obtained experimental data, the effectiveness of cleaning the air flow polluted with the solid particles of more than 20 microns in diameter is up to 93% when the concentration of such particles in the airflow before cleaning is 5.9 g/m^3.

Key words: channel, concentration, cyclone, efficiency, solid particle

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1. Introduction

A possible solution to cleaning gas flows contaminated with particulate matter (PM) produced in industry remains one of the most important issues of atmosphere protection. Due to pollution, air quality decreases and working conditions become unfavourable for employees and equipment performance. When particulate matter enters the human body, it can cause eye, skin and breathing injuries, blood vessel and heart diseases and have a carcinogenic effect (Vasile et al., 2012).

Progress in various branches of industry is related to environmental protection objectives the main one of which is cleaning the polluted air. Electrostatic and sleeve filters most commonly applied in world practice are highly effective equipment employed for purifying air from particulate matter. However, they are expensive and their exploitation is rather difficult (Blumberga et al., 2012).

Cyclones are widely used among other types of air cleaning equipment to clean the polluted airflow from particulate matter. They are incomparable in terms of the price and simplicity of construction and exploitation. Due to their specific construction that does not contain any movable parts or filtering surfaces that would require constant maintenance, comparatively small aerodynamic resistance and high effectiveness, cyclones are likely to remain competitive in the modern market of air cleaning equipment for a long time. Cyclones are

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used for various purposes, but most usually for separating a dense phase of PM with multiphase flow. The intake into the cyclone through inlet parts of various forms can be axial or tangential (Avci and Karagoz, 2003; Ingham and Ma, 2002). Tangential inflow is widely applied for particle separation from gas flow (Altmeyer et al., 2004; Mothes and Loffler 1988).

The work of the common hollow filter is based on the widespread principle of separating particulate matter with the appearance of centrifugal forces influenced by the turbulent airflow inside the equipment shell. The effectiveness of the above mentioned cyclone makes from 75 to 85%, and air is cleaned from particulate matter that is more than 20 microns in diameter. According to the objectives of EU Directive 2008/50/EC on ambient air quality and cleaner air for Europe, this is not sufficient (Gimbun et al., 2005; Jurca et al., 2014; Kovacs et al., 2014; Luca and Ioan, 2012; Raoufi et al., 2008; Sandu et al., 2012; Tucaliuc et al. 2014).

The objective of this research is to investigate the performance of new generation air cleaning equipment – multichannel cyclones that can remove very small particulate matter of up to 2 microns from airflows and reach the general air cleaning effectiveness of 90%. A multichannel cyclone is a possible alternative to electrostatic and contact filters. The application of the multichannel cyclone for air cleaning is possible in the atmosphere with increased temperature and humidity. The work of the multichannel cyclone is based on centrifugal forces and occurring additional filtration process. Additional filtration is caused by the interaction between the flow coming from the later channel (peripheral) and other floating towards the axis of the cyclone (transitional). When air flow is filtrated through the peripheral flow, a curtain is formed behind the curvilinear half-ring separation zone, which results in an increase in cleaning efficiency. The two-phase flow gets into the cyclone and the dense phase of the mixture (PM) influenced by centrifugal forces starts moving relatively towards the radial direction and is separated from the main flow. This is a difficult task, because many parameters, including the dimensional one, have influence on them (Kenny and Gussman 1995; Pushnov and Berengarten, 2011). The construction of the two-level cyclone allows reaching greater gas (air) flow efficiency with the same measurements of the employed equipment. Thus, space needed for the work of the equipment and expenses for production and exploitation are saved (Vaitiekūnas and Jakštonienė 2010; Zhao et al., 2006; Zhoue and Soo 1990).

Analyzing airflow dynamics and velocity distribution in the channels of the multichannel cyclone as well as their dependence on the parameters of the inner structure and estimated resistance allows making judgments on the turbulence of the flow, flow movement in the cross-sections of the channel and intra-ring zones.

One issue of evaluating cyclone effectiveness is the influence of parameters on flow dynamics. Generally, the flow is turbulent in large cyclones, and the supposed friction factors and results are significant. However, this is not true for small cyclones where flow and exploitation conditions, i.e. velocity, temperature, pressure or the diameter of the cyclone, are likely to be more important because the flow can be laminar, turbulent or transitional (Blachman and Lippman, 1974; Meier and Mori 1999; Salzman and Hochstrasser, 1983). The turbulent flow could be laminar at the cyclone inlet. Exploitation parameters have a bigger influence on cyclone effectiveness in the laminar flow than in the turbulent one. As for small cyclones, it is very difficult to forecast the influence of the flow mode on effectiveness and pressure loss in comparison to the influence of geometric parameters (Baltrenas et al., 2012; Kaya and Karagoz, 2008; Stairmand 1951).

It is difficult to comprehend the meaning that could improve exploitation in the two-phase flow process of the cyclone, because, regardless of the supposed simplicity, flow dynamics is rather complex, including flow movement and ring zones of the back flow. In the regions of the closed turbulent flow, field characteristics of many flows have not been distinguished yet. The issue related to mathematic modelling of the detailed flow structure includes closely related partial nonlinear differential equation solution of mass and impulse conservation and does not have an analytical solution (Baltrenas and Zagorskis, 2010). Moreover, the evaluation of turbulence is based on an isotropic assumption and cannot be applied in the cases of quickly turning flows (Boysan et al., 1982; Bernardo et al., 2006; Gujun et al., 2008). A similar opinion has been stated in researches conducted by other authors (Hoffmann and Stein, 2002).

The aim of the described research is to apply the regulation of half-rings in the multichannel cyclone and changes in the ratios of peripheral and transitional flows getting into the channels of the device as well as to investigate changes in airflow velocity at different levels of the cylindrical casing and their channels when the velocity of inflow/efficiency of the cyclone varies. Changes in the arrangement of half-rings allow adapting the same cyclone for cleaning the airflow of different nature (density) polluted by particulate matter. Our study refers to curvilinear half-rings that increase the effect of filtration and distribution of flows in channels. Also, the article deals with the effectiveness of the cyclone in cleaning gas from small dispersive particulate matter under changes in the above mentioned parameters of inner construction and flow dynamics.

2. Case studies

An experimental stand of a new-generation cleaning device has been made at the Institute of Environmental Protection of Vilnius Gediminas

Technical University (VGTU). The principal scheme for the inner structure of the multichannel (six-channel) cyclone is provided in Fig. 1.

The two-phase airflow tangentially enters through the entrance hole and reaches the first channel of the cyclone limited by the peripheral wall and the first curvilinear half-ring. The two-phase air flow tangentially flows though the inlet and enters the first channel of the cyclone restrained by the peripheral wall and the first curvilinear half-ring. The flow moving from the previous channel encounters the half-ring wall and is distributed into two flows: peripheral and transitional. A part of the peripheral flow moves into repeated filtration in the cyclone, whereas, the transitional flow – into the following channel towards the axis of the device and the outlet of the cyclone. This way, the airflow is distributed evenly in the channels with different curves and is filtered through the spaces between half-rings.

The turbulent flow influences the activity of centrifugal forces, and an additional filtration effect occurs in the flow distribution zone. The overall effect of forces influences the precipitation of particulate matter on the bottom of the six-channel cyclone. The cleaned air that has gone through all six channels of the cyclone flows out of the system through the outlet. Dusty air is filtrated in the active zone of channel space and as a result of particulate matter interaction under coagulation.

Research on changes in air flow parameters of the two-level multichannel cyclone have been conducted concerning the one-phase air flow. The cleaning effectiveness of the multichannel cyclone has been determined by letting in appropriately processed granite particulate matter of up to 20 μm. The dynamic pressure of air flow has been measured using a dynamic Pitot-Prandtl tube connected to multi-functional measuring instrument Testo-400 in the corresponding inner channels of the cyclone structure (Fig. 1).

The carried out research has proved the dependence of air flow velocity in the separate channels of the two-level multichannel cyclone on different inflow velocities in the constructed six-channel curvilinear half-ring system. A change in airflow velocity at different levels of the cyclone has been investigated when the inflow velocity/efficiency of cyclone changes using half-rings (Fig. 2).

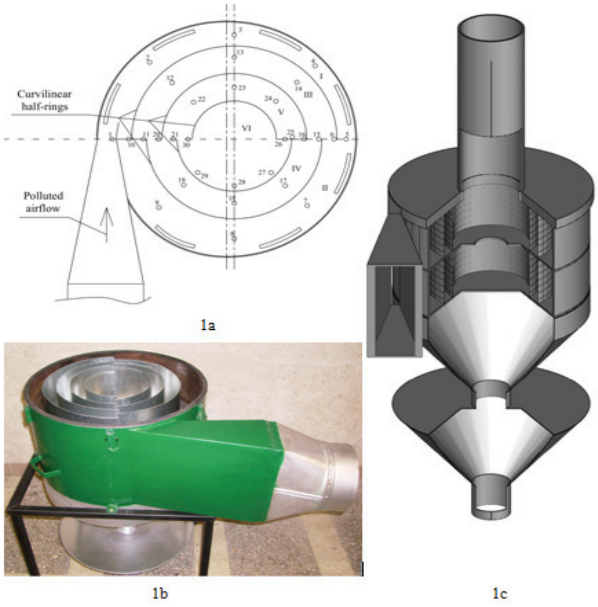
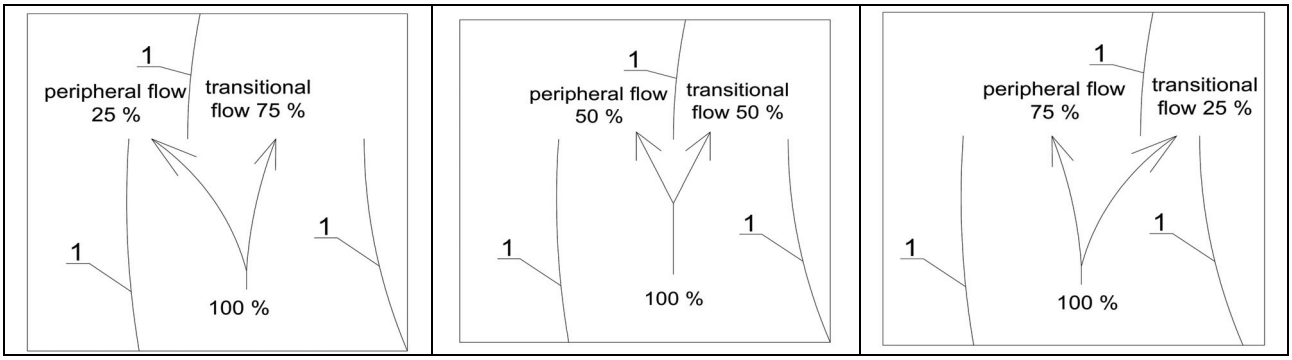


Fig. 1. Principal scheme for the inner construction of the multichannel cyclone (a), pilot cyclone (b) and 3D view (c): 1 – 30 – measurement points; I–VI – cyclone channels



a **b** **c**

Fig. 2. Ratio schemes for flow distribution (a – case of 25/75, b – case of 50/50, c – case of 75/25) in the two-level cyclone: 1 – curvilinear half-ring

The dependence of changes in velocity in the channels, when the ratios between peripheral and transitional flows vary, has been researched. The cases when the two-level six-channel cyclone is constructed have been analyzed. There are three positions of curvilinear half-rings: 50/50 – peripheral (returning) and transitional (moving into the following channel) flows are equal; 25/75 – the peripheral flow is made of 25% of the overall inflow and transitional - of 75%; analogically, in the case 75/25, the peripheral flow is made of 75% and transitional – of 25%. In the case when the peripheral flow is larger, additional filtration of the flow returning to the previous channel is done (Fig. 2).

Researches have been carried out and the dependence of air cleaning effectiveness on the parameters of the polluted flow (concentration and size of particles) and the different geometry of the channels of the cyclone choosing the optimal parameters of flow dynamics (velocity and machinery resistance) has been received.

In order to determine velocities directly measuring dynamic pressures, the Pitot-Prandtl tube was connected to measuring instrument Testo-400 with rubber tubes the internal diameter of which is 6 mm, and the external one is 8 mm (range of temperature measurements is 20–70 °C, deviation is ± 0.2 °C, range of velocity measurements is 1–30 m/s and deviation is ±0.05 m/s).

The gaps made in the chamber lid of cyclonic separation provide the opportunity to put a dynamic pressure measuring tube in the most significant places: the cyclone separation chamber is distributed into six zones made from 45° segments, and the points are selected in the border lines of these sectors. In every channel, five points have been analogically chosen: at the beginning of the channel (0°) and at the angles of 45°, 90°, 135° and 180° distributed in the cross-sections of the channel. In order to ensure measuring preciseness in the marked points (30 units) presented in Fig. 1, the averages of pressure values have been calculated according to the conducted measurements at different heights of the points (2 cm above the bottom of the separation chamber, in the middle of channel height and 2 cm below the lid of the separation chamber) in the channels of the cyclone at both levels.

The aerodynamic resistance of cyclones reveals what pressure is lost when air flow moves through the curvilinear half-ring system arranged in the device. Aerodynamic resistance has been measured using differential pressure measurer DSM-1 (range of measurements is 0–20 000 kPa; deviation ± 5Pa). Measurement devices and branch pipes installed in air flow inlet and outlet ducts were connected with rubber tubes. This way, the indication of differential pressure measurement has been registered.

In order to analyze tendencies for changes in the parameters of the two-level multichannel cyclone, different inflow velocities have been chosen for research purposes, the average velocity of which in the channels equals to 8 m/s, 12 m/s and 16 m/s.

Researches on dynamic pressure and aerodynamic resistance have been made regulating spaces between curvilinear half-rings: three positions have been determined (25/75, 50/50 and 75/25). This regulation method has been applied in order to determine the most suitable distribution of the half-ring, to reach the optimal aerodynamic features of the device and air cleaning effectiveness.

3. Results and discussion

The analysis of the distribution of air flow velocities in the structure of the multichannel cyclone is one of the main tasks that should be solved aiming to optimize the effective work of the device by cleaning the flow from the particulate matter of small dispersion. Research on variations in velocity has been conducted changing the inner structure of the multichannel two-level cyclone by adjusting the position of the curvilinear half-ring and changing the ratio of flow distribution in the channels.

The results of the conducted research are grouped in order to stress changes in velocities at every level of the cyclone with different inflow into cyclone velocities. Under the inflow velocity of 15.7 m/s, the highest velocities have been recorded in the case of flow distribution 50/50. The maximum velocity value is reached at the second level of the cyclone and is equal to 17.2 m/s, whereas velocity at the first level is by 16.3% lower, and its value is equal to 14.4 m/s. In all analyzed cases, first level velocities are lower than those at the second level due to a rise in the flow along the cyclone axis in the vertical direction (Fig. 1).

When the axial flow reaches the height of the second level, a part of the flow leaves through the outlet leaving the system of the device. However, a part of the flow remains due to resistance along the flow outlet. With the help of active centrifugal forces, peripheral flows distribute the flow from the 1st level into all channels at the 2nd level. After a change in flow distribution ratio, velocities decrease, in case of 25/75 by 1.2% (when the inflow into the 1st level is 15 m/s and that into 2nd - 15.7 m/s), and in case of flow distribution ratio 75/25 – by 3.5%. According to the received results, the assumption could be made that when a part of the peripheral flow is larger, i.e. 75/25, the resistance of the system increases, which disturbs the flow and partially slows it.

When the peripheral flow is the lowest and makes 25/75, velocities are no higher than with even distribution 50/50; due to an increase in cross-sections along the way of the transitional flow, flow pressure decreases along with velocity.

A line of a change in velocity in the cyclone at the 1st level is almost horizontal, which shows a relatively small impact on a change in velocities by changing the parameter of flow distribution ratio.

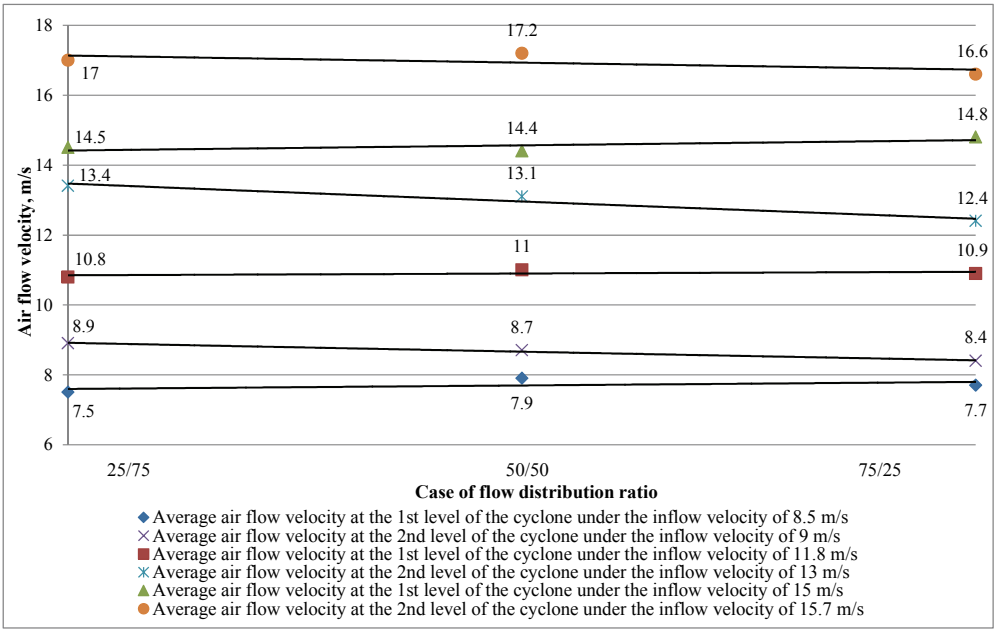


Fig. 3. The dependence of air flow velocity at two levels of the cyclone on the case of flow distribution ratio under different inflow velocities into the cyclone

However, it is important to mention that the maximum velocity has been noticed in the case when a part of the peripheral flow was the largest (75/25). It is assumed that, due to high velocity (more than 15 m/s) and caused turbulence, the flow with a particular half-ring position only partially is distributed according to determined peripheral and transitional flow ratios. Thus, a fairly small 2.7% difference between maximum and minimum values is obtained. The ratio between velocities at two levels in the multichannel cyclone is 1.16 times, which reveals that the flow at the second level is supplemented by 16% from the first level, which is distributed while leaving through space between levels.

When inflow velocity into the cyclone is average (11.5 – 13 m/s), a tendency for changes in velocity differs. First, the maximum velocity occurs in the case when a smaller part of the peripheral flow has been determined (25/75) and when the value of the cyclone at the 2nd level is 13.4 m/s. Such a velocity is by 22.1% lower than the maximum value, whereas the average velocity in the channels has changed by 21.3% (from 15 m/s to 11.8 m/s). Thus, a conclusion that the flow is not that intensive and no significant restrictions are formed due a decrease in the cross-section of the peripheral flow or vice versa as regards an increase in the transitional flow could be made.

A change in velocities at the second level is more intensive by increasing a part of the peripheral flow, than in the case where inflow velocity into the cyclone is 15 m/s. When distribution is even (50/50), velocities are not that significantly lower when in the case of 25/75; however, when the position of the curvilinear half-ring has been determined by forming the largest peripheral flow, velocity, in comparison to the previous case, decreases by 7.5% or 1 m/s of the absolute value. This indicates that when velocities are lower and when a part of the peripheral flow is bigger than the transitional flow, velocities decrease. It is possible to assume that when inflow velocities range within the interval of 11–12 m/s, a low turbulence flow is formed and returns to the previous channel due to the determined position of the half-ring, which increases the resistance of the system. The distribution of velocities at the first level have the opposite dependence, but the values of velocity are very similar; the difference between maximum and minimum values is under 2%; thus, it is possible to state that, at the first level, the half-ring position, when changing flow distribution, does not have a significant influence on changes in velocity.

The velocity ratio between cyclone levels is more significant than that in the case of the inflow velocity of 15 m/s into the cyclone and is equal to 1.19 times. Thus, it is possible to state that when inflow velocity decreases along with the one in channels, the difference between velocities from cyclone levels increases and the flow at the second level is filled by a bigger part of the flow leaving from the first level.

The pressure parameter of air flow is one of the main characteristics causing energy input and revealing the resistance of the multichannel two–level cyclone system to moving air flow. In order to reduce energy loss and to achieve appropriate conditions for a high rate of effectiveness cleaning the multichannel cyclone, it is necessary to research the distribution of air flow pressure in order to determine an optimal structure of the inner device.

Following the analysis of the aerodynamic resistance of the six-channel cyclone, it has been

noticed that the maximum resistance value of all analyzed cases occurs when maximum inflow velocity into the cyclone is 15.3 m/s and flow distribution ratio is 75/25. In this case, the obtained aerodynamic resistance is 1562 Pa, which is by 10.4% higher than in the following case when flow distribution ratio is 50/50. Minimum resistance occurs with minimum velocities (inflow velocity into the cyclone is 8.8m/s) in the case of 25/75. The maximum value of aerodynamic resistance is equal to 467 Pa (inflow velocity is 8.8 m/s in the case of 25/75).

When the average of the chosen air flow velocities is minimum 8.8 m/s, maximum aerodynamic resistance occurs under the flow distribution ratio of 75/25; then, the biggest part of the flow returns to the previous channels and is equal to 660 Pa. It is possible to assume that, in the case of flow distribution ratio 25/75, a low turbulence flow is formed and moves through the channels with the slightest energy loss. In the case the peripheral flow is increased up to 50%, flow unevenness occurs, and the necessity to flow around the curvilinear half–ring causes additional complications for air flow, which results in a 10% increase in resistance value (Fig. 4).

When flow distribution ratio is even (50/50), a part of the returning flow is smaller than that in the case of 75/25, and the determined resistance is by 8.8% lower and equal to 602 Pa. Minimum resistance has been registered when a part of the transitional flow is bigger (case 25/75). The obtained resistance of 467 Pa is by 29.2% lower than the one having maximum resistance when inflow velocity is 8.8 m/s under the flow distribution ratio of 75/25. When the average of the chosen air inflow velocities is 12.4 m/s, maximum aerodynamic resistance occurs under the flow distribution ratio of 75/25 equal to 1050 Pa.

When flow distribution ratio is even (case 50/50), a part of the returning flow is smaller than in the case of 75/25 and the determined resistance is by 5.9% lower and equal to 988 Pa. Minimum resistance has been recorded when a part of the transitional flow is bigger (case 25/75). The obtained resistance of 773 Pa is by 26.4% lower than the one having maximum resistance when inflow velocity into the six-channel cyclone is 12.4 m/s under the flow distribution ratio of 75/25. When the peripheral flow forms a bigger part in the case of flow distribution ratio 75/25, resistance decreases in comparison to the case of 50/50; thus, it could be assumed that this way a bigger part of the returning flow decreases the transitional flow through the channel towards the cyclone axis and flow turbulence due to the decreased flow moving into the following channel.

In this case, turbulence has a weaker influence on resistance values, but the overall energy loss of the flow complements the influence of local restrictions when the curvilinear half-ring flow moves around. When the case (25/75) of a bigger part of the transitional (flowing towards the device axis) flow is analysed, minimum aerodynamic resistance is recorded and is equal to 1305 Pa.

The analysis of a change in flow velocity with the maximum chosen inflow velocity of 15.3 m/s has shown that inflow velocity at the first level of the cyclone is 28 m/s, whereas that at the second – 29 m/s. When gas flow enters the first curvilinear channel, velocity decreases and is equal to 15.3 m/s while at 2nd level it is equal to 15.8 m/s. When getting closer to the middle of channel 1, velocity at the 1st level of the cyclone decreases. This may be influenced by an increase in the cross-section by 1.68 times after the inlet and caused flow weakening by occurring resistance forces flowing from inlet into curvilinear form channel.

The minimum velocity point at both levels is at No. 2 where velocities, in comparison to inflow velocities, are equal and their average is 15.5 m/s. Flow velocity towards the end of the first channel increases; the maximum velocity of the first channel has been recorded at measurement point 5, which is equal to 29.1 m/s at the 1st level and 30.5 m/s at the 2nd. The increase could be related to a decrease in the cross-section area between the first constant radius of the curvilinear half-ring and the wall of the peripheral cyclone when the area of the cross-section is equal to $5.48 \cdot 10^{-3}$ m^2 (Fig. 5).

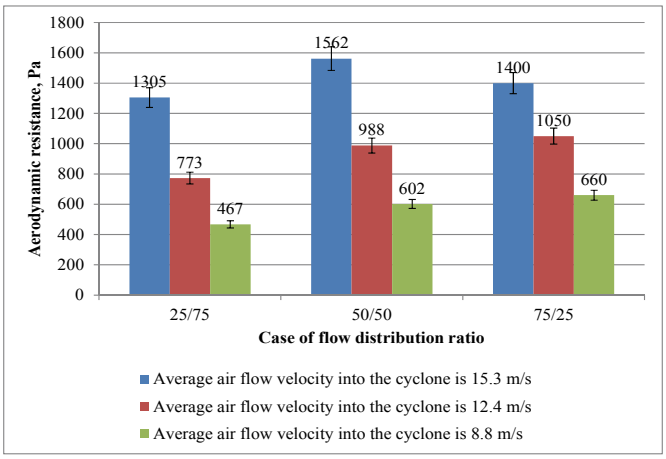


Fig. 4. The dependence of the aerodynamic resistance of the cylindrical two-level six-channel cyclone on the case of flow distribution ratio under the average air flow velocities of 15.3 m/s, 12.4 m/s and 8.8 m/s into the cyclone

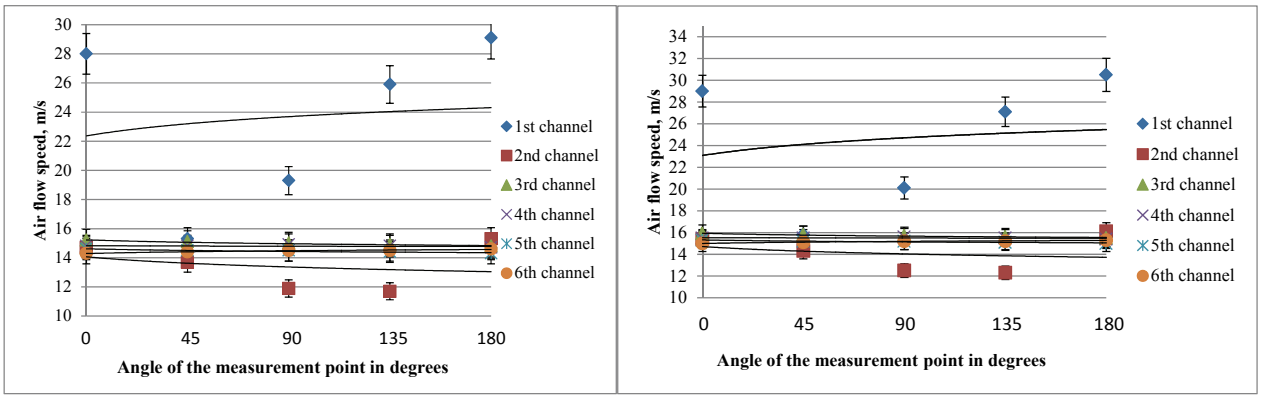


Fig. 5. Changes in velocity at the first (a) and second (b) levels of the cyclone concerning measurement points of six-channels under the maximum inflow velocity of 15.3 m/s

Minimum velocities in the cyclone have been observed in the second channel. The overall average of velocity in the second channel at the 1st level is 13.5 m/s, whereas that at the 2nd makes 14.1 m/s. A fast decrease in velocity occurs due to an increase in the cross-section along the border between the first and second channels. The ratio of the cross-section area is equal to 1.81; thus, when air flow enters the second channel, velocities significantly decrease. A decrease in the flow continues up to the middle of the channel when the maximum cross-section area equal to 0.0121 m^2 is reached.

Due to narrowing at the end of the second channel, flow push is formed, which causes an increase in velocity. Thus, an assumption that, as a result of this effect at the fifth point of the second channel, the velocity of 15.3 m/s is reached has been made, i.e. velocity is 1.18 times higher than velocity average in other points of the channel. Fractionally changing velocities of low turbulence prevail in the third channel and change in the range of 14.8 – 15.2 m/s along the whole length of the channel. Table 1 displays a possibility of assuming that distribution is fractionally decreasing; thus, an assumption that flow weakening is caused by the inner construction of the multichannel cyclone is made.

Air flow moving through curvilinear channels changes its trajectory at an angle of 180°; therefore, the occurring losses of way and friction between wall surfaces decrease the flow by 2.64%.

The fourth channel of the cyclone has constant velocities, and their values have a decreasing tendency; however, the change is not significant, and the average of velocity in the channel is 14.8 m/s. Velocities at the 2nd level are higher than those at the 1st level by almost 4.5%; nevertheless, tendencies for changes in velocity remain similar, and the average velocity in the channel is equal to 15.5 m/s.

Velocities in the fifth and sixth channels at the 1st level merely differ among one another, and most of them are equal to the average velocity in the channel, which is 14.5 m/s. Thus, a conclusion that the flow in the same channels of the cross-section moves getting closer to laminar flow can be made. Changes in velocities at the 2nd level follow the same tendency as that in the first channel, though velocities are averagely higher by 4.5%.

The performed analysis shows changes in air flow volume at both levels of the six-channel cyclone calculated on the basis of the obtained velocity results, which indicates that the average value at the first level is approximately 480 m^3/h and that at the second level – 505 m^3/h.

A change in air flow volume at both levels decreases by getting closer to the cyclone axis, which is more apparent at the 1st level. In the first measurement points of the first channels of cyclone levels one of the biggest values have been determined; at the 1st level it makes 500 m^3/h while at the 2nd – 520 m^3/h. According to the results provided in Fig. 6, the following conclusion that the largest air flow volume unevenness has been determined in the first two channels of both levels as well as in the case of velocity measuring could be made.

This could have been influenced by changes in the cross-sections of the channel and a sudden change in the cross-section when air flow moved from the first to the second channel, which is reflected by changes in air flow volume from the 4th to 6th point at both levels of the cyclone. The following values, by evaluating possible deviations, approximately coincide with all average value curve results of the level (Fig. 6).

The results of the conducted research on the overall cleaning effectiveness are provided in Fig. 7 and determine that air flow cleaning effectiveness removing granite particulate matter of small dispersion from 0 to 20 μm is the highest compared with the maximum chosen inflow velocity into the cyclone which is 15.3 m/s when the determined particulate matter concentration in the polluted flow is 5.9 g/m^3. In this case, the cleaning effectiveness of 93.1% is achieved, which is more by 11.5% and 16.2% when inflow velocity into the cyclone is 12.4 m/s and 8.8 m/s respectively. The flow polluted by granite particulate matter of larger fraction (20–50 μm) is cleaned by 1.06 times more effectively, and effectiveness makes 95.9%.

Table 1. Changes in velocities at the measurement points of the cyclone at two levels under the flow velocity of 15.3 m/s into the cyclone

Angle of the measurement point in degrees		*0*	*45*	*90*	*135*	*180*	*Average*
1st level of six-channel cyclone velocities under the air flow velocity of 15 m/s							
Channel of the cyclone	1st channel	28.0	15.3	19.3	25.9	29.1	23.5
	2nd channel	14.7	13.7	11.9	11.7	15.3	13.5
	3rd channel	15.2	15.1	15.0	14.9	14.8	15.0
	4th channel	14.8	14.8	14.9	14.8	14.7	14.8
	5th channel	14.6	14.5	14.5	14.4	14.3	14.5
	6th channel	14.3	14.4	14.5	14.5	14.6	14.5
2nd level of six-channel cyclone velocities under the air flow velocity of 15.7 m/s							
Channel of the cyclone	1st channel	29.0	15.8	20.1	27.1	30.5	24.5
	2nd channel	15.4	14.3	12.5	12.3	16.1	14.1
	3rd channel	15.9	15.8	15.7	15.6	15.5	15.7
	4th channel	15.5	15.5	15.6	15.5	15.4	15.5
	5th channel	15.3	15.2	15.2	15.1	15.0	15.2
	6th channel	15.0	15.1	15.2	15.2	15.3	15.2

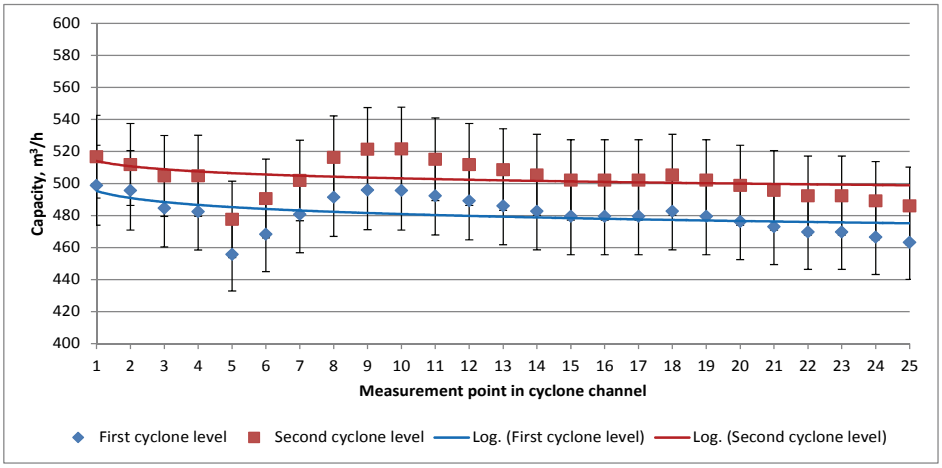


Fig. 6. Changes in air flow volume at the first and second levels of the cyclone at the measurement points of the cyclone under the maximum inflow velocity of 15.3 m/s

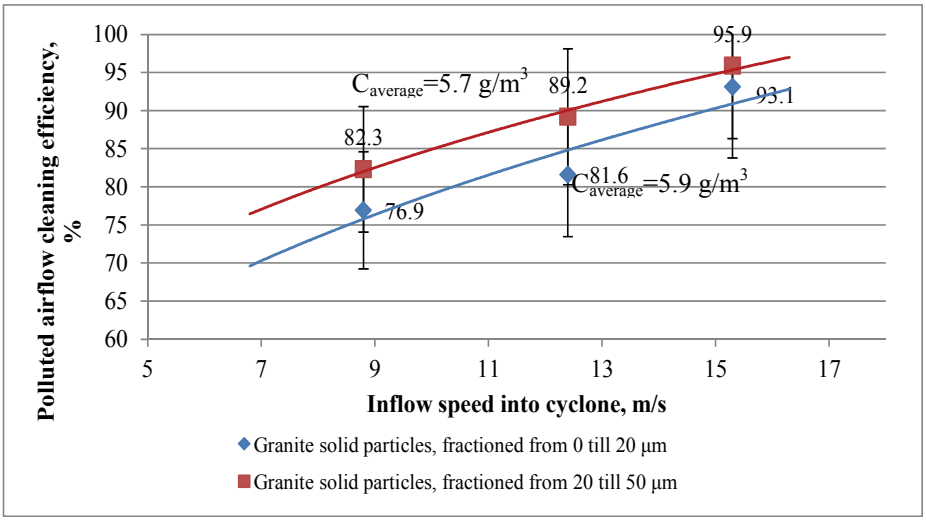


Fig. 7. The dependence of the overall cleaning effectiveness of the air flow polluted by granite particulate matter in the cylindrical two-level six-channel cyclone on air inflow velocity into the cyclone under the flow distribution ratio of 75/25

The recorded distribution of cleaning efficiency reveal that, an increase in air inflow velocity into the cyclone reduces the difference between the obtained cleaning efficiencies using the flow polluted with the particles of different dispersion. Under the inflow velocity of 8.8 m/s,

difference in velocity makes 1.07 times under a rate of 12.4 m/s – 1.09. Thus, it is possible to suggest that when air flow velocities are high, the influence of the physical parameter (dispersion) of high density particles, such as granite in the polluted air flow, on the cleaning process of the contaminated air flow decreases.

Moreover, it is possible to suggest that small dispersion particles of up to 20 μm and those from 20 μm to 50 μm are appropriately caught by a turbulent flow and settled by directing them through segmental spaces in the separation chamber. The determined optimal velocity in the channels of the cyclone is up to 16 m/s, which explains that velocity lower than the previous one creates the air flow of insufficient turbulence, which is not suitable for granite particulate matter with large specific weight to appropriately settle in the multichannel cyclone.

Under the inflow velocity of 12.4 m/s, the decreasing value turn from the connecting curve trajectory is observed; thus, it is assumed that the particles that are not appropriately directed by centrifugal force affect curvilinear half-rings and finally the peripheral wall because of their appropriate settlement through segmental spaces; therefore, they do not settle.

Moreover, when flow velocity is too high (critical), the turbulent flow replaces the laminar one; in such a case, the particles of small dispersion are flown together with output due to which the cleaning level in the multichannel cyclone should decrease.

4. Conclusions

1. Air cleaning effectiveness in the two-level six-channel cyclone increases when air flow velocity in the channels increases from 8 m/s to 16 m/s. In order to effectively clean the air flow polluted with granite particulate matter, optimal air flow velocity in the channels of the cyclone is 16 m/s and flow distribution ratio is 75/25. The introduced parameters allow reaching the effectiveness of 93.1% when particulate matter have small dispersion of up to 20 μm and 95.9%when particles are from 20 to 50 μm.
2. Maximum aerodynamic resistance has been recorded under the flow distribution ratio of 75/25 and maximum inflow velocity of 15.3 m/s under the aerodynamic resistance of 1562 Pa. When the flow is even or the peripheral one dominates, resistance increases because of a change in turbulent flow trajectories and causes additional energy loss.
3. In comparison to air flow velocities regarding the levels of the multichannel cyclone, they are significantly (approximately by 15-30%) higher at the second level. Thus, it is possible to state that as a result of the structure of the cyclone, aerodynamic resistance is lower at this level.
4. Considering the evaluation of pilot research results of the multichannel cyclone, it is possible to make a conclusion that the above discussed device is suitable for cleaning gaseous effluents into the atmosphere from small dispersion particulate matter of up to 20 μm.

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References

Altmeyer S., Mathieu V., Jullemier S., Contal P., Midoux N., Rode S., Leclers J.P., (2004), Comparison of different models of cyclone prediction performance for various operating conditions using a general software, *Chemical Engineering Progress,* **43**, 511-522.

Avci A., Karagoz I., (2003), Effect of flow and geometrical parameters on the collection efficiency in cyclone separators, *Journal of Aerosol Science,* **34**, 937-955.

Baltrėnas P., Vaitiekūnas P., Jakstoniene I., Konoverskyte S., (2012), Study of gas-Solid Flow in a Multichannel Cyclone, *Journal of Environmental Engineering and Landscape Management,* **20**, 129-137.

Baltrėnas P., Zagorskis A., (2010), Investigation into the air treatment efficiency of biofilters of different structures, *Journal of Environmental Engineering and Landscape Management,* **18**, 23-31.

Bernardo S., Mori M., Peres A.P., Dionisio R.P., (2006), 3-D Computational fluid dynamics for gas and gas-particle flows in a cyclone with different inlet section angles, *Powder Technology,* **162**, 190-200.

Blachman W., Lippmann M., (1974), Performance characteristics of the multicyclone aerosol sampler, *American Industrial Hygiene Association Journal,* **35**, 311-326.

Blumberga D., Vigants E., Veidenbergs I., Vigants G., Vitolins V., (2012), Eco-intensity analysis for a chip-fuelled boiler house, *Journal of Environmental Engineering and Landscape Management,* **20**, 249-255.

Boysan F., Ayers W.H., Swithenbank J.A., (1982), A fundamental mathematical modelling approach to cyclone design, *Institution of Chemical Engineers,* **60**, 222-230.

Gimbun J., Chuah T.G., Fakhru'l-Razi A., Choong T.S.Y., (2005), The influence of temperature and inlet velocity on cyclone pressure drop: A CFD study, *Chemical Engineering Progress,,* **44**, 7-12.

Gujun W., Guogang S., Xiaohu X., Mingxian S., (2008), Solids concentration simulation of different size particles in a cyclone separator, Powder Technology, **183**, 94-104.

Hoffmann A.C., Stein L.E., (2002), *Gas Cyclone and Swirl Tubes - Priciples, Design and Operation*, Springer-Verlag, Berlin.

Hu L.Y., Zhou L.X., Zhang J., Shi M.X., (2005), Studies on strongly swirling flows in the full space of volute cyclone separator, *AIChE Journal,* **51**, 740-749.

Ingham D.B., Ma I., (2002), Predicting the performance of air cyclones, *International Journal of Energy Research,* **26,** 633-652.

Jurca A., Lupu C., Paraian M., Vatavu N., Iacob-Ridzi F. T., (2014), Analysis of explosivity parameters and

environmental safety for combustible dusts, *Environmental Engineering and Management Journal,* **13**, 1433-1438.

Kaya F., Karagoz I., (2008), Performance analysis of numerical schemes in highly swirling turbulent flows in cyclones, *Current Science,* **94**, 1273-1278.

Kenny L.C., Gussman R.A., (1995), Characterization and modeling of a family of cyclone aerosol preseparators, *Journal of Aerosol Science*, **26**, 777-778.

Kovacs M., Toth L., Ghetie G., Draghici A., Laurentiu T. V. G., (2014), Best management practices applied to prevent and reduce concentrations of dust and gases released from power plants, *Environmental Engineering and Management Journal,* **13**, 1421-1426.

Luca F.A., Ioan C.A.M., (2012), Air quality management in Iasi city, *Environmental Engineering and Management Journal,* **11**, 377-383.

Meier M., Mori M., (1999), Anisotropic behavior of the Reynolds stress in gas and gas-solid flows in cyclones, *Powder Technology,* **101,** 108-119.

Mothes H., Loffler F., (1988), Prediction of particle removal in cyclone separators, *International Chemical Engineering,* **28,** 51-55.

Pushnov A., Berengarten M., (2011), Ecological aspects of industrial cooling towers exploitation and it‘s influence to environment, *Journal of Environmental Engineering and Landscape Management*, **19**, 158-166.

Raoufi A., Shams M., Kanani H., (2008), CFD analysis of flow field in square cyclones, *Powder Technology,* **101,** 1-9.

Saltzman B.E., Hochstrasser J.M., (1983), Design and performance of miniature cyclones for respirable aerosol sampling, *Environmental Science and Technology,* **17**, 418-424.

Sandu I.-O., Bulgariu L., Macoveanu M., (2012), Evaluation of environmental impact using active biomonitoring studines of air pollution, *Environmental Engineering and Management Journal*, **11**, 1527-1534.

Stairmand C.J., (1951), Design and performance of cyclone separator, *Transactions of the Institution of Chemical Engineers,* **29**, 356-373.

Tucaliuc O. M, Cretescu I., Nemtoi G., Breaban I. G., Soreanu G., Iancu O. G., (2014), Monitoring of mercury from air and urban dust in the industrial area of Iasi municipality, *Environmental Engineering and Management Journal,* **13**, 2051-2062.

Vaitiekūnas P., Jakštonienė I., (2010), Analysis of numerical modeling of turbulence in a conical reverse-flow cyclone, *Journal of Environmental Engineering and Landscape Management*, **18**, 321-328.

Vasile A., Caldararu M., Hornoiu C., Bratan V., Ionescul N.I., Yuzhakova T., Redey A., (2012), Elimination of gas pollutants using SnO_2-CeO_2 catalysts, *Environmental Engineering and Management Journal*, **11**, 481-486.

Zhao B., Su Y., Zhang J., (2006), Simulation of gas flow pattern and separation efficiency in cyclone with conventional single and spiral double inlet configuration, *Chemical Engineering Research and Design,* **84,** 1158-1165.

Zhoue L.X., Soo S.L., (1990), Gas solid flow and collection of solids in a cyclone separator, *Powder Technology,* **63**, 45-53.