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Section: Environmental protection

Experimental Researches and Comparison of Cylindrical Multiple Levels Six–channel Cyclone

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Abstract

The one-level, two-level and three-level six-channel cyclone is designed and constructed in Laboratory of Environment Protection in Vilnius Gediminas Technical University. The aim of this research is to measure air purification effectiveness in one–level, two–level and three–level cyclone when the particles are up to 20 μm in size. The experiments were performed when average airflow velocity in channels are 16 m/s, 12 m s and 8 m/s. The particle concentration in air inlet and outlet ducts is determined by weight method. By comparing the obtained data with each other, it was found that the best air cleaning efficiency is when air distribution ratio in cyclone's channels is 75/25. Granite particles are separated most effectively. Their separation effectiveness of the three-level cyclone is 92.8%. The lowest air purification efficiency is in one–level cyclone in comparison to two–level and three–level cyclones.

Keywords: multichannel; cyclone; airflow; solid particles; air purification.

1. Introduction

Cyclones are widely used for separation of solid particles from airflow when industrial processes occur in low temperature, and for separating smoke particles form high temperature smoke (300–500 °C). They are designed in such way that gas flows in two directions: tangential and axial [1–2]. These devices are usually characterized by simple construction, comparatively small size, and small exploitation costs, because they do not require extensive maintenance and do not have any moving or quickly worn out parts in them. The disadvantage of cyclones is not sufficient purification effectiveness and high pressure resistance, when inlet velocity is high [3–5].

Gas flow purification from solid particles in cyclone is a complex heat and mass exchange process that has been researched for almost 120 years [6]. Many types of cyclones with more or less similar features have been proposed during this period. Cyclone that is composed of a shell, inlet/outlet tubes is simply produced, constructed and exploited; moreover, it is universal and economical [7], [8].

In enterprises, the air is purified of solid particles by one or several purification steps, from which the first is usually a cyclone. In order to avoid two steps, one step purification could be employed, but then the purification device must be very effective. In such cases, devices with closed set system can be used.

Purification devices with closed set system, e.g., cyclones, have simple construction are easily produced and constructed. They are reliable, universal and economical. Their modules, differently from cyclones that are connected into groups, reach high gas purification quality without any changes in productivity. The basis of this device is internal curvilinear channels that create closed set systems [9]. The gas flow polluted with solid particles is filtered through several layers of air polluted with solid particles that circulate in closed chain. The combination of dusty airflow filtration and centrifugal purification is a new direction in inert and gas purification filters [10], [11].

In these new generation cyclones closed cylindrical form sets have different diameters and are distributed in angle $\varphi=\pi$; they are formed with two different diameter ring walls. Each pair of nearby channels forms one separate closed set. The number of these channels is depended on the number of rings in the device [12], [13].

Closed sets join inlet/outlet holes in the same level as other systems of composing part and as the whole system. Closed sets perform control mechanism for the connection that occurs from the distribution of semi-rings, i.e., it makes the system stable [14]. Spaces between half–rings of different diameters can compensate turbulent phenomenon that is formed in

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channels. The optimal airflow distribution could be determined by changing these spaces, and this does not burden the creation of devices at all. In such way, the complex processes, such as movement of polluted air, could be effectively controlled [7].

Theoretical efficiency of cyclones with closed loops system can be characterized by the dust concentration C_k after purification, which depends on the incoming concentration of dust C_H and from the number of channels n. This is defined by the ratio [13]:

$$C_k = \frac{C_H}{1+2^{n-1}}. \tag{1}$$

Here: C_k – dust concentration after purification, g/m^3; C_H – incoming dust concentration, g/m^3; n – number of channels.

Aerodynamic pressure drop is very important for these cyclones. The total pressure of the channels has the greatest impact of aerodynamic pressure coefficient, the other factor is system pressure drop. General pressure coefficient is expressed in sum of [13]:

$$\xi_n = \xi_0 + \sum_{i=1}^{n} \xi_i. \tag{2}$$

Here: ξ_0 – system pressure coefficient; ξ_i – channel aerodynamic pressure coefficient; n – number of channels.

Circle moving biphasic flow (tangential angle of the moving particles and air), describes the potential rotation ratio [16]:

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

Here: σ – tension coefficient, created in cyclone's channels; ρ – density of particles; a – circulating air flow parameter; r – radius of channel.

In order to purify high air volumes, large purification devices should be used, which is disadvantageous in terms of economics and productivity [16]. When the size of the device is increasing, the rate of purified air should increase as well; however, the purification effectiveness of all purification devices decrease when their size is increasing. In such cases a two–level multichannel cyclone is used. In this device there are two levels above one another. On both levels there is the same number of channels, and the partition between levels distributes coming airflow into two equal parts [14].

Technical requirements that are applied for cyclones, as well as for any other air purification equipment, aim to ensure the highest air purification effectiveness by creating the lowest aerodynamic resistance. With the increasing aerodynamic resistance the amount of energy used to reach a bigger amount of airflow increases as well [17]. Thus, in order to improve cyclone construction, the best variant of aerodynamic resistance that depends on airflow velocity and air purification effectiveness is sought.

The aim of this work is to experimentally research of purification effectiveness of dust polluted air and to compare particles separation effectiveness between different cyclone levels.

2. Methodology

The experimental research has been conducted with cylindrical one–level, two–level and three–level six–channel cyclone that is constructed in Laboratory of Environment Protection at Vilnius Gediminas Technical University (Fig. 1 and 2). This multi–level cyclone laboratory stand scheme is provided in Figure 3.

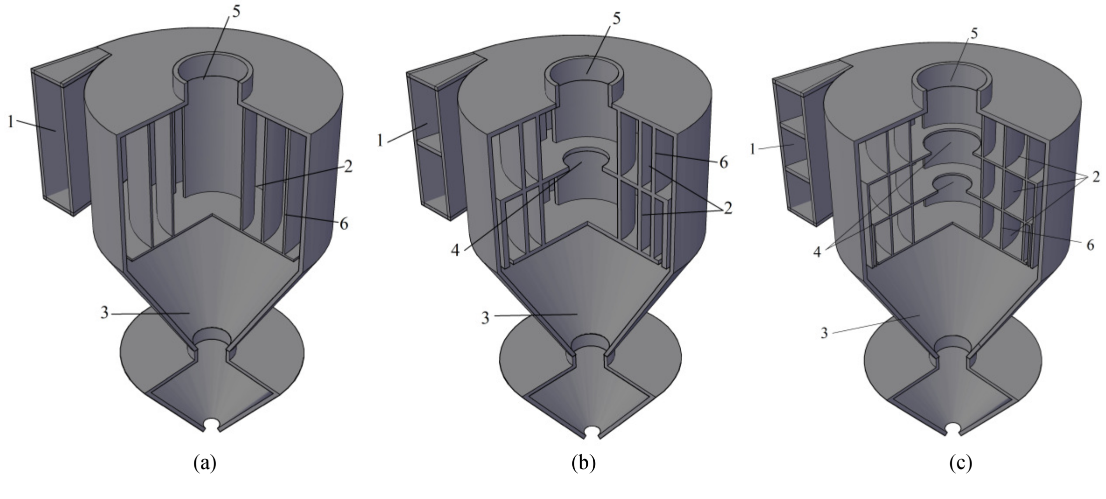

Fig. 1. Models of cylindrical six-channel multi-level cyclones: (a) – one-level cyclone; (b) – two-level cyclone; (c) – three-level cyclone

The system consists of centrifugal ventilator, where the necessary airflow is created, two–level multichannel cyclone and air inlet/outlet ducts. The polluted airflows into the purification device through air inlet duct with diameter of 200 mm, then in multichannel cyclone the solid particles are separated from the air and settle onto the double hopper of the cyclone. The purified air is removed through air outlet duct with diameter of 160 mm.

Fig. 2. Made model of cylindrical multi-channel cyclone

The polluted air flows through the air inlet duct and is distributed into equal parts that enters different levels in cyclone diffuser. The separated solid particles flow into the double hopper through spaces between segmented rings, and the purified air is removed from the air outlet ducts.

Equipment used during the experiment:

1. Multi-functional measuring instrument Testo – 400.
2. Rubber tubes.
3. Wing anemometer.
4. Aspirator, velocity deviation of air suction ± 6%;
5. Electronic laboratory scales AG–204, section value 0.1 mg;
6. Filter holders;
7. Filters AFA–VP–20;

All measurements have been made by changing airflow rate created by the ventilator. In such way the airflow velocity are evaluated in the device depending on different air rate created by the ventilator. The amount of air is changed in the management block of the ventilator.

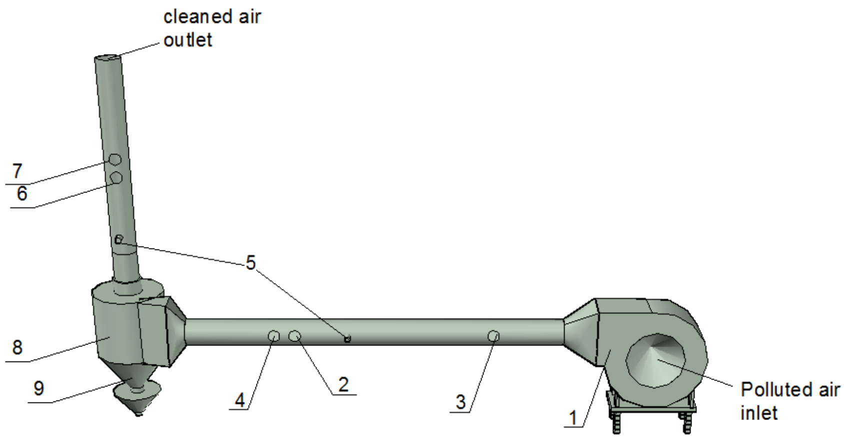

Fig. 3. The experimental stand of multichannel cyclone: 1 – centrifugal ventilator; 2 – suction place of particle concentration before purification; 3 – place of particle inflow; 4 –measuring place of airflow velocity in air inlet duct with wing anemometer; 5 – measuring nozzles for resistance created by the system; 6 – suction place of particle concentration after purification; 7 – measuring place of airflow velocity in air outlet duct with wing anemometer; 8 –multi-level cyclone; 9 – double hopper.

The measurements have been made with three different constructions of six-channel cyclone (Fig. 4). The basis of construction is composed of 5 half–rings of different diameters; that create a channel of a different diameter and volume. The airflow that enters and leaves every channel can be adjusted. The adjustment is made by changing distances between half–rings of different diameter. Three different positions have been chosen: 1. Peripheral (returning) airflow volume is equal to transitional (flowing into following channels) airflow volume (position 50/50); 2. Peripheral airflow volume is bigger than transitional air volume by 50% (position 75/25); 3. Peripheral airflow volume is lesser than transitional air volume by 50% (position 25/75).

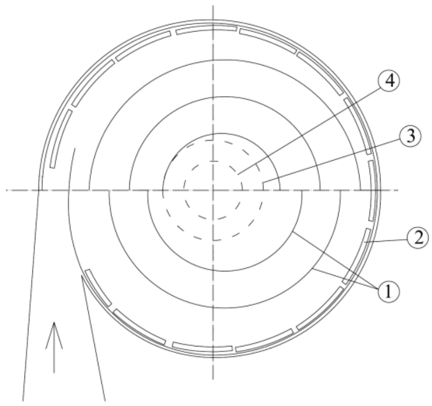

Fig. 4. Distribution scheme of semi-rings of different diameters: 1 – half-rings of different diameter; 2 – segmental spaces; 3 – airflow outlet from second level; 4 – airflow outlet from first level

In every measuring point three measurements are done, in order to avoid systemic deviations, and to acquire the least possible average deviation.

The velocity was measured with wing anemometer and measuring instrument Testo – 400 in ducts before and after cyclone. Due to the improved construction of cyclone, the airflow velocity can be only measured with anemometer in inlet/outlet ducts. According to these measured velocities it is possible to determine airflow continuity more precisely and an accurate amount of air that enters cyclone. The measurements in the duct have been made according to Lithuanian normative document LAND 27–98/M–07 "Airflow velocity and volume rate measuring in ducts".

Purification effectiveness of air polluted with solid particles is calculated by measuring dust concentration in the air before the new generation cyclone and after it. The concentration measurements are made with a stand shown in Figure 3. First, AFA−VP−20 type filters that are used for determining solid particles concentration are prepared. Filters are weighted, and their numbers, as well as their initial weight is noted.

The first filter, which is connected with airflow inlet duct, reveals value of entering concentration by determining particle weigh with weight method. The second – reveals air concentration with solid particles after purification. Thus, when the value of sucked air volume and filter weight difference is known, the cyclone's air purification effectiveness for researched solid particles is calculated.

3. Results and their analysis

Six-channel cyclone air cleaning efficiency measurements were performed with three particles, granite, wood and wood ashes. The particle diameter of up to 20 μm. The results of researches, which were accomplished with one–level, two–level and three-level cyclones are in Table 1 and Table 2, and in Figures 5, 6 and 7.

After experimental investigation the contaminated air with wood ashes particulates from 0 μm to 20 μm in diameter purification efficiency was found, the highest value is using a three–level cyclone at 75/25 flow distribution ratio, amounted to 82.7%, when average air speed in the cyclone's channels is 16 m /s (Table 1). The purification efficiency increases when the average air flow speed in cyclone's channels is increasing, so purification efficiency of air polluted by wood ashes is lower and reaches 77.9%, when average air speed is 12 m/s. Also, wood ashes particles have comparatively low specific weight, which affects the particle sedimentation efficiency. However, filtration in ongoing flow distribution areas are more intense compared to the 50/50 distribution ratio, which occurs more efficient separation of particles from the air.

Table 1. Purification efficiency of air polluted with wood ashes up to 20 μm in size

Average air flow speed	**One-level cyclone**			**Two-level cyclone**			**Three-level cyclone**		
	25/75 position	50/50 position	75/25 position	25/75 position	50/50 position	75/25 position	25/75 position	50/50 position	75/25 position
17 m/s	**73.4%**	**77.5%**	**80.1%**	**77.3%**	**78.1%**	**80.2%**	**78.1%**	**78.6%**	**80.6%**
16 m/s	**75.3%**	**81.1%**	**81.5%**	**79.3%**	**81.3%**	**82.1%**	**80.4%**	**81.5%**	**82.7%**
12 m/s	**72.0%**	**75.3%**	**75.8%**	**74.8%**	**75.5%**	**76.0%**	**73.3%**	**75.8%**	**77.9%**
8 m/s	**66.6%**	**71.5%**	**72.0%**	**70.1%**	**71.8%**	**72.3%**	**71.2%**	**72.4%**	**72.5%**

When the airflow distribution ratio is 25/75, and after measuring wood ashes (from 0 to 20 μm) concentration in the air, before and after purification (air inlet/outlet ducts), the maximum air purification effectiveness in the two–level six–channel cyclone is 80.4%, when the average airflow velocity in cyclone is 16 m/s. When the airflow velocities are 8 m/s and 12 m/s, the purification effectiveness from solid particles of granite is respectively smaller, and equal to 71.2% and 73.3%. The tendency of increasing effectiveness when the average airflow velocity is increasing is rather surprising. The effectiveness is from 1% to 6% smaller in comparison to the airflow distribution ratio 50/50 with all inlet and outlet velocities. It is observed that the purification efficiency of air polluted with wood ashes is the best in three-level cyclone.

When the airflow distribution ratio is the same, and while purifying air polluted with wood particles, the maximum calculated effectiveness in three-level cyclone is 87.8% when the average airflow velocity is 16 m/s. When the average airflow velocities decrease to 12 m/s and 8 m/s, the effectiveness decreases to 7.5% and 3.2% respectively. The effectiveness is smaller in comparison to airflow distribution ratio 50/50 with all inlet velocities, the same tendency of increasing effectiveness when the airflow velocity increases is rather surprising.

Three-level cyclone purification efficiency is 2–3% bigger than the two-level cyclone and about 7% more efficient than one-level cyclone. Wood particles due to their organic properties better coagulates with each other, so they are precipitated out more efficient in cyclone hopper.

Table 2. Purification efficiency of air polluted with wood particles up to 20 μm in size

Average air flow speed	**One-level cyclone**			**Two-level cyclone**			**Three-level cyclone**		
	25/75 position	50/50 position	75/25 position	25/75 position	50/50 position	75/25 position	25/75 position	50/50 position	75/25 position
17 m/s	**80.0%**	**80.8%**	**84.2%**	**84.2%**	**85.0%**	**88.6%**	**86.6%**	**88.3%**	**89.4%**
16 m/s	**80.1%**	**83.9%**	**86.5%**	**84.3%**	**88.3%**	**91.1%**	**87.8%**	**89.5%**	**91.7%**
12 m/s	**74.7%**	**77.7%**	**75.8%**	**78.6%**	**81.8%**	**79.8%**	**80.3%**	**83.2%**	**86.2%**
8 m/s	**72.7%**	**74.3%**	**72.9%**	**76.5%**	**78.2%**	**76.8%**	**77.1%**	**81.1%**	**82.9%**

Wood and wood ashes particles are precipitated most effectively in six–channel cyclone, when air flow distribution ratio is 75/25. The highest efficiency is in the three–level cyclone and reaches 91.7%, when wood particles are separated from polluted air. When peripheral flowing air ratio is three times bigger than the transitional, a thicker air "curtain" is formed. In the airflow encounter place two processes occur: particles are directed to the wall and particle coagulation. The larger–sale particles that are formed are more easily separated with centrifugal force. More particles are flowing together with bigger peripheral airflow, they coagulate with inflowing particles; therefore, the air is purified in a more efficient manner.

Separation efficiency of granite particles from 0 to 20 μm in size is smaller when air flow distribution ratio is 25/75, in comparison to the airflow distribution ratio 50/50. Efficiency is 90.8%, when average airflow speed is 16 m/s, after reducing speed to 12 m / s, the efficiency is reduced to 83.2%. Granite particle separation efficiency is 74.3%, when the average airflow rate reduced to 8 m/s. Two–level cyclone efficiency is about 2–3% smaller in comparison to the three–level cyclone at all inlet velocities. There is a lower channel height in three–level cyclone and it prevents the formation of turbulent flow and due to centrifugal force the particles are precipitated effectively.

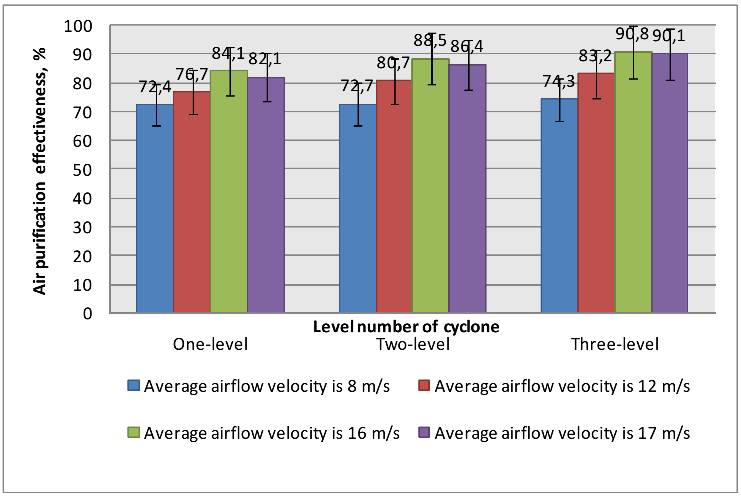

Fig. 5. The effectiveness of air purification from granite solid particles, which dispersion is from 0 to 20 μm, when the airflow velocities in cyclone and cyclone's levels differ and the airflow distribution ratio is 25/75

Data from Figure 6 and Table 1 shows that the six-channel one-level cyclone, when the air distribution ratio of curved half–rings is 50/50, purification efficiency is highest when separating granite particles, the worst – of wood ashes. The difference between granite and wood ashes particles separation efficiency reaches 5–10%, and this difference increases by increasing the average air velocity in the channels. The most efficient purification of granite particles contaminated air, when average airflow velocity is 8 m/s, is 77.3%. The maximum efficiency of the separation of solid particles is when separating of granite particles, at 16 m/s and 12 m/s average airflow velocities.

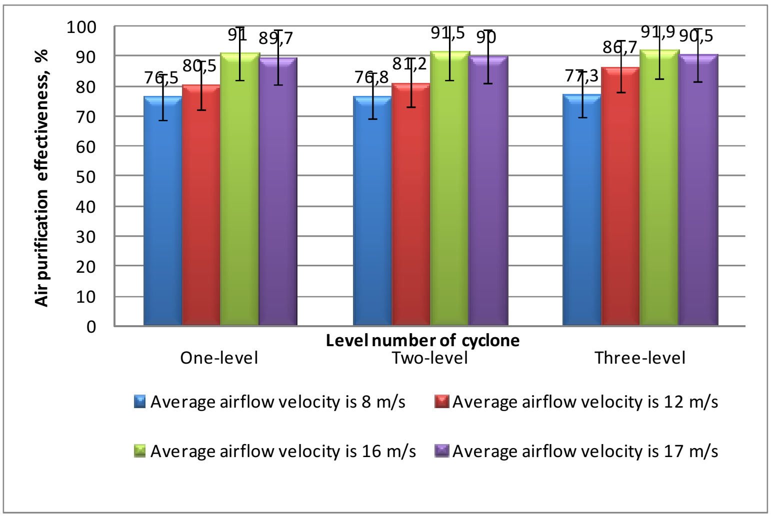

Fig. 6. The effectiveness of air purification from granite solid particles, which dispersion is from 0 to 20 µm, when the airflow velocities in cyclone and cyclone's levels differ and the airflow distribution ratio is 50/50

According to the results showed at figure 6, the most effective air purification is when airflow velocity is high (16 m/s), air cleaning efficiency is 91.9% when particles is up to 20 µm in size. When the velocity decreases to 12 m/s, effectiveness decreases to 86.7%. When the average airflow velocity decreases to 8 m/s, the granite particle separation effectiveness decreases to 77.3%.

Increasing peripheral air flow volume improves air purification efficiency. Increasing the flow of the peripheral by 25% the separation efficiency of the wood and granite particles increases by about 3%, and wood ashes – 4%.

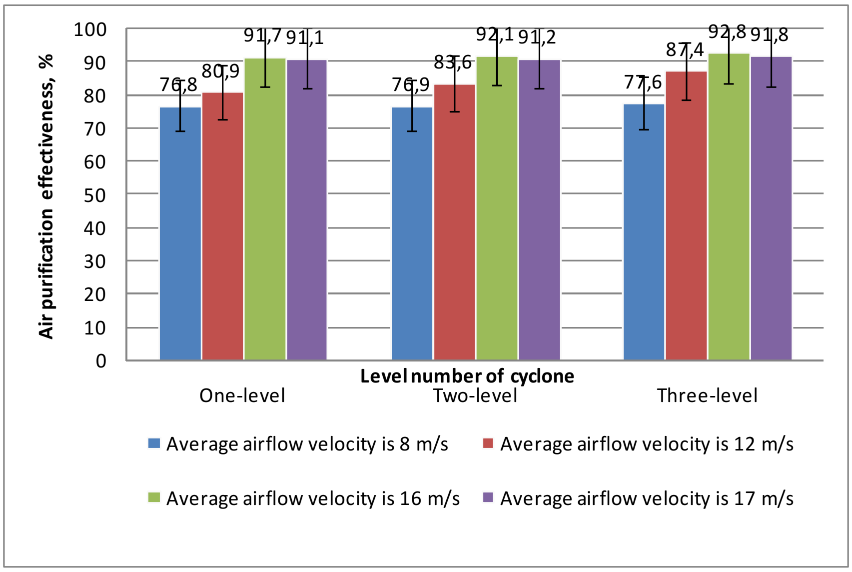

Fig. 7. The effectiveness of air purification from granite solid particles, which dispersion is from 0 to 20 µm, when the airflow velocities in cyclone and cyclone's levels differ and the airflow distribution ratio is 75/25

Separation of granite particles from 0 µm to 20 µm in diameter effectiveness is highest when the air flow distribution ratio in three-level cyclone is 75/25, the average velocity of airflow is 16 m/s (Fig. 7). The tendency of increasing effectiveness when the average airflow velocity is increasing is rather surprising. The effectiveness is from 4% to 8% smaller in comparison to the airflow distribution ratio 50/50 with all inlet and outlet velocities. Increasing airflow velocity of 12 m/s to 16 m/s in three–level cyclone, an increase of efficiency is 5.4%.The purification efficiency decreased slightly, when airflow velocity increases to 17 m/s, compared with 16 m/s. Thus, 17 m/s average speed is the limit when particles due to excessive force bounces from the cyclone separation chamber wall and dust are carried along with the air flow.

The air purification effectiveness is increasing when levels of cyclone increases. The biggest alteration is when average air flow velocity is 12 m/s. At this speed the differences in effectiveness by separating granite particles between one–level and two–level cyclones is 2.7%, and between two–level and three–level cyclones – 3.8%. When average airflow velocity in cyclone is 12 m/s and 8 m/s, difference is not so great, but the tendency remains the same.

Installation of a cyclone levels reduces the channel height, and airflow becomes more stable and reduces turbulence. When reduced airflow turbulence, particles preferably pressed against the peripheral wall of the cyclone and better deposited in the double hopper.

4. Conclusions

1. Wood and wood ashes particles are precipitated most effectively in six-channel cyclone, when air flow distribution ratio is 75/25. The highest efficiency is in the three-level cyclone and reaches 91.7%, when wood particles are separated from polluted air. Wood particles due to their organic properties better coagulates with each other, so they are precipitated out more efficient in cyclone hopper.
2. When peripheral flowing air ratio is three times bigger than the transitional, a thicker air "curtain" is formed. In the airflow encounter place two processes occur: particles are directed to the wall and particle coagulation. The larger-scale particles that are formed are more easily separated with centrifugal force. More particles are flowing together with bigger peripheral airflow, they coagulate with inflowing particles; therefore, the air is purified in a more efficient manner.
3. The highest efficiency of air purification is when separating granite particles from air, when the airflow distribution ratio is 75/25 and average airflow velocity is 16 m/s in three–level cyclone. Efficiency is 92.8%. The best purification effectiveness of wood ashes contaminated air (82.7%), as well as, is at the three-level cyclone, when airflow distribution ratio is 75/25 and airflow velocity is 16 m/s.
4. The air purification effectiveness is increasing when levels of cyclone increases. The biggest alteration is when average air flow velocity is 12 m/s. At this speed the differences in effectiveness by separating granite particles between one–level and two–level cyclones is 2.7%, and between two-level and three–level cyclones – 3.8%. When average airflow velocity in cyclone is 12 m/s and 8 m/s, difference is not so great, but the tendency remains the same.

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