VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Inga JAKŠTONIENĖ

RESEARCHES AND DEVELOPMENT OF CYLINDRICAL MULTICHANNEL CYCLONE WITH ADJUSTABLE HALF-RINGS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
ENVIRONMENTAL ENGINEERING (04T)

VGTU
LEIDYKLA TECHNIKA
Vilnius 2012

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2008–2012.
Scientific Supervisor
Prof Dr Habil Petras VAITIEKŪNAS (Vilnius Gediminas Technical University, Technological Sciences, Environmental Engineering – 04T).
Consultant
Dr Dmytro SEREBRYANSKYY (Institute of Engineering Thermophysics of National Academy of Science of Ukraine (Kyiv), Technological Sciences, Enviromental Engineering – 04T).

The dissertation is being defended at the Council of Scientific Field of Environmental Engineering at Vilnius Gediminas Technical University:
Chairman
Prof Dr Habil Donatas BUTKUS (Vilnius Gediminas Technical University, Technological Sciences, Environmental Engineering – 04T).
Members:
Prof Habil Dr Rimantas KAČIANAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T),
Dr Dainius MARTUZEVIČIUS (Kaunas University of Technology, Technological Sciences, Environmental Engineering – 04T),
Dr Vidmantas ULEVIČIUS (State Scientific Research Institute Centre for Physical Sciences and Technology, Physical Sciences, Physics – 02P),
Dr Alvydas ZAGORSKIS (Vilnius Gediminas Technical University, Technological Sciences, Environmental Engineering – 04T).
Opponents:
Prof Dr Habil Vladislovas Algirdas KATINAS (Lithuanian Energy Institute, Technological Sciences, Energetics and Power Engineering – 06T),
Assoc Prof Dr Dainius PALIULIS (Vilnius Gediminas Technical University, Technological Sciences, Environmental Engineering – 04T).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Environmental Engineering in the Senate Hall of Vilnius Gediminas Technical University at 2 p. m. on 22 January 2013.
Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.
Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;
e-mail: doktor@vgtu.lt
The summary of the doctoral dissertation was distributed on 21 December 2012.
A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

© Inga Jakštonienė, 2012

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Inga JAKŠTONIENĖ

CILINDRINIO DAUGIAKANALIO CIKLONO SU REGULIUOJAMAIS PUSŽIEDŽIAIS TYRIMAI IR TOBULINIMAS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
APLINKOS INŽINERIJA (04T)

VGTU
LEIDYKLA TECHNIKA
Vilnius 2012

Disertacija rengta 2008–2012 metais Vilniaus Gedimino technikos universitete.
Mokslinis vadovas

prof. habil. dr. Petras VAITIEKŪNAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, aplinkos inžinerija – 04T).

Konsultantas

dr. Dmytro SEREBRYANSKYY (Ukrainos mokslų akademijos šiluminės fizikos institutas (Kijevas), technologijos mokslai, aplinkos inžinerija – 04T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Aplinkos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. habil. dr. Donatas BUTKUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, aplinkos inžinerija – 04T).

Nariai:

prof. habil. dr. Rimantas KAČIANAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

dr. Dainius MARTUZEVIČIUS (Kauno technologijos universitetas, technologijos mokslai, aplinkos inžinerija – 04T),

dr. Vidmantas ULEVIČIUS (Valstybinis mokslinių tyrimų institutas Fizinių ir technologijos mokslų centras, fiziniai mokslai, fizika – 02P),

dr. Alvydas ZAGORSKIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, aplinkos inžinerija – 04T).

Oponentai:

prof. habil. dr. Vladislovas Algirdas KATINAS (Lietuvos energetikos institutas, technologijos mokslai, energetika ir termoinžinerija – 06 T),

doc. dr. Dainius PALIULIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, aplinkos inžinerija – 04T).

Disertacija bus ginama viešame Aplinkos inžinerijos mokslo krypties tarybos posėdyje 2013 m. sausio 22 d. 14 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.

Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;

el. paštas doktor@vgtu.lt

Disertacijos santrauka išsiuntinėta 2012 m. gruodžio 21 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

VGTU leidyklos „Technika“ 2102-M mokslo literatūros knyga.

© Inga Jakštonienė, 2012

Introduction

Topicality of the problem

Main pollution sources of solid particles (SP) in Lithuania are energy objects – thermal power plants, boiler-houses and industrial companies. In turn, costs resulting from the deterioration of population health, reduction of crop yields and acceleration of fixed capital depreciation are conditioned by the contamination of the atmosphere. The Ministry of Environmental protection and Natural Resources of the Russian Federation predicts that the gas resources will end in 2025; and from the year 2030 coal and nuclear energy will take up the priority. Such changes in fuel and energy balance will necessitate the use of the most economical and efficient air cleaning devices in the world.

European Union and the Lithuanian legal acts regulate the two pollutant groups – SP_{10} (aerodynamic particles of up to 10 microns in diameter) and $SP_{2,5}$ (up to 2.5 microns). SP with an aerodynamic diameter greater than 2.5 μm are the contaminants of the most concern to the health. Their effects vary – from a little effect on the respiratory system to premature death. Efficiency of normal centrifugal air cleaning devices ranges from 85 to 90%, but deficiency of many cyclones is low collection efficiency of particles less than 10 μm. This is especially relevant when environmental requirements related to the SP emissions into the air harmful to the health are to be met strictly. Other high-efficiency air cleaning equipment created for removal of SP (bag, electrostatic filters, etc.) is quite expensive, and their exploitation is complicated.

In order to comply with maximum concentrations of SP emissions into the atmosphere permissible by the EU states, the use of effective air cleaning equipment is necessary.

Object of the work. Air cleaning equipment: a cylindrical multichannel cyclone (four-channel and five-channel) with adjustable half-rings.

Aim and tasks of the work. To examine the influence of factors related to the removal of solid particles from a two-phase flow in multichannel cyclone. On the grounds of experimental results of research, to improve the multichannel cyclone through the determination of optimal positions of adjustable half-rings.

The main tasks of the work are:

1. To carry out the researches of single-phase flow in velocity channels of cylindrical four-channel and five-channel cyclone.
2. To determine the overall efficiency dependences of cylindrical multichannel cyclone on different parameters (airflow inlet rate, SP dispersivity, density, concentration, number of helical half-rings), using solid particles of different origins.

3. To perform the researches of the removal of fine-dispersive particles from the airflow in cylindrical multichannel cyclone at different positions of helical half-rings through the determination of optimal position of half-rings.
4. To carry out the simulation of aerodynamic processes of single-phase and two-phase airflow in cylindrical multichannel cyclone and compare the results received with the experimental ones.

Methodology of research. The experimental stand and research methodology used has been described. The method for the determination (weight) of gas flow rate and measurement of volume flow rate in the duct and concentration of solid particles has been applied, as well as the research methodology for the determination of capture efficiency of fine-dispersive particles from the airflow has been used in the work. For the simulation of single-phase and two-phase flow, PHOENICS 3.5 software package has been used.

Scientific novelty. Complex experimental researches on efficiency of cylindrical four-channel and five-channel cyclones with an adjustable half-rings system and researches of fine-dispersive particles (from 1–7 μm) involve the development and modelling processes of cyclones, which showed that efficiency of five-channel cyclone with adjustable half rings is comparable to the efficiency of six-channel one without adjustable half-rings (centrifugal filter).

Practical value. On the grounds of the results of accomplished researches it may stated that after having determined the optimum position of half-rings, cylindrical five-channel cyclone can be used for the removal of fine-dispersive solid particles of different origins from gas (air) flow.

Defended propositions

1. Efficiency of five-channel cyclone with adjustable half-rings is comparable to the efficiency of six-channel cyclone without adjustable half-rings (centrifugal filter).
2. Overall efficiency of four-channel and five-channel cyclone when removing solid particles from the air depends on the ratio of airflow rate, concentration of solid particles, density and the distribution of airflow volume in the gaps of cylindrical half-rings into the peripheral and transit ones.
3. Improved five-channel cyclone can remove fine-dispersive solid particles of aerodynamic diameter of 1 to 7 μm from the airflow, and that is not specific to traditional cyclones, by reaching cleaning efficiency of 1 μm – 49.1%, 2 μm – 65.1%, 4 μm – 77.9%, 7 μm – 98.3%.

The scope of the scientific work. The dissertation consists of an introduction, six chapters, general conclusions and recommendations, list of references and author's publications. It also has one appendix included. Scope of work is of 141 pages, 28 numbered formulas, 68 figures and 20 tables have been used in the text. When writing the dissertation, 105 references have been used.

1. Air pollution by solid particles, their separation from gas (air) flow by cyclone

The chapter analyzes the design, operating principles, scope of application and effectiveness of air-cleaning equipment – standard and multichannel (centrifugal filters) cyclones. It has SP properties described, formation of SP levels from stationary pollution sources in Lithuania analyzed, simulation programs for carry processes presented. The review of references showed that the number of helical half-rings determines the efficiency of centrifugal filter. The equipment with five cylindrical half-rings, but without spacing system of adjustable curved channel is 97% efficient. With the increasing number of helical half-rings, capture efficiency of particles is increasing as well, which represents the equipment defects – large size and aerodynamic resistance. The analysis of scientific literature did not reveal any data related to the multichannel cyclones with adjustable half-rings of different geometry system.

Therefore, the following has been decided in this dissertation: to improve the experimental cylindrical multichannel cyclone (four-and five-channel) by introducing cylindrical half-rings of variable geometry system; to achieve SP cleaning efficiency of six-channel centrifugal filter in cylindrical four-channel and five-channel cyclone, finding the optimal gaps for adjusted half-rings and ratio of transit and peripheral airflows.

In order to evaluate the potentials of this equipment, it is necessary to establish the dependences of SP cleaning efficiency of cylindrical multichannel cyclone on airflow rate, SP size, density and concentration. To perform the simulation of aerodynamic processes in multichannel cyclone and to compare the results received with the experimental ones.

2. Researches of air flow welocity in cyclone adjusted semi-rings channels

Cylindrical multichannel cyclone is different from a typical cyclone and centrifugal filter separation chamber by its design, which contains the gaps of adjustable half-rings. The experimental four-channel (of three half-rings) and five-channel (of four half-rings) cyclone has been constructed with the aim of improving its design to acquire high efficiency of SP capture. The experiments described in this chapter have been carried out using a cylindrical multichannel

cyclone (four- and five-channel) (Fig. 1). Equipment structure has been connected in series by curved channel system with angular twists $\varphi = 0 - \pi, \pi, 2\pi, 2\pi, 3\pi, 3\pi-4\pi$. The design of cylindrical multichannel cyclone consists of an airflow inlet and outlet, separation chamber with adjustable cylindrical half-rings and conical hopper for collection of particles.

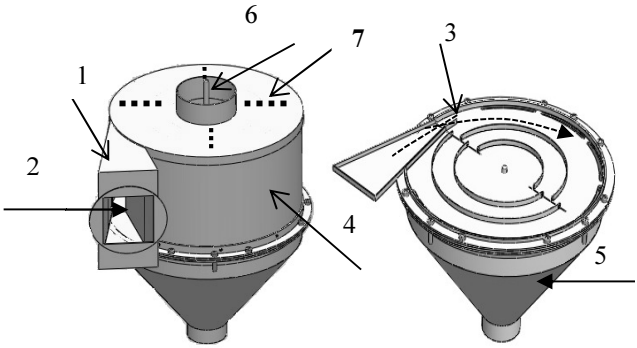


Fig. 1. Experimental cylindrical multichannel cyclone: 1 – confusor, 2 – airflow inlet opening into confusor, 3 – airflow inlet into cyclone (into the first channel), 4 – separation chamber, 5 – hopper, 6 – airflow outlet opening, 7 – measurement points of dynamic pressure

The aim of experimental researches is to determine the distribution of single-phase flow rate in cylindrical four-channel and five-channel cyclone channels, cyclone axial part and the distribution of the ratio of airflow part amount within gaps of helical half-rings (Fig. 2). This chapter provides the research methodology of airflow rate in channels and results obtained. Measurement of dynamic pressure revealed the airflow inlet rates into the cyclone (into the first channel, see Fig. 1): 12, 14, 16 and 22 m/s and in cylindrical channels of multichannel cyclone (Fig. 2). Four-channel cyclone consists of three half-rings, Fig. 3, where half-ring forming a second channel may change its position by parallel push from the left to the right by 10 mm (A_1 position of half-rings) and 20 mm (A_2 position of half-rings). The five-channel one consists of four half-rings, Fig. 4, where twohalf-rings forming the second and third channel may change their position by parallel push from the left to the right by 10 mm. In this way, both types of cyclones have 3 positions of half-rings: A_1 (all radii of half-rings have joint centre – the central axis of cyclone), A_2 and A_3. It was found that airflow rate in four-channel and five-channel cyclones increases with decrease of channel gaps.

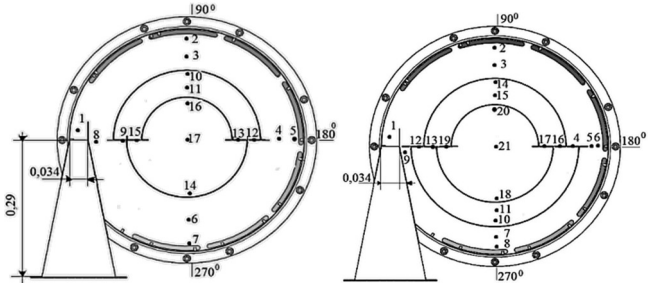
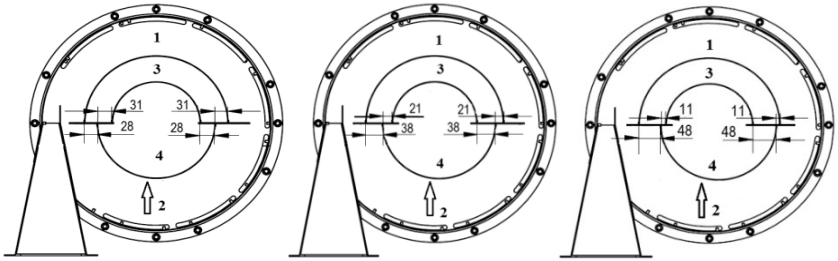
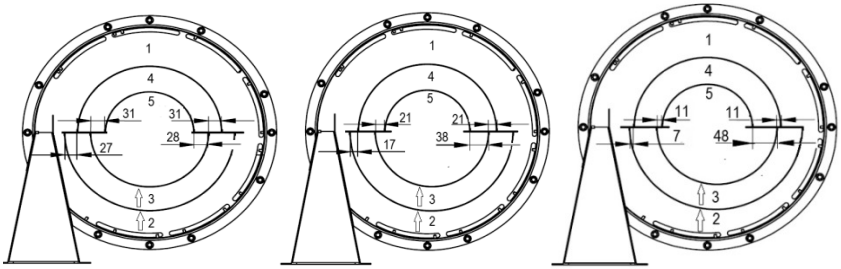


Fig. 2. Airflow measurement points in half-rings channels of cylindrical (a) four-channel and five-channel (b) cyclone



I position of half-rings II position of half-rings III position of half-rings

Fig. 3. Scheme of channel gaps of cylindrical Cyclone four-channel adjustable half rings. The arrow shows half-rings of reversible position (1, 2, 3, 4 – channel sequence)



I position of half-rings II position of half-rings III position of half-rings

Fig. 4. Scheme of channel gaps of cylindrical Cyclone four-channel adjustable half-rings. The arrow shows half-rings of reversible position (1, 2, 3, 4 – channel sequence)

Decrease of airflow rate in four-channel was determined at A_2 and A_3 positions of half rings when the cross-sectional width of channel gaps was 21 mm and 11 mm (Fig. 3), in five-channel – 21 mm – 17 mm, 11 mm – 7 mm (Fig. 4).

Aerodynamic resistance influences the decrease of the rate due to the increase of channel gap width of half-rings. Having evaluated the airflow rates of cylindrical four-channel and five-channel cyclone in channel gaps of half-rings, the ratio of distribution of airflow parts in the channel gaps has been determined.

3. General efficiency researches of multichannel cyclone using solid particles of different origin

The chapter covers methodology and results of experimental researches on general efficiency of cylindrical multichannel (four-channel and five-channel) cyclone. SP of different origin have been chosen for experimental researches on the basis of their different characteristics: density and dispersity – wood ash, density 2451 kg/m^3, quartz sand flour (silicon dioxide, SiO_2), density 2427 kg/m^3, cement clinker dust, density 3160 kg/m^3. SP used for experimental studies were sifted out using 20 and 50 μm sieves.

The aim of these researches was to determine the influence of design solutions on efficiency of multichannel cyclone – the number of helical half-rings, the gap width of adjustable half rings and distribution of airflow amount ratio in them, as well as flow rate and SP of different origins.

Three positions were used for adjustment of half-rings of channel cyclone (A_1, A_2 and A_3) (Fig. 3). This chapter presents the results of general efficiency researches of cyclone at A_3 position of half-rings, when the gap width of half-rings is12 and 13 at the measurement points, 11 mm – 48 mm (Fig. 3). At A_1 position of half-rings results of experimental researches received were 2% lower than of A_3 position of half-rings. 1.5% lower efficiency was received after setting A_2 position of half-rings. Researches have shown that general efficiency of four-channel cyclone removing SP smaller than of 50 μm diameter at 22 m/s airflow rate from the air and 4 g/m^3 concentration of cement clinker SP – 95.8%, wood ash – 91.1% quartz sand flour – 89.5%, when the ratio of parts of peripheral and transit airflow amount – 68:32 (at 8, 9 measuring points) and 19:81 (at 12, 13 measuring points) (Fig. 5).

Using five-channel cyclone for experiments, higher general efficiency values of cement clinker of approximately 1.8% were obtained compared with four-channel cyclone, removing particles of smaller than 50 mm diameter from the air while removing the ones of less than 20 m – 17.6% (Fig. 6).

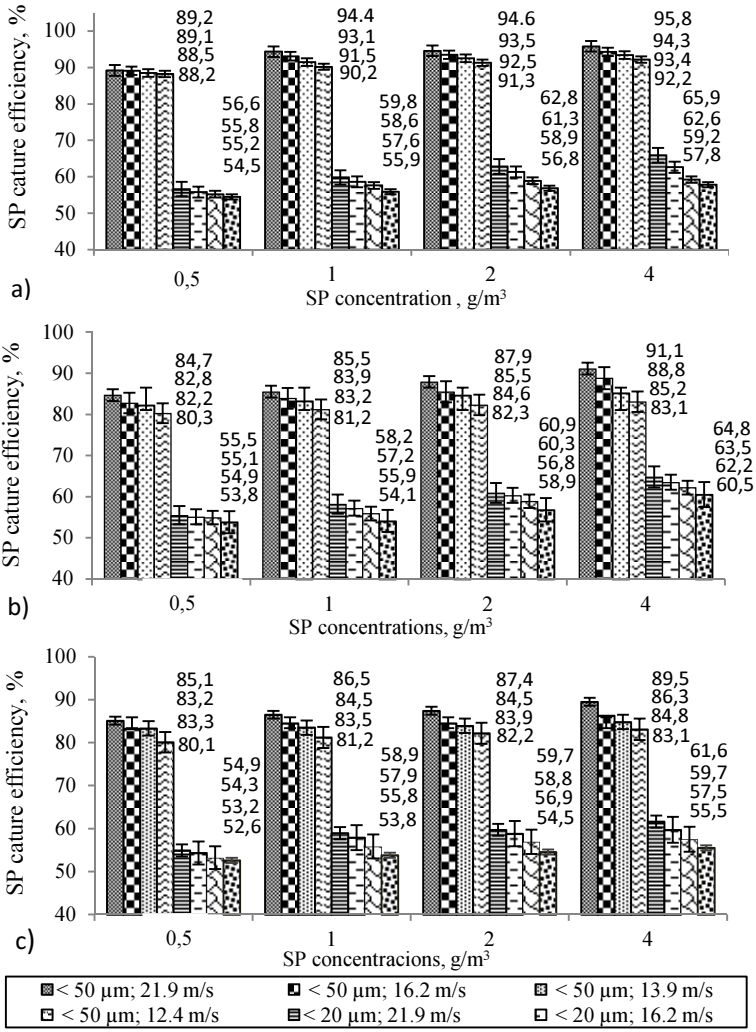


Fig. 5. Efficiency dependence of cylindrical four-channel cyclone on a) cement clinker, $\rho = 3160$ kg/m^3, b) wood ashes, $\rho = 2451$ kg/m^3, c) flour of quartz sand, $\rho = 2427$ kg/m^3, SP concentrations (0,5, 1, 2, 4 g/m^3), air flow inlet rate (12, 13, 16 and 22 m/s) and SP aerodynamic diameter <20 µm and <50 µm at A_3 position of half-rings

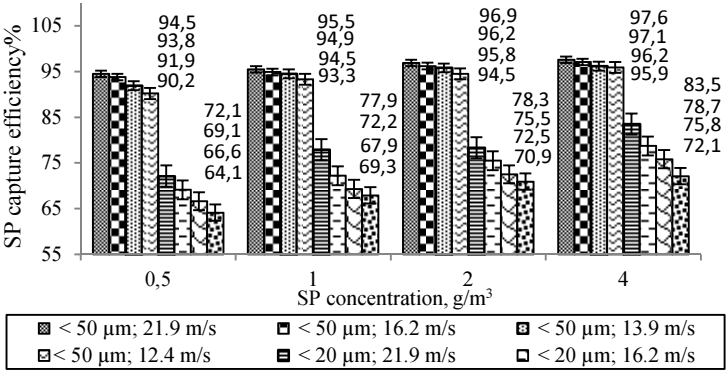


Fig. 6. Efficiency dependence of cylindrical five-channel cyclone on cement clinker, $\rho = 3160$ kg/m^3, SP concentrations (0.5, 1, 2, 4 g/m^3), airflow inlet rate (12, 14, 16 and 22 m/s) and SP aerodynamic diameter <20 µm and <50 µm at A_3 position of half-rings

Researches have shown that the five-channel cyclone removes SP more effectively than the six-channel (centrifugal filter): clinker SP – 3.4% wood ash – 3.3%, quartz sand flour – 2.6%. For capture of cement clinker ($\rho = 3160$ kg/m^3) and wood ash ($\rho = 2451$ kg/m^3) SP, cylindrical five-channel cyclone is recommended at A_3 position at half-rings with gap width of 7 mm and 11mm, when peripheral and transit flow parts reached 45% and 55%.

4. Research and analysis of removal of different dispersion solid particles in multichannel cyclone from air flow

This chapter presents the methodology and results related to the efficiency research on removal of fine-dispersive SP of cylindrical four-channel and five channel from the airflow. The same SP as for general efficiency researches have been used in experimental researches (Chapter 3). After the accomplishment of general efficiency results, A_3 cyclone position was chosen and applied for examination of fine-dispersive particles in Chapter III. Researches of fine-dispersive SP have been carried out at A_1 position of half-rings when the airflow amount is distributed – at a ratio of 0.53:0.47, the research results obtained were by 4% lower than when using A_3 position of half-rings. The removal of fine-dispersive SP from the airflow was received less than 3% at A_2 position of half-rings when the airflow amount is distributed at a ratio of 0.36:0.64. Further experimental researches of fine-dispersive SP removal from the air have been carried out only at A_3 position of half-rings when gap width of four-channel was 11 mm – 48 mm, five-channel – 7 mm – 11 mm (Figs. 2–3). The aim of this

works is to determine the removal efficiency of fine-dispersive particles of cylindrical four-channel and five-channel cyclone from the air flow.

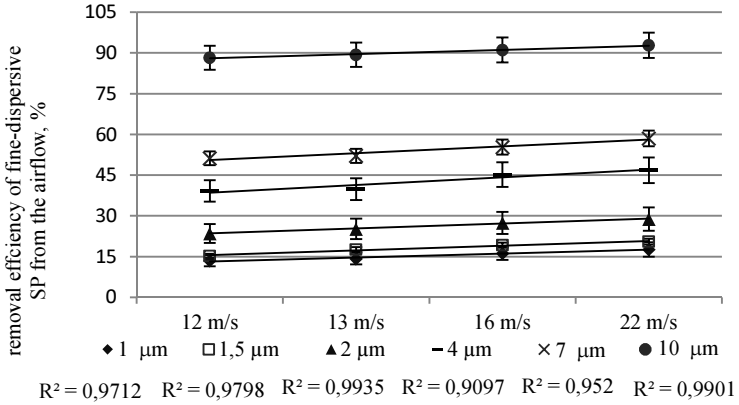


Fig. 7. Efficiency dependences in four-channel cylindrical cyclone during the removal of quartz sand flour of different dispersion from the air flow at 4 g/m^3 concentration and airflow inlet rate (12, 14, 16, 22 m/s), density – 2427 kg/m^3, at A_3 position of the half-rings

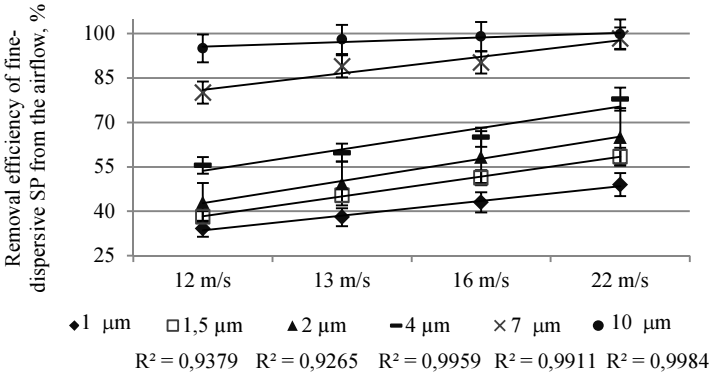


Fig. 8. Efficiency dependences in four-channel cylindrical cyclone during the removal of cement clinker SP of different dispersion from the air flow at 4 g/m^3 concentration and airflow inlet rate (12, 14, 16, 22 m/s), density – 3160 kg/m^3, at A_3 position of the half-rings

The experiment researches showed that efficiency of four-channel cyclone reached 92.8%, when removing 10 μm SP at the highest concentration of 4 g/m^3 and 22 m/s airflow rate, when the peripheral airflow part rate was 55%, and transit

airflow – 45%, and five-channel's was 99.8%. Four-channel cyclone is able to remove fine-dispersive SP of aerodynamic diameter of up to 1 to 7 μm from the airflow, reaching cleaning efficiency of 1 μm – 17.6%, 2 μm – 28.8%, 4 μm – 46.8%, 7 μm – 58.5% (Fig. 7). Five-channel cyclone is able to remove fine-dispersive SP of aerodynamic diameter of up to 1 to 7 μm from the airflow, reaching cleaning efficiency of 1 μm – 49.1%, 2 μm – 65.1%, 4 μm – 77.9%, 7 μm – 98.3% (Fig. 8). Experimental researches have shown that efficiency of removal of SP particles in multichannel cyclones from the airflow increases with increase of SP density, concentration from 1 to 4 g/m^3, SP aerodynamic diameter – from 1 to 10 mm, the airflow rate – from 12 to 22 m/s, during the increase of transit airflow amount rate, at the aerodynamic resistance of 150 Pa to 375 Pa.

5. Simulation of aerodynamic processes of multichannel cyclone

This chapter examines the aerodynamics of air – solid particles in multichannel (three-and four-ring) cyclone with a tangential flow inlet. For simulation of single-phase and two-phase flow PHOENICS 5.3 software package was used. Mathematical model of airflow movement in cyclone was based on Reynolds (for turbulent flow) three-dimensional differential equations. Carry differential equations for non-condensable turbulent flow inside the cyclone were numerically solved by means of the finite volume method using the RNG (Renormalization Group k-ε model) – for single-phase flow and Reynolds stress model (RSM). Modification of Chen-Wood k- epsilon model used for the simulation of two-phase flow with SP. Two-phase flow (air – SP) simulation was performed with particles of different sizes – 1, 2, 10, 20 and 50 μm, using the IPSA (Inter-Phase-Slip Algorithm) method. The simulation was carried out when airflow inlet rate was 12–22 m/s, the Reynolds number – $2.2 \times 10^4 – 4.2 \times 10^4$, which shows the turbulent flow in cyclone. Simulation results were compared with experimental results. According to physical model of cyclone, discretisation was made for its numerical model, and cylindrical space was divided by finite volume elements. Figure 9 shows the cyclone simulation area in three-dimensional space of cylindrical coordinate system, which is divided into cells x, y, z in the directions of coordinate axes: $x \times y \times z = 40 \times 36 \times 45 = 64.800$ (Fig. 9.) and $x \times y \times z = 60 \times 36 \times 45 = 97\,200$ volumetric cells was made. Four speeds were used for airflow inlet (inlet opening on the side of cylinder) into cyclone: 12, 14, 16 and 22 m/s. At the outlet (opening at the top of cyclone), zero-pressure conditions were adopted.

The chapter analyzes the tangential speed contours in four-channel cyclone, when the inlet rate is 22 m/s at A_1 (Fig. 10 a) position. Also, this chapter presents the analysis of experimental and simulation results. Single-phase simulation results in four-channel cyclone were compared with experimental results.

Experimental researches have shown that given the inlet airflow rate – 12 m/s, at A_2 position at 9 measuring point, the experimental results are lower (13.2 to 14.5 m/s) and form a local relative error of 9.8%. Experimental Results of third channel at 12 measuring point are higher than the numerical results, and form a marginal local relative error of ±3.6%. Results of the third channel got at 13 measuring point showed that the rate of experimental researches is greater by ±3% than the numerical ones, the rate of experimental researches at 15 measuring point is greater than the numerical ones by±15.7%.

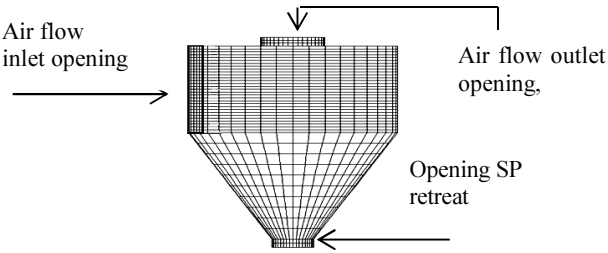


Fig. 9. Grid sketch of cylindrical multichannel cyclone calculation

Total comparative average error of experimental and simulation rates in five-channel cylindrical cyclone (with inlet velocities 12, 16 and 22 m/s) is ±9.2%. The greatest comparative average relative error was obtained at inlet rate of 22 m/s, lesser errors were received at the inlet rates of 12 and 16 m/s, 7.4 and 7.2%, respectively. This chapter also describes numerical simulation for the two-phase flow in cylindrical multichannel cyclone. SP concentration of 4.0 g/m^3 was used for researches (wood ash, density – 2451 kg/m^3). SP contours of volumetric part in cross-section z – 0.14 m from the top of cyclone at the first position of five-channel cyclone half-rings, at inlet rate of 22 m/s with particle sizes of 50 20, 10, 2 and 1 μm are given (Fig. 10 b). Comparison of experimental and simulation results related to general effciency of five-channel cyclone using wood ash SP at concentration of 0.5 to 4 g/m^3, when SP diameter is 0.47 to 50 μm: A_1 position of half-rings, the average relative error is±1.48%, A_3 position of half-rings ±1.41%. A numerical model coincided with the experimental efficiency results of cyclone efficiency by removing SP of aerodynamic diameter of up to 50 μm. The average relative error between the experimental and simulation results determined was ±14.2% when wood ash of 1–2 μm aerodynamic diameter was removed in five-channel cyclone at concentration of 0.5 to 4.0 g/m^3. Results of SP concentration distribution in cyclone show that the centrifugal force does not have a significant effect on the movement of small particles and leads to lower collection efficiency of particles – 30.6 to 50%. Removal efficiency of SP of 1.0 μm aerodynamic

diameter in cyclone when the inlet rate – 22 m/s is up to – 48.0%, while the simulation showed a 33% efficiency, the discrepancy of results is±15%.

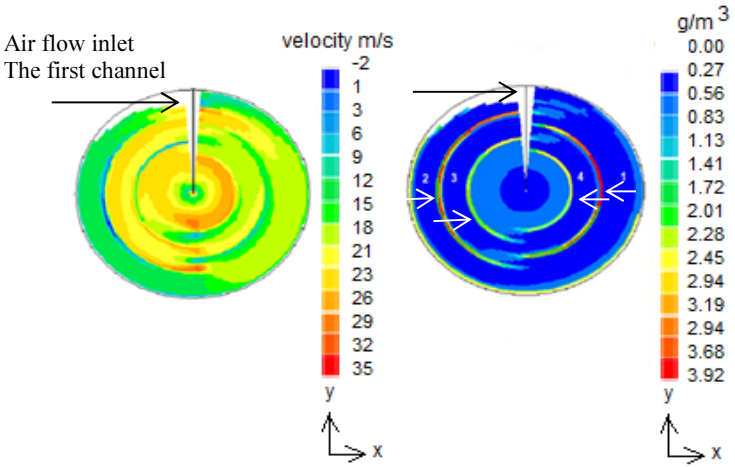


Fig. 10. Distribution of speeds (u) m/s within cross section Z – 0.14 m from the top of cyclone in cylindrical and five-channel inlet velocity 22 m/s a) distribution of first phase speeds; b) SP distribution of concentration in cyclone, d_{SP} = 50 mikrons (4.0 g/m^3)

The methodology (numerical experiment) for claculation of general efficiency determination in cyclone was formed, corresponding to the two-phase flow experimental results with an error of ±15.0%. The mathematical-numerical model received can be used as a research tool, with other parameters and inlet rates.

6. Engineering solution

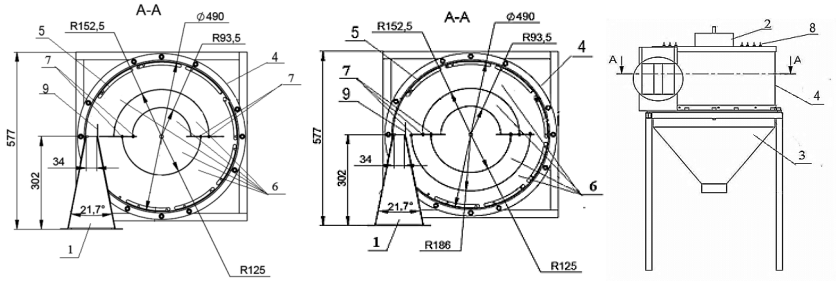
This chapter provides a cylindrical multichannel cyclone for cleaning of air (gas) through the extraction of (SP) from them. According to the cleaning method, this equipment is assigned to the dry air cleaning devices. According to the accomplished experimental researches, this equipment can be used for the removal of wood ash and cement clinker. To adapt cylindrical multichannel cyclone to other airflow rate, geometrical parameters of cyclone (diameter and height of cyclone separation chamber) should be recalculated according to the following approximate empirical formula:

$$G_2=G_1\times \sqrt[4]{\frac{X_2}{X_1}},$$

G_1 – geometric parameter of created cylindrical multichannel cyclone m; G_2 – geometric parameter of cyclone under design, m; X_1 – flow rate of created cyclone, m^3/ s; X_2 – flow rate of cyclone under design, m^3/s.

This empirical formula is derived after the mathematical analysis of the same type of multichannel cyclones cleaning different air flow contaminated with SP. Data for mathematical analysis have been taken from the following website source: http://www.ecologenergy.narod.ru/Publish/m0219.pdf *comparing multi-channel cyclones of 2500 and 10 000 m^3/h flow rate).* After having divided the diameter of cyclone housing under design by the diameter of improved cyclone, we find a coefficient of geometric similarity – 1.18, which is applied to the detection of cyclone half-rings'and their layout in the cyclone separation chamber. Width of cross-section of cyclone regulated half-rings can be calculated knowing the ratio of peripheral and transit flow. This cylindrical multichannel cyclone has cylindrical half-rings of different radii with adjustable intervals and gaps in separation chamber for SP removal (Fig. 11 a, b).

The goal of the invention is to improve the design of cyclone through the adjustment of the width of channel gaps of half-rings in order to increase the efficiency of SP removal from the airflow.



a) b)

Fig. 11. Principled scheme of cylindrical four-channel (a) and five-channel (b) cyclone with adjustable gaps of curved channels

Confusor (1), purified air outlet opening (2), conical hopper (3), cylindrical chamber (4) with slots for SP removal (5), curved channels with cylindrical half-rings of different radii (6), adjustable gaps between the half-rings (7), retainig devices for

adjustable half-rings (8), airflow partition from the side of half-rings (9). Figure 13 presents principled scheme of five-channel and four-channel cyclone. Airflow runs in tangential direction through the inlet opening (1) and enters the chamber (4), where circulating airflow is distributed within channels of different curvature (6) and filtered through the gaps of half-rings (7). SP in channels (6) under the exposure of centrifugal and weight force are removed through the slots on the bottom of separation chamber (5) and get into a conical hopper (3), where most of SP mass is eliminated. The remaining smaller particles return through the gaps of half-rings (7) into the active area of half-rings of channels (6), are continued to be filtered and enter into the conical hopper (3). Having consistently passed all channels, purified airflow is discharged from the system through the opening (2).

Improved design of cyclone increases the efficiency of SP removal. There is a partition near the tangential airflow openings to guide the airflow only to the first channel. Partition height is equal to the height of chamber, and width – to the width of inlet opening. Such design of multichannel cyclone allows dust of different origin to control equipment system individually for maximum SP cleaning from the airflow. Equipment dimensions: diameter of cylindrical housing – 0.50 m, total height of cyclone (with a conical hopper) – 0.72 m, diameter of flow outlet opening – 0.16 m, size of flow inlet opening (into the first channel) – 0.034 × 0.29 m^2. The goal of the invention is to improve the design of cyclone through the adjustment of the width of channel gaps of half-rings in order to increase the efficiency of SP removal from the airflow. Two patent requests for acquisition of patent have been prepared and submitted.

General conclusions

1. After the analysis of the scientific literature it was found that the efficiency of removal of multichannel cyclone (centrifugal filters) solid particles depends on the number of cylindrical half-rings in the equipment. Based on the experiences of other scientists it is possible to improve the design of multichannel cyclone.
2. Maximum efficiency of the removal of 97.6% solid particles from gas (air) flow can be achieved by adjusting half-rings in the five-channel cyclone.
3. Experimental researches have shown that the increase of concentration of solid particles from 0.5 to 4 g/m^3 and airflow rate from 12 to 22 m/s, when the part of peripheral flow is 45%, while the part of transit flow is 55%, will lead to the overall efficiency of four-channel cyclone of 95.8%, five-channel – 97.6% during the removal of solid particles of less than 50 μm from the airflow and particles 65.9 to 83.5% of less than 20 μm.
4. Efficiency of five-channel cyclone when removing solid particles of 10 μm totals 99.8%. This was determined by density of solid particles –

3160 kg/m^3, maximum concentration of 4 g/m^3, airflow rate – 22 m/s, when distribution of peripheral airflow amount made 45%, and transit one's – 55%.

5. Results of the distribution of solid particles concentration in the cyclone show that the movement of fine – dispersive particles is not significantly influenced by the centrifugal force, and leads to lower efficiency of the removal of particles, i.e. 18–50%.
6. It was found that efficiency of numerical simulation results of the particles smaller than 50 μm in the five-channel cyclone were close to the results of physical experiment at inlet velocity of 12 to 22 m/s and at concentration of 0.5 to 4.0 g/m^3. Average relative error of the results obtained was ± 2.8%, which represents the suitability of theoretical model for the calculation of the tasks of such kind (two-phase).
7. Experimental researches have shown that during the adjustment of optimal gaps of regulated half-rings, the five-channel cyclone removes SP more effectively than six-channel centrifugal filter, i.e.: clinker solid particles – 3.4%, wood ash – 3.3%, quartz sand flour – 2.6%.

List of published works on the topic of the dissertation
In the reviewed scientific journals

Vaitiekūnas, P.; Jakštonienė, I., 2010b. Analysis of numerical modelling of turbulence in the conical reverse flow cyclon. *Journal of Environmental Engineering and Landscape Management.* Vilnius: Technika. ISSN 1648-6897. 18 (4): 321–328. IF=1.958 (Thomson ISI Web of Science).

Vaitiekūnas, P.; Jakštonienė, I.; Serebryanskyy, D. 2010c. Analysis of numerical modelling of turbulence in the multichannel cyclone. *Journal of Chemical and Process Engineering– Inżynieria Chemiczna i Procesowa.* ISSN 0208-6425. 31(4):635– 645. IF=0.2 (ISI Master List)

Baltėrnas, P.; Vaitiekūnas, P.; Jakštonienė , I.; Konoverskytė, S. 2012a. Study of Gas–Solid Flow in a Multichannel Cyclone. *Journal of Environmental Engineering and Landscape Management*. Vilnius: Technika. ISSN 1648-6897. 20 (2):129–137. IF=1.958 (Thomson ISI Web of Science).

Jakštonienė, I., Vaitiekūnas, P. 2009. Skaičiuojamosios fluidų dinamikos modeliavimo taikymas kūginiam grįžtamojo srauto ciklonui. **[**Application of computable fluid dynamics modelling for conical cyclone of reverse flow**]**. *Mokslas – Lietuvos ateitis. Aplinkos apsaugos inžinerija* 1(4): 51–55. ISSN 2029-2341 (Index Copernicus).

Jakštonienė, I.; Vaitiekūnas, P. 2010a. Dujų turbulencijos ciklone modeliavimas. **[**Modelling of gas cyclone turbulence**]**. *Mokslas – Lietuvos ateitis. Aplinkos apsaugos inžinerija* 2(5): 17–23. ISSN 2029-2341. (Index Copernicus).

In other editions

Jakštonienė, I.; Vaitiekūnas, P. Daugiakanalio ciklono efektyvumo tyrimai. 2011a. [Researches on the efficiency of multichannel cyclone]. *Mokslas – Lietuvos ateitis. Aplinkos inžinerija: Straipsnių rinkinys.* ISBN 978-9955-28-956-2. Lietuva, Vilnius. Technika, 18–22 (Index Copernicus).

Jakštonienė, I.; Vaitiekūnas, P. Oro srauto greičio cilindrinio daugiakanalio ciklono kanaluose tyrimai. 2012 b. *Mokslas – Lietuvos ateitis. Aplinkos inžinerija. Straipsnių rinkinys*. Lietuva, Vilnius: Technika, 11–14. ISBN 978-9955-28-956-2 (Index Copernicus).

Jakštonienė, I.; Serebryanskyy, Dmytro.; Vaitiekūnas, Petras. 2011b. Experimental research on the work of centrifugal Filter when eliminating solid particles from clinker cooling system. *The 8th International Conference, Environmental Engineering, selected paper,* May 19–20, 2011. ISBN 978-55-28-826-8. (1 Volume). Vilnius Gediminas Technical University Press „Technika", 134–138.

Prepared request for patent

Baltrėnas, P.; Vaitiekūnas, P., Sygal, A.; Serebryanskyy, D.; Jakštonienė, I. 2011. *Clindrinis daugiakanalis ciklonas* [Cylindrical multichannel cyclone]. Nr. 2011 041.

Baltrėnas, P.; Serebryanskyy, D.; Jakštonienė, I. 2011. *Spiralinis daugiakanalis ciklonas,* [Helical multichannel cyclone]. Nr. 2011 03389.

About the author

Inga Jakštonienė was born in Kretinga on 28 August 1966.

In 2005, took a Bachelor's degree in Environmental Engineering at Faculty of Chemical Technology of Kaunas University of Technology. In 2007, completed Master's degree in Chemical Engineering at Faculty of Chemical Technology of Kaunas University of Technology. From 2008 to 2012, PhD student of Vilnius Gediminas Technical University. Has been working at Utena college since 2006.

CILINDRINIO DAUGIAKANALIO CIKLONO SU REGULIUOJAMAIS PUSŽIEDŽIAIS TYRIMAI IR TOBULINIMAS

Mokslo problemos aktualumas

Pagrindiniai kietųjų dalelių (KD) išmetimo į aplinką Lietuvoje šaltiniai yra energetikos objektai – šiluminės elektrinės ir katilinės bei pramonės įmonės. Užteršta atmosfera savo ruožtu sąlygoja išlaidas, atsirandančias dėl pablogėjusios gyventojų sveikatos. Rusijos Federacijos Aplinkos apsaugos ir gamtos išteklių ministerija prognozuoja, kad dujų ištekliai pasibaigs 2025 m., o nuo 2030 m. pirmenybė bus teikiama anglies ir atominei energetikai. Tokie kuro ir energetikos balanso pasikeitimai visame pasaulyje gali pareikalauti ekonomiškiausių ir efektyviausių oro valymo įrenginių panaudojimo. Europos Sąjungos (2008/50/EB) ir Lietuvos teisės aktai reglamentuoja dviejų teršalo frakcijų – KD_{10} (iki 10 mikrometrų skersmens dalelės) ir $KD_{2,5}$ (iki 2,5 μm skersmens dalelės). Kietosios dalelės, kurių aerodinaminis skersmuo yra ne didesnis už 2,5 μm, yra daugiausia problemų sveikatai keliantys teršalai. Įprastų išcentrinių oro valymo įrenginių efektyvumas siekia nuo 85–90 %, tačiau daugelio ciklonų trūkumas – žemas mažesnių nei 10 μm dalelių surinkimo efektyvumas. Tai ypač aktualu, kai dėl sveikatai žalingų kietųjų dalelių išmetimo į orą reikia laikytis griežtų aplinkosauginių reikalavimų. Kiti sukurti aukšto efektyvumo oro valymo nuo kietųjų dalelių įrenginiai (rankoviniai, elektrostatiniai filtrai ir kt.) yra gana brangūs, o jų eksploatacija sudėtinga. Taigi, norint atitikti didžiausias ES šalių leidžiamas išmetamų kietųjų dalelių koncentracijas į atmosferą, būtinas efektyvių oro valymo įrenginių panaudojimas. Mažinant oro taršą kietosiomis dalelėmis yra įgyvendinami naujos Direktyvos (2008/50/EB) dėl aplinkos oro kokybės ir švaresnio oro Europoje tikslai. Parenkant atitinkamas oro valymo technologijas, gali būti pasiektas teigiamas efektas, kuris dažniausiai išreiškiamas ir įvertinamas kapitalinėmis ir eksploatacinėmis išlaidomis, pasirinkto oro valymo įrenginio efektyvumu ir patikimumu. Literatūros šaltiniuose nerasta duomenų apie ciklonus, turinčius pusžiedžių tarpų reguliavimo sistemą, bei atliktus eksperimentinius tyrimus. Todėl labai aktualu sukurti naujos kartos cilindrinį daugiakanalį su reguliuojamąja pusžiedžių sistema cikloną, kuris būtų skirtas skirtingos kilmės, dispersijos, tankio bei koncentracijos kietosioms dalelėms iš dujų (oro) srauto valyti. Pastaruoju metu tyrinėtojai Tananajev (1997), Serebryanskyy, Prijomov (2004) pasižymėjo tuo, kad prisidėjo prie ciklono efektyvumo didinimo, kurdami naują daugiakanalio ciklono (išcentrinio filtro) modelį, kurio konstrukcijoje yra skirtingo spindulio pusžiedžiai.

Tyrimų objektas. Oro valymo įrenginys – cilindrinis daugiakanalis ciklonas (keturkanalis ir penkiakanalis) su reguliuojamais pusžiedžiais.

Darbo tikslas ir uždaviniai. Ištirti veiksnių kietosioms dalelėms iš dvifazio srauto daugiakanaliame ciklone šalinti įtaką ir remiantis eksperimentinių tyrimų rezultatais patobulinti daugiakanalį cikloną nustatant optimalias reguliuojamų pusžiedžių padėtis.

Darbo tikslui pasiekti darbe reikia spręsti šiuos uždavinius:

1. Atlikti vienfazio srauto cilindrinio keturkanalio ir penkiakanalio ciklono greičių kanaluose tyrimus.
2. Nustatyti cilindrinio daugiakanalio ciklono bendro efektyvumo priklausomybę nuo įvairių parametrų (oro srauto įtekėjimo greičio, kietųjų dalelių dispersiškumo, tankio, koncentracijos, cilindrinių pusžiedžių skaičiaus) naudojant skirtingos kilmės kietąsias daleles.
3. Atlikti smulkiadispersinių kietųjų dalelių šalinimo iš oro srauto tyrimus cilindriniame daugiakanaliame ciklone esant skirtingoms cilindrinių pusžiedžių padėtims tyrimus, nustatant optimalią pusžiedžių padėtį.
4. Atlikti vienfazio ir dvifazio oro srauto cilindriniame daugiakanaliame ciklone aerodinaminių procesų modeliavimą ir gautus rezultatus palyginti su eksperimentiniais.

Tyrimų metodika. Darbe taikomi dujų srauto greičio ir tūrio debito ortakyje matavimo ir kietųjų dalelių koncentracijos nustatymo (svorio) metodai, smulkiadispersinių kietųjų dalelių išvalymo iš oro srauto efektyvumui nustatyti tyrimų metodika. Vienfaziui ir dvifaziui srautui modeliuoti naudotas PHOENICS 3.5 programinės įrangos paketas.

Mokslinis darbo naujumas. Atlikti kompleksiniai eksperimentiniai cilindrinio keturkanalio ir penkiakanalio ciklonų, turinčių reguliuojamą pusžiedžių sistemą, efektyvumo ir smulkiadispersių dalelių (nuo 1–7 μm) tyrimai apima šių ciklonų tobulinimo ir modeliavimo procesus, kuriais nustatyta, kad penkiakanalio ciklono su reguliuojamais pusžiedžiais efektyvumas prilygsta šešiakanalio neturinčio reguliuojamų pusžiedžių (išcentrinio filtro) efektyvumui.

Praktinė reikšmė. Remiantis atliktų tyrimų rezultatais galima teigti, kad cilindrinis penkiakanalis ciklonas, nustačius optimalias pusžiedžių padėtis, gali būti naudojamas skirtingos kilmės smulkiadispersinėms kietosioms dalelėms iš dujų (oro) srauto šalinti.

Ginamieji teiginiai

1. Penkiakanalio ciklono su reguliuojamais pusžiedžiais efektyvumas prilygsta šešiakanalio ciklono (išcentrinis filtras) neturinčio reguliuojamų pusžiedžių efektyvumui.
2. Keturkanalio ir penkiakanalio ciklono bendras efektyvumas šalinant iš oro kietąsias daleles priklauso nuo oro srauto greičio, kietųjų dalelių koncentracijos, tankio bei periferinio ir tranzitinio oro srauto kiekio pasiskirstymo cilindrinių pusžiedžių tarpuose.
3. Patobulintas penkiakanalis ciklonas gali pašalinti iš oro srauto smulkiadispersines – nuo 1 iki 7 μm aerodinaminio skersmens kietąsias daleles, o tai nebūdinga tradiciniams ciklonams, pasiekdamas 1 μm – 49,1 %, 2 μm – 65,1 %, 4 μm – 77,9 %, 7 μm – 98,3 % valymo efektyvumą.

Darbo apimtis. Disertaciją sudaro įvadas, 6 skyriai, išvados ir rekomendacijos, literatūros sąrašas, autoriaus publikacijų sąrašas ir priedas. Darbo apimtis yra 141 puslapiai, tekste panaudotos 28 numeruotos formulės, 68 paveikslai ir 20 lentelių. Rašant disertaciją buvo panaudoti 105 literatūros šaltiniai.

Pirmasis skyrius skirtas literatūros apžvalgai, kurioje nagrinėjama oro tarša KD, pasaulyje naudojamų ciklonų konstrukcijos ir jų panaudojimo sritys, aprašytos pernašos procesų modeliavimo programos. Skyriaus pabaigoje formuluojamos išvados ir uždaviniai. Antrajame skyriuje pateikta oro srauto greičio kanaluose tyrimų metodika, tyrimų rezultatai, analizė ir išvados. Trečiajame skyriuje pateikta daugiakanalio ciklono bendro efektyvumo naudojant skirtingos kilmės KD eksperimentinių tyrimų metodika, tyrimo rezultatai ir analizė, suformuluotos išvados. Ketvirtajame skyriuje pristatyta skirtingo dydžio KD šalinimo iš oro srauto daugiakanaliame ciklone metodika ir pateikta gautųjų rezultatų analizė ir išvados. Penktajame skyriuje pateiktas vienfazio ir dvifazio srauto skaitinis modeliavimas. Gauti rezultatai pavaizduoti, aprašyti ir palyginti su eksperimentiniais duomenimis. Šeštajame skyriuje aprašytas patobulintas daugiakanalis ciklonas ir jo naudojimo sritis.

Bendrosios išvados

1. Išanalizavus mokslinę literatūrą nustatyta, kad daugiakanalių ciklonų (išcentriniai fltrai) kietųjų dalelių šalinimo efektyvumas priklauso nuo cilindrinių pusžiedžių skaičiaus įrenginyje. Todėl remiantis kitų mokslininkų patirtimi yra galimybė patobulinti daugiakanalio ciklono konstrukciją.
2. Maksimalų 97,6 % kietųjų dalelių šalinimo iš dujų (oro) srauto efektyvumą galima pasiekti penkiakanaliame ciklone reguliuojant pusžiedžius.

3. Eksperimentinių tyrimų metu nustatyta, kad didėjant kietųjų dalelių koncentracijai nuo 0,5 iki 4 g/m^3 bei oro srauro greičiui nuo 12 iki 22 m/s, kai periferinio srauto dalis – 45 %, o tranzitinio srauto dalis – 55 % bendras keturkanalio ciklono efektyvumas siekia – 95,8 %, penkiakanalio – 97,6 % šalinant iš oro srauto mažesnes nei 50 µm kietąsias daleles ir 65,9–83,5 % mažesnes nei 20 µm daleles.
4. Penkiakanalio ciklono efektyvumas šalinant 10 µm kietąsias daleles siekia 99,8%. Tai lėmė kietųjų dalelių tankis – 3160 kg/m^3, didžiausia 4 g/m^3 koncentracija, oro srauto greitis – 22 m/s, kai periferinio oro srauto kiekio pasiskirstymas siekė 45 %, o tranzitinio – 55 %.
5. Kietųjų dalelių koncentracijos ciklone pasiskirstymo rezultatai rodo, kad išcentrinė jėga neturi didelės įtakos smulkiadispersinių dalelių judėjimui ir lemia 18–50 % žemesnį dalelių šalinimo efektyvumą.
6. Nustatyta, kad mažesnėms nei 50 µm dalelėms penkiakanalio ciklono efektyvumo skaitinio modeliavimo rezultatai yra artimi fizinio eksperimento rezultatams, esant įtekėjimo greičiui nuo 12 iki 22 m/s bei 0,5–4,0 g/m^3 kietųjų dalelių koncentracijai. Gautų rezultatų vidutinė santykinė paklaida ±2,8 % rodo teorinio modelio tinkamumą tokio pobūdžio (dvifaziams) uždaviniams skaičiuoti.
7. Eksperimentinių tyrimų metu nustatyta, kad nustatant optimalius reguliuojamų pusžiedžių tarpus penkiakanalis ciklonas efektyviau šalina kietąsias daleles nei šešiakanalis išcentrinis filtras, t. y. klinkerio kietąsias daleles – 3,4 %, medienos pelenų – 3,3 %, kvarcinio smėlio miltų – 2,6 %.

Trumpos žinios apie autorių

Inga Jakštonienė gimė 1966 m. rugpjūčio 28 d. Kretingoje.

2005 m. įgijo Aplinkos inžinerijos bakalauro laipsnį Kauno technologijos universito Cheminės technologijos fakultete. 2007 m. baigė chemijos inžinerijos magistro studijas Kauno technologijos universito Cheminės technologijos fakultete. 2008–2012 m. Vilniaus Gedimino technikos universiteto doktorantė. Nuo 2006 m. dirba Utenos kolegijoje.