VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Darius OZAROVSKIS

THE RESEARCH OF ACOUSTIC CYCLONE

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
MECHANICAL ENGINEERING (09T)

VGTU LEIDYKLA
Vilnius TECHNIKA 2012

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2008–2012.

Scientific Supervisor

Prof Dr Habil Vladas VEKTERIS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

The dissertation is being defended at the Council of Scientific Field of Mechanical Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Habil Rimantas KAČIANAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

Members:

Prof Dr Habil Vytautas BARZDAITIS (Kaunas University of Technology, Technological Sciences, Mechanical Engineering – 09T),

Assoc Prof Dr Mindaugas JUREVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T),

Dr Darius MARKAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T),

Prof Dr Habil Piotr VASILJEV (Lithuanian University of Educational Sciences, Mechanical Engineering – 09T).

Opponents:

Prof Dr Habil Bronius BAKŠYS (Kaunas University of Technology, Technological Sciences, Mechanical Engineering – 09T),

Assoc Prof Dr Arnas KAČENIAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Mechanical Engineering in the Senate Hall of Vilnius Gediminas Technical University at 9 a. m. on 25 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).

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Darius OZAROVSKIS

AKUSTINIO CIKLONO TYRIMAS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
MECHANIKOS INŽINERIJA (09T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2012

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

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

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

Pirmininkas

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

Nariai:

prof. habil. dr. Vytautas BARZDAITIS (Kauno technologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

doc. dr. Mindaugas JUREVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

dr. Darius MARKAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Piotr VASILJEV (Lietuvos edukologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Oponentai:

prof. habil. dr. Bronius BAKŠYS (Kauno technologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

doc. dr. Arnas KAČENIAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Disertacija bus ginama viešame Mechanikos inžinerijos mokslo krypties tarybos posėdyje 2013 m. sausio 25 d. 9 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“ 2106-M mokslo literatūros knyga

Introduction

Topicality of the problem. The expansion of science and technology is related to negative impact on the environment: the amounts of waste are increasing, more resources are used up and environment pollution is growing.

All these materials are recycled, burned and returned to environment as a waste. During the processes of recycling raw materials, producing half-finished and finished products, breaking up raw materials (such as coal, different ore, etc.), burning fossil fuel, the industry creates dust – fine hard particles flowing in the air. Thrown out industrial gas, polluted by the dust, has to be cleaned. The dust created during these operations consists of particles the size of which can be from 0,01 μm. The smaller the particles are, the more difficult it is to separate them from the cleaned air flow. The attention should be drawn to the fact that cyclones do not compress the particles of size less than 10 μm efficiently. The methods of compressing such size particles are costly, their usage and maintenance is complicated.

The object of research. The object of research – acoustic cyclone and processes taking place in it.

Aim and tasks of the work. The aim of the thesis is to develop and explore acoustic cyclone and to improve research methods of such systems. In order to achieve the aim the following tasks are to be completed in the thesis:

1. To carry out the review of scientific literature on the employment of acoustic field for interaction of fine particles.
2. To analyze and ground the impact of acoustic field parameters on the adhesion of fine particles.
3. To analyze and to ground the concept of acoustic cyclone, its working principles and simulation of flows theoretically.
4. To design acoustic cyclone based on returning flow principle.
5. To carry out experimental research with the designed cyclone.

Methodology of research. Numerical and experimental methods are applied in the thesis. Numerical research is carried out using special software SolidWorks Flow Simulation 2011 2.0. Build 1525. The generated acoustic fields of aerodynamics acoustic generators were tested according methodology of Brüel & Kjær company.

Scientific novelty

1. The research method of fine particles' interaction due acoustic field in air flow is developed.
2. The methodology for the formation of the secondary flow in the cyclone is developed.
3. Defined primary and secondary flows' relative parameters on the dependenses of efficiency of acoustic cyclone.

Practical value. The application of acoustic cyclone makes the process of cleaning fine particles simplified; it becomes cheaper, takes less time and costs less work expenditure in comparison to other currently used methods. Acoustic cyclone can be used in various technological processes of mechanical treatment industry.

Defended propositions

1. The new method of precipitation of fine particles is based on the secondary flow formation in acoustic field increses the efficienty of cleaning of acoustic cyclone.
2. Methodology for estimation of acoustic field influent on particles' in air flow is developed.
3. Combination of traditional dry and acoustic agglomeration cleaning methods in acoustic cyclone extends cleaning range in regards to particle size.

The scope of the scientific work. The thesis consists of an introduction, 4 chapters, conclusions, a list of references and a list of publications by the author. The thesis contains 97 pages, 33 numerated equations, 60 figures and 7 tables. The first chapter is dedicated for the literature review. The research of particles' interaction in acoustic field and development of acoustic sources improvement process are provided in this chapter. In the end of the chapter the conclusions are provided and the tasks of the thesis are specified. In the second chapter the development process and research of acoustic sources are described. In the third chapter the impact of acoustic field parameters on fine particles' adhesion is analyzed. In the fourth and the fifth chapters numerical and experimental research of acoustic cyclone and their results are presented.

1. The review of acoustic cyclones, the analysis of behavior of ultrafine particles in air flow and source of acoustic field

In order to create a system for cleaning a polluted air flow by acoustic field effect, it is necessary to understand not only the behaviour of one particle, but also the behaviour of all particles that appear to be in acoustic field. Acoustic coagulation theory is based on a few physics tasks. The first one involves the behaviour of a separate particle and the behaviour of fine particles' system in a powerful acoustic field. The solution of this task allows estimating the regularities of physical mechanism in particles' adhesion in acoustic field. In this chapter the research of fine particles' interaction in acoustic field will be carried out on the basis of the model of physical hydrodynamic interaction.

In acoustic field, around the flowing particle a particular viscous flowing around hydrodynamic field is formed. Therefore, it is possible to estimate relative movement of two or more particles only after estimating the interaction of their flow-around fields. Depending on configuration of the particle in particular limited conditions we can estimate hydrodynamic field around that particle by using Navier-Stokes equation. The distribution of velocity fields around that particle depends on Reynold's number Re which characterizes working conditions of the flow-around. The flowing around task of solid spherical particle with smaller Reinold's numbers $Re<<1$ was solved by Stokes. With absolutely viscous Stokes flow-around working conditions, field of velocities around the particle is symmetrical.

The top approximation boundary of Stokes applicability can be considered to be as follows: when $0,5 < Re < 1,0$. If velocity of particle increases, when $Re > 1$, inertness of environment has significant impact on viscous flow. Hydrodynamic flow around spherical particles becomes unsymmetrical and Osen's approximation has to be used for its descriptions.

Having Osen's flow-around working conditions with long distances r from the centre of the sphere, in the front of the sphere and in the narrow streak behind it, a radial flow directed towards movement of the sphere occurs.

It is necessary to note that having working conditions of Stokes and Osen's flow-around, the nature of velocity distribution behind the particle is the same.

Most often in the particles' of the size less than 1–5 μm acoustic interaction sound pressure of 140–160 dB is used and Reynold's number- less than 0,1–0,5.

The analysis of cyclones with acoustic generators. Acoustic cyclone (Fig. 1) with the secondary contrary flow consist of cylindrical frame 1, a pipe 2 for supplying polluted air tangentially attached to frame's side wall and a pipe for removing cleaned air looking upwards through the frame's 1 symmetry axis 3. Next to the lower part of cylindrical frame 1, conical part 5 of the frame is attached, narrowing down from cylindrical part 1 of the frame. The narrowest part 6 of conical frame is hermetically attached to container collecting pollution 7, at the bottom of which a damper 7 is located for removing pollution.

Acoustic generator 9 is located in the narrowest part 6 of conical frame through the central symmetrical axis 3. The outside diameter of the nave 10 of acoustic generator 9 is smaller than inside diameter of conical frame 6 and, thus, a gap 11 appears between them. At the bottom of the nave 10 there is a flow forming nozzle 12 fixed and joined to the pipe 13 for supplying compressed air. Above the nozzle 12 in the inside zone of the nave 10 there is a reflector 14 fixed, to the outside walls of which at angle α from central cyclone axis, 3 the plates 15 are fastened. The top of the angle α is directed opposite from the direction of the pipe 2 of polluted air supply in order to tangentially enter the cylindrical part 1 of the frame. Two air flows emerge in the cyclone – the first flow 16 and the second flow 17.

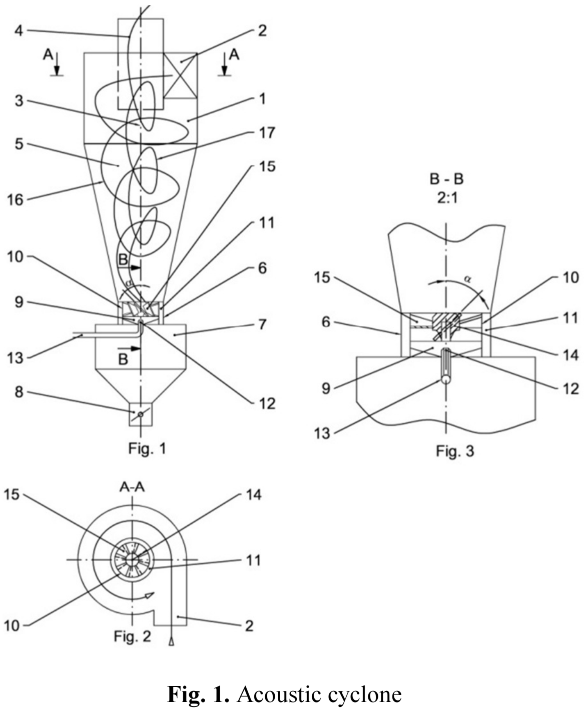


Fig. 1. Acoustic cyclone

Interaction of particles in the acoustic field. Hydrodynamic interactions of particles in the acoustic adhesion play an important role. However, it is not enough for the description of physical process and construction of a model of acoustic conglutination, which would allow calculating acoustic energy needed for cleaning a polluted air flow as well as estimating the characteristics of the particles influenced by acoustic field. In order to construct an overall view of scaly system made of large amount of particles affected by acoustic field, it is necessary to get acoustic coagulation macro process equations.

The analysis of acoustic field sources development. Aerodynamic generators convert kinetic energy of the flow into ultrasound frequency resilient oscillation energy. The generators of such type can be compact enough and their production is not complicated. In coagulation, drying and froth extinguishing processes dynamic sirens and static sirens (also called gas flow whistles) are the most popular among aerodynamic generators.

Static (gas flow) aerodynamic generators. In static aerodynamic generators gas comes out with ultrasonic velocity from the nozzle 1 and periodically fills the resonator 2, later the gas outburst coming out from resonator collides with gas flow coming from the nozzle. Thus, the leap of density is formed which while oscillating generates sound. The simplest construction of such gas flow whistle (Fig. 2) was created by Hartman. The construction consists of a nozzle, a resonator and mechanism which regulates the volume of resonator.

If we measure the pressure of flow using Pitot tube in different distances from the nozzle exit hole and place the results in the diagram, we would get the curve K as illustrated in Fig. 2b.

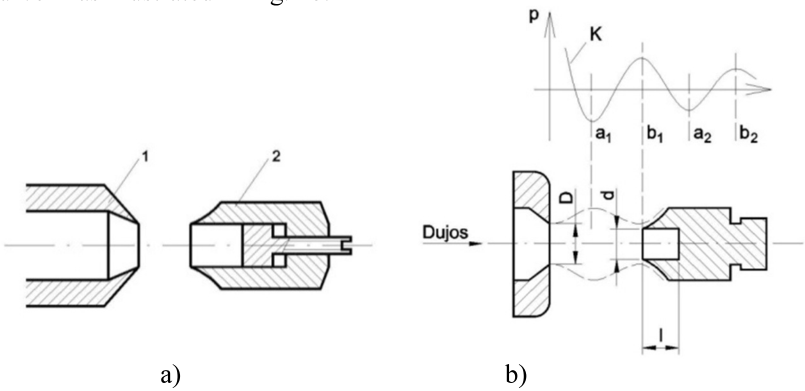


Fig. 2. Construction of gas flow generator: 1 – nozzle, 2 – resonator

Dynamic sirens. The working principle of dynamic sirens is based on interruptions of compressed air flow supply. The air is supplied through system of holes. The holes are distributed one in front of another in circle in two discs installed in one axis: the stationary one (stator) and the spinning one (rotor). In this manner the air flow is interrupted between the holes located in rotor and stator. Periodical opening and closure of the holes creates altering resistance of the air flow. This resistance alters from minimal value (the holes are fully opened) to maximal value (the holes are fully closed). This evokes periodical rarifying and compression of the air flow, or, in other words, resilient oscillations.

Electro-mechanical acoustic generators. Electro-mechanical acoustic generator is equipment which converts electricity oscillation energy into mechanical oscillation. Electro-mechanical radiators depending on their working principle are separated into electro-magnetic, electro-dynamic, piezoelectric, magnetostrictive and elecrtostatic ones.

The working principle of electro-magnetic generators is based on the moving mechanical system oscillation caused by electrical magnet evoked by altering electricity current.

In electro-dynamic radiators oscillation is evoked by magnetic field between stationary magnet and by electric coil interaction.

In electrostatic radiators acoustic oscillation is generated through interaction of membrane and electric field created by stator. Stator can be made of metal plates with holes or of tight wire.

The working principle of magnetostrictive radiators is based on oscillation caused by pivot made of magnetoscrictive material and altering its geometric dimensions affected by altering magnetic field.

In piezoelecrtic radiators acoustic oscillation is evoked by cell which has piezoelectric properties and which is affected by electric field.

2. The research of parameters of acoustic sources

The formation of acoustic fields can occur for various reasons. The cases analyzed in this chapter are related to air flows which create acoustic field. Therefore, it is important to know the reasons for formation of acoustic field as well as dependences on air flow, to estimate their characteristics and to select the parameters of acoustic generators.

The formation of acoustic field in air flowing process. Acoustic oscillation is the density of the air altering at high frequency and spreading in the environment. In common case, in acoustics it may be called a sound.

The research of acoustic oscillation generators. Six aerodynamic acoustic field generators were constructed and produced for the research. They were tested in order to estimate the parameters of acoustic field generated by them: the pressure and frequency of sound. The construction of generators is presented in Fig. 3.

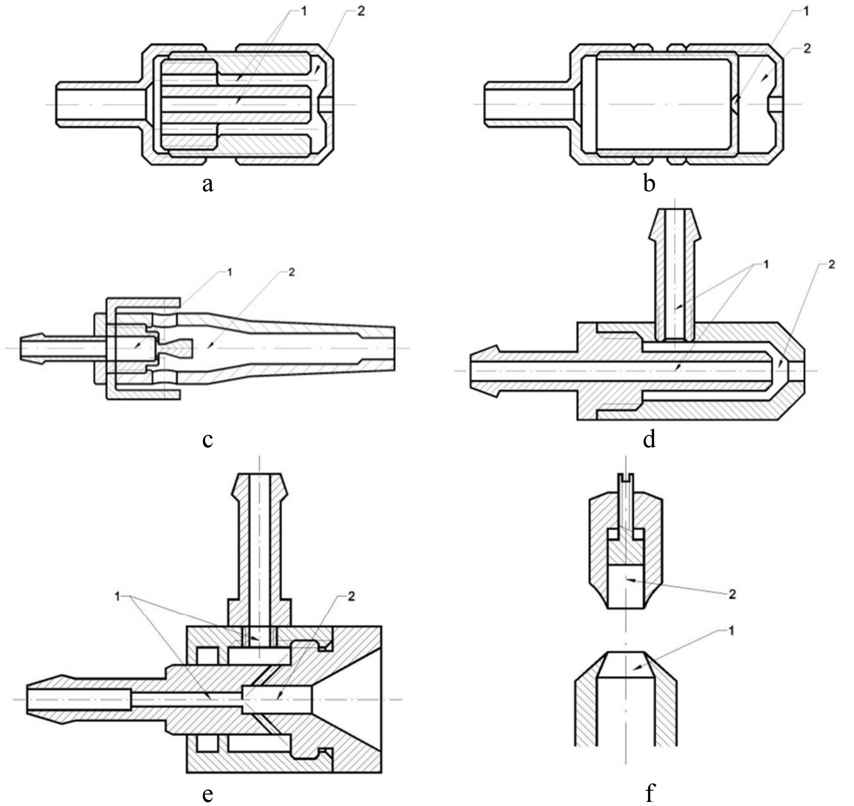


Fig. 3. The construction of acoustic generators:
a – AAG-1; b – AAG-2; c – AAG-3; d – AAG-4; e – AAG-5; f – AAG-6.

The working principle of all presented aerodynamic acoustic generators is the same. In static aerodynamic generators gas coming out from a nozzle 1 periodically fills a resonator 2, later the outburst of gas coming out from a resonator collides with a gas flow coming out from the nozzle. Thus, the leap of density is formed which oscillates and generates sound.

The characteristics of acoustic field spread by aerodynamic acoustic generators are presented in Fig. 4. We can maintain that aerodynamic acoustic generator AAG-6 is most pawerfull from others.

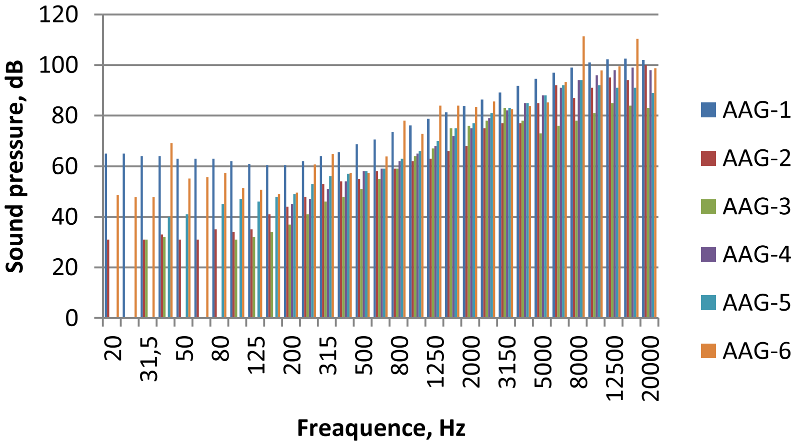


Fig. 4. The acoustic field emitted by aerodynamic acoustic generators at different frequency

From Fig. 4 we can find out, that the high level of pressure sound is observed at 8 and 16 kHz.

3. Influence of acoustic field parameters on agglomeration of particles in the air flow

Experimental research of horizontal acoustic chamber. For the research of acoustic field parameters on adhesion of particles a special stand was designed and produced. The stand consists of pipes with air flow analysers 1, acoustic chamber 2, throttle 3, ventilator 4, dosator 5, HEPA filter 6, aerosol particles diluter 'Ati TDA-D100' 7 and particles' measuring and calculating system 'Lasair II" 8. The scheme of stand is presented in Fig. 5.

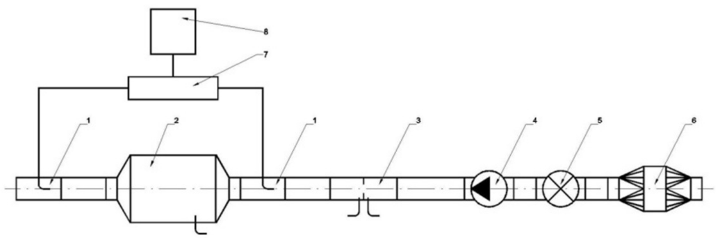


Fig. 5. The scheme of experimental stand

By the help of ventilator 4 air is sucked into HEPA filter 6, which filters particles in the air flow up to size of 5 µm. Into the cleaned air flow grinded silica sand is provided by dosator 5. The size of grinded silica sand grains is up to 5 µm. Then, the air flow with silica sand particles moves through the throttle 3 towards the acoustic chamber 2. In front of acoustic camera 2 there is a pipe 1 with air flow analyser fixed. In this way the size of particles in the air flow is recorded and their amount in fractions before the influence of acoustic field. Air flow with silica sand particles enters acoustic chamber 5, where the flow is affected by aerodynamic generator generated by acoustic field. Then, the air flow affected by acoustic field moves through the pipe with flow analyser 1 fixed just behind the chamber 2 and flows out to the environment. Two air flow analysers 1 fixed in front of and behind acoustic chamber 2 help us to compare the size of particles in the flow as well as their amount in fractions before the impact of acoustic field and after it.

The result of experiment showed that concentration of different size particles altered differently. In the picture presented in Fig. 6 the alteration of different size particles concentration in the air flow is illustrated.

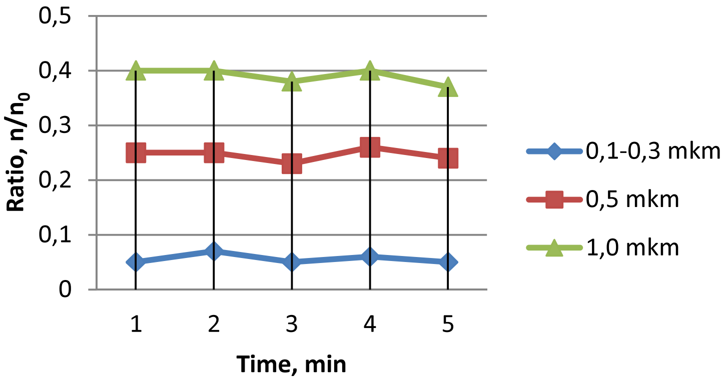


Fig. 6. The alteration of different size particles' concentration in air flow: n_0 – the amount of particles 1 m^3 before the effect of acoustic field; n – the amount of particles 1 m^3 after the effect of acoustic field

It was noticed that the smaller the particles are, the smaller is the alteration of their concentration and vice versus – the larger the particles are, the bigger alteration of their concentration is before and after the effect of the acoustic field. In both cases, the concentration of particles after the impact of acoustic field was reducing. This allows making a presumption that particles affected by acoustic field acquire displacement and approaching one another merge. In this way agglomeration of particles takes place, the particles grow larger and heavier and their amount is changing depending on the size of the particle.

4. Experimental and numerical research of acoustic cyclone

Experimental research of acoustic cyclone. The aim of this chapter is to carry out experimental and numerical research of acoustic cyclone, i.e., to measure the parameters of the air flows existing in cyclone with and without the secondary contrary air flow entry. These measurements are to be compared with theoretical - numerical results. The efficiency of cleaning cyclone and acoustic cyclone is also to be estimated. All listed parameters will be compared and conclusions will be made on the second contrary air flow and the effect created by acoustic source.

Acoustic cyclone was designed and constructed for experimental research. Its construction, component parts and working principle are described in detail in the first chapter. Complete experimental stand (Fig. 7) consists of acoustic cyclone 1, ventilator 2, air providing pipe 3, dosator 4, compressed air providing pipe 5, bunker 6 and aerodynamic acoustic generator 7.

From ventilator 2 air flow is provided through the pipe 3 to cyclone 1. Between providing pipe 3 and cyclone 1, there is dosator 4 fixed, through which silica sand is added to the air flow. In the cyclone silica sand separated from the flow is poured to collecting bunker. Compressed air flow enters acoustic generator's reflector 7, where air pressure pulsations take place. The secondary air flow pulsing goes through vanes 8 that turn the flow and further on the secondary flow, whirling the opposite direction to the main flow, rises upwards.

The research of the air flows in cyclones. In the walls of constructed cyclone the holes were additionally drilled, through which Pitot tube could be entered and used for air flow measuring (Fig. 8). Pitot tube were entered through each hole and the air flow was measured in four directions.

The data collected during measuring process was presented in a graph and diagrams of flows' velocities were drawn across and along the central axis of the cyclone. The diagrams of air flow velocities are presented in Fig. 9. The arrows placed next to the curves display the direction of the air flow.

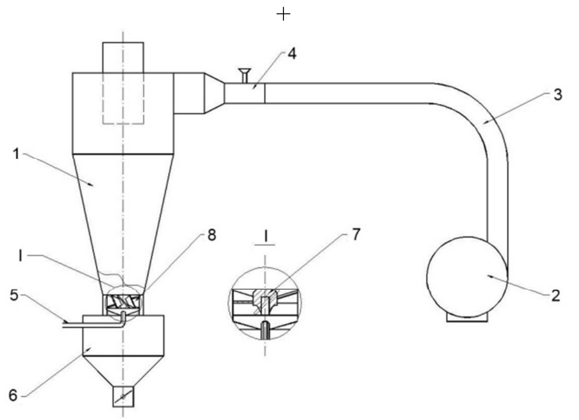


Fig. 7. Experimental stand
of acoustic cyclone

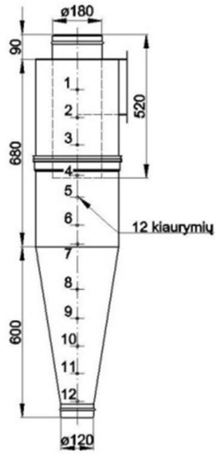


Fig. 8. Experimental
cyclone

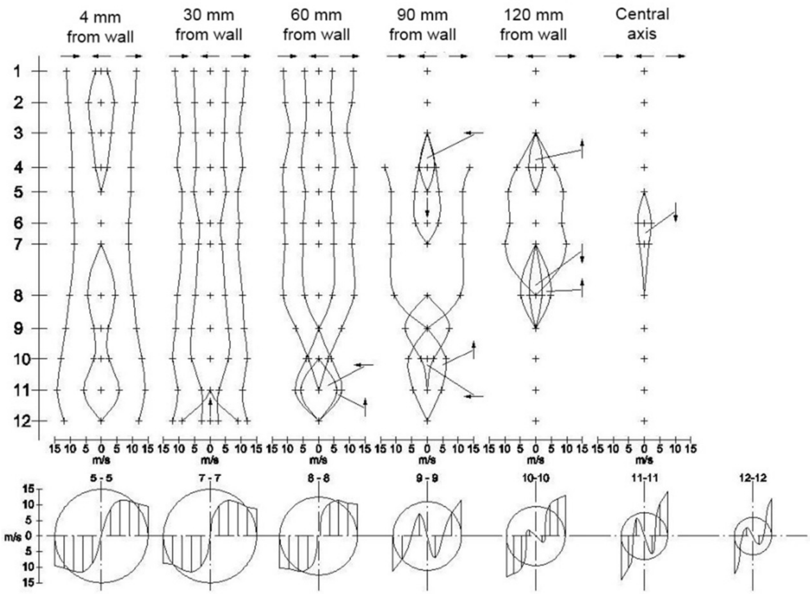


Fig. 9. Graphs of the flows' velocities in acoustic cyclone

Experimental research of cyclones' cleaning efficiency. Before the research of cyclones' efficiency, acoustic background existing in cyclone while providing the main air flow from ventilator in three sections of cyclone was measured using Bruel & Kjær measuring equipment. Then the flow of compressed air was spread into aerodynamic acoustic generator. The acoustic field spread by generator in the cyclone was measured in the same three sections (Fig. 10).

The average sound level in acoustic cyclone is about 120 dB, but the pitches of sound level are recorded at every 8 kHz, that is at 8 kHz, 16 kHz and 24 kH. At the pitches the sound reaches up to pressure amplitude 170 dB. Therefore, we can maintain that air pressure pulsations in aerodynamic acoustic generator take place at frequency of 8 kHz.

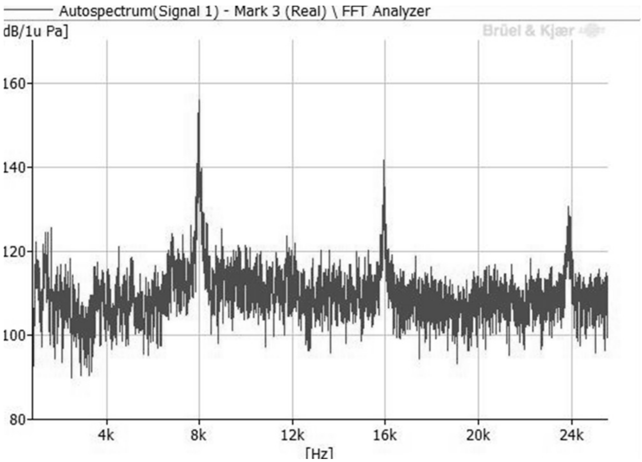


Fig. 10. Acoustic field inside acoustic cyclone

Cleaning efficiency of traditional cyclone varied from 82,9 to 90,2 percent., the average 87,2 percent., and cleaning efficiency of acoustic cyclone – from 97,1 to 98,0 percent., the average 97,5 percent. Therefore, we can claim that the impact of the secondary flow and acoustic field significantly increases the efficiency of cyclone's cleaning.

In Fig. 11 dependence of cleaning efficiency upon the ratio Q_2/Q_1, that is, the ratio of the main (primary) air flow Q_1 and the contrary (secondary) air flow Q_2.

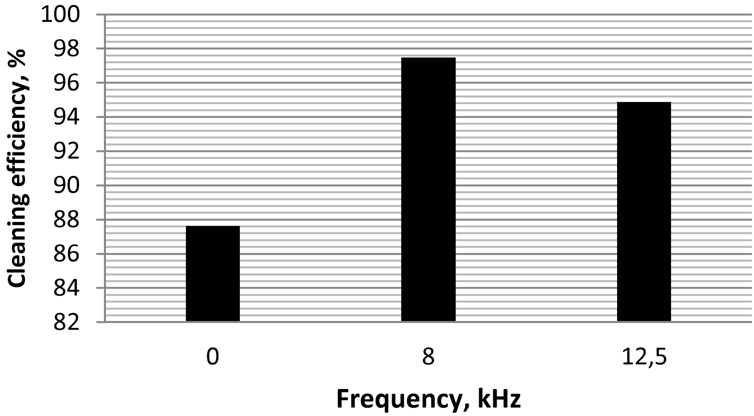


Fig. 11. The dependence of cleaning efficiency upon Q_2/Q_1: Q_1 – the primary air flow; Q_2 – the secondary air flow

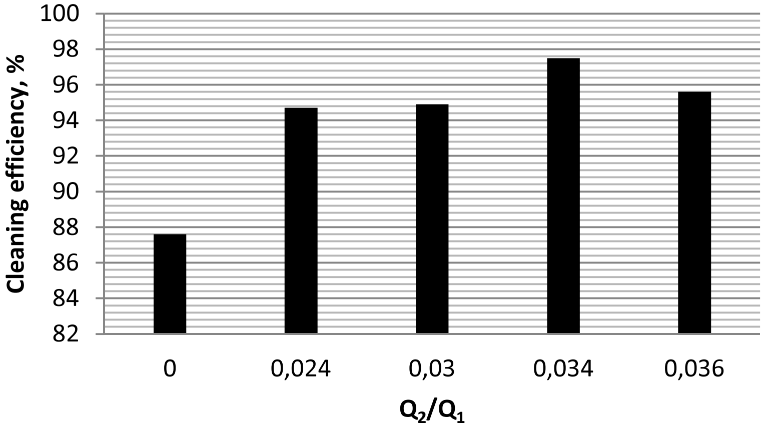


Fig. 12. Dependence of cleaning efficiency upon acoustic field's frequency

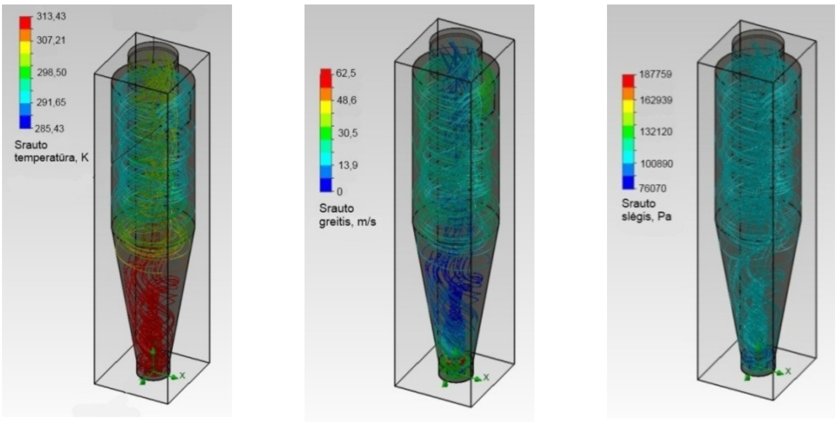
The highest efficiency of acoustic cyclone was revealed while effecting polluted air flow by acoustic field of 8 kHz frequency (Fig. 12). During the experiment it was also noticed that the effect of acoustic generator was highest on detachment of larger particles. In the meantime, for the detachment of the smallest particles (smaller than 1 μm) ultrasound acoustic generator should be used.

Numerical research of acoustic cyclone. In this chapter the processes that take place in cyclones are analyzed. Numerical research is carried out using software SolidWorks Flow Simulation 2011 2.0. Flow Simulation solves the Navier-Stokes equations, withch are formulation of mass, momentum and energy conservation laws for fluid flows. The equations are supplemented by fluid state equations defining the nature of the fluid, and by empirical dependencies of fluid density, viscousity and thermal conductivity on temperature. A particular problem is finally speciefied by the definition of its geometry and initial conditions.

Flow Simulation is capable of predicting both laminar and turbulent flows. Most of the fluid flows encountered in engineering practice are turbulent, so Flow Simulations was mainly developed to simulate and study turbulent flows. To predict turbulent flows, the Faver-avaraged Navier-Stokes equations are used.

Numerical simulation carried out allows to understanding the processes that take place in cyclones easier.

The results of numerical research of acoustic cyclone. The results of numerical research of the acoustic cyclone with the secondary contrary flow are presented in a graph in Fig. 13.



a b c

Fig. 13. Numerical analysis of air flows in acoustic cyclone: a – temperature values; b – velocity values; c – pressure values

The main exclusivity of the acoustic cyclone is located in the integrated aerodynamic acoustic generator, at the lower part of the cyclone. As numerical research showed in the reflector of the generator intensive pressure pulsations take place which generate acoustic field.

General conclusions

1. The connection of acoustic agglomeration and cyclone air cleaning methods significantly enhances the efficiency of cyclone air cleaning and makes it possible to use it for ultrafine particle separation from the cleaned air flow.
2. Having measured the parameters of acoustic field inside acoustic cyclone, we can maintain that aerodynamic acoustic generator matches with pressure of acoustic field provided in literature – 140–160 dB by which the interaction, that is adhesion of particles with 1–5 μm diameter takes place. Such level of pressure sound is observed at 8, 16 and 24 kHz, that is at every 8 kHz.
3. Numerical research showed that the highest pressure pulsations in acoustic cyclone take place in aerodynamic acoustic generator: minimum pressure – 54,4 kPa; maximum pressure – 267,6 kPa. Pressure pulsation generates acoustic field which affects the finest particles: they interact with one another, agglomerate, increase and become heavier and later, affected by rotary gravitational forces, they are removed from the cleaned air flow.
4. The entry of the contrary secondary flow into cyclone significantly influences the processes in it: in the conical part contrary whirling flow opposite to the main flow is formed, the air flow velocities are increased, high pressure pulsations are evoked, and in the lower part of the cyclone chaotic turbulent movement of the air flow is developed.
5. The impact of the secondary stream and acoustic field significantly increases the efficiency of cyclone control. The experiment showed that the average efficiency of cleaning traditional cyclone reached 87,7 percent, while that of acoustic cyclone reached 97,5 percent. The highest efficiency of cyclone was reached when affecting polluted air flow by 8 kHz frequency acoustic field.

List of published works on the topic of the dissertation
In the reviewed scientific periodical publications

Vekteris, V.; Striška, V.; Mokšin, V.; Ozarovskis, D. 2011. Study of the interaction between particles in the acoustic cyclone separator, *Ultrasound* Vol. 66, No. 1. ISSN 1392-2114 (INSPEC).

Vekteris, V.; Ozarovskis, D.; Zaremba, R.; Mokšin, V. 2011. Tribology of particles in acoustic field, *Ultrasound* Vol. 66, No. 3. ISSN 1392-2114 (INSPEC).

Vekteris, V.; Striška, V.; Mokšin, V.; Ozarovskis, D.; Zaremba, R. 2012. Tribological adhesion of particles in an acoustic field, *Journal of Vibroengineering,* Vol. 14, No 2. ISSN 1392-8716 (Thomson ISI Web of Science).

In the other editions

Vekteris, V.; Ozarovskis, D.; Striška, V. 2009. The Research of Acoustic Influence on Polluted Air Flow. in Proceeding of 14th International Conference "Mechanika 2009", Kaunas. ISSN 1822-2951 (ISI Proceedings)

Vekteris, V.; Ozarovskis, D.; Striška, V. 2010. The Research of Generators of Aerodynamic Acoustic Field. in Proceeding of 15th International Conference "Mechanika 2010", Kaunas. ISSN 1822-2951 (ISI Proceedings)

Vekteris, V.; Striška, V.; Mokšin, V.; Ozarovskis, D. 2011. Adhesion of particles in secondary air flow. in 15th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT, Prague. ISSN 1840-4944 (ISI Proceedings).

About the author

Darius Ozarovskis was born in Vilnius, on 27 of April 1978.

First degree in Mechanical Engineering, Faculty of Mechanics, Vilnius Gediminas Technical University, 2000. Master of Since in Mechanical Engineering, Faculty of Mechanics, Vilnius Gediminas Technical University, 2002. In 2000–2002 was working as constructor at UAB "Vultus". In 2002–2007 was working as chief of production department at UAB "Vilpra". From 2007 is working as managing director at UAB "Vilpros pramonė". In 2008–2012 PhD student of Vilnius Gediminas Technical University.

AKUSTINIO CIKLONO TYRIMAS

Problemos aktualumas. Mokslo ir technikos plėtra yra susijusi su neigiama įtaka aplinkai: didėja atliekų kiekis, sunaudojama daugiau išteklių, labiau teršiama aplinka. Gamybos medžiagos perdirbamos, deginamos ir atliekų pavidalu vėl patenka į aplinką.

Perdirbant žaliavas, gaminant pusfabrikačius ir galutinius produktus, smulkinant žaliavas (akmens anglį, rūdą ir pan.), deginant iškastinį kurą, pramonėje susidaro dulkės – smulkiadispersinės kietosios dalelės, pakibusios ore. Išmetamosios pramoninės dujos, užterštos dulkėmis, turi būti valomos. Šių operacijų metu susiformavusių dulkes sudarančių dalelių dydis būna nuo 0,01 µm. Kuo mažesnės dalelės, tuo sudėtingiau jas atskirti iš valomo oro srauto. Reikia atkreipti dėmesį, kad ciklonai daleles, kurių dydis yra mažesnis kaip 20 µm, sulaiko neefektyviai. Metodai tokio dydžio dalelėms atskirti yra brangūs, jų eksploatacija ir priežiūra sudėtinga.

Tyrimų objektas. Tyrimų objektas – akustinis ciklonas ir procesai vykstantys jame.

Darbo tikslas ir uždaviniai. Ištirti akustinį cikloną ir suformuluoti jo tyrimo metodiką. Darbo tikslui pasiekti darbe sprendžiami šie uždaviniai:

1. Atlikti mokslinės literatūros apžvalgą apie ciklonuose naudojamo akustinio lauko poveikį smulkių dalelių aglomeracijai.
2. Išanalizuoti ir pagrįsti akustinio lauko parametrų įtaką smulkių dalelių sukibimui ciklono srautuose.
3. Išanalizuoti ir teoriškai bei eksperimentiškai pagrįsti procesus, vykstančius akustiniame ciklone.
4. Sukurti akustinio ciklono prototipą, pagrįstą grįžtamojo srauto principu.
5. Atlikti sukurto akustinio ciklono eksperimentinius tyrimus.

Darbo mokslinis naujumas

1. Pasiūlytas eksperimentinis akustinio lauko parametrų poveikio smulkioms dalelėms ciklono oro sraute tyrimo metodas.
2. Pasiūlyta metodika, leidžianti formuoti antrinį srautą ciklone.
3. Nustatyta pirminio ir antrinio srautų santykinių parametrų įtaka akustinio ciklono efektyvumui.

Tyrimų metodika. Darbe taikomi skaitiniai ir eksperimentiniai metodai. Skaitiniai tyrimai atlikti baigtinių elementų metodu paremta programine įranga

„SolidWorks 2011 SP2.0 Flow Simulation 2011 2.0. Build 1525“. Atlikti aerodinaminių akustinių generatorių skleidžiamų akustinių laukų matavimai. Pagal sukurtą metodiką nustatytas akustinio lauko parametrų poveikis dalelėms oro sraute ir eksperimentiškai ištirtas naujai sukurtas akustinio ciklono prototipas.

Praktinė reikšmė. Taikant akustinį cikloną, labai supaprastinamas smulkių dalelių valymo procesas, jis tampa pigesnis, užima mažiau laiko ir darbo sąnaudų, lyginant su kitais šiuo metu taikomais būdais. Akustinis ciklonas gali būti naudojamas įvairių apdirbamosios pramonės technologinių procesų metu.

Ginamieji teiginiai

1. Pateikas smulkių dalelių nusodinimo būdas, pagrįstas antrinio srauto formavimu akustiniame ciklone, padidina įrenginio valymo efektyvumą.
2. Sukurta metodika leidžia įvertinti akustinio lauko parametrų poveikį smulkioms dalelėms oro sraute.
3. Apjungus tradicinius sausuosius ir akustinės dalelių aglomeracijos oro valymo metodus akustinis ciklonas gali išvalyti platesnio dydžių diapazono daleles.

Darbo apimtis. Darbą sudaro įvadas, 4 skyriai, išvados, literatūros bei autoriaus publikacijų sąrašai. Disertacijos apimtis – 94 puslapiai neskaitant priedo, 33 numeruotos formulės, 60 iliustracijų ir 7 lentelės. Pirmasis skyrius skirtas literatūros apžvalgai. Jame pateikta dalelių sąveikos akustiniame lauke ir akustinių šaltinių tobulinimo raidos analizė. Skyriaus pabaigoje formuluojamos išvados ir tikslinami disertacijos uždaviniai. Antrajame skyriuje aprašomi akustinių šaltinių kūrimas bei tyrimai. Trečiajame skyriuje tiriama akustinio lauko parametrų įtaka smulkių dalelių sukibimui. Ketvirtajame skyriuje pateikti skaitiniai ir eksperimentiniai akustinio ciklono tyrimai bei jų rezultatai.

Bendrosios išvados

1. Atlikus oro valymo metodų analizę, įvertinus eksperimentinius bei teorinius tyrimus nustatyta, kad akustinės aglomeracijos ir ciklono oro valymo būdų apjungimas ženkliai padidina ciklono oro valymo efektyvumą bei suteikia galimybę taikyti jį ultrasmulkių dalelių atskyrimui iš valomo oro srauto.
2. Išmatavus akustinio lauko parametrus akustinio ciklono viduje galime teigti, kad aerodinaminio akustinio generatoriaus skleidžiamas

akustinis laukas atitinka literatūroje nurodomą 140–160 dB akustinio lauko slėgį, prie kurio vyksta 1–5 μm skersmens dalelių aglomeracija. Toks garso slėgio lygis stebimas prie 8, 16 ir 24 kHz, kas 8 kHz.

3. Skaitiniai tyrimai parodė, kad didžiausios akustinio ciklono slėgio pulsacijos vyksta aerodinaminiame akustiniame generatoriuje: minimalus slėgis lygus – 54,4 kPa, maksimalus – 267,6 kPa. Slėgio pulsacija generuoja akustinį lauką, jo veikiamos smulkiausios dalelės sąveikauja tarpusavyje, sukimba, sustambėja ir pasunkėja, o tada veikiamos išcentrinių ir gravitacinių jėgų pašalinamos iš valomo oro srauto.
4. Papildomas antrinio priešpriešinio srauto padavimas į akustinį cikloną ženkliai įtakoja ciklone vykstančius procesus: kūginėje dalyje susiformavęs priešpriešinis sūkurinis srautas pagrindinio srauto atžvilgiu, padidina oro srautų greitį, sukelia dideles slėgio pulsacijas akustinio generatoriaus, apatinėje ciklono kūgio dalyje.
5. Antrinio srauto ir akustinio lauko poveikis ženkliai padidina ciklono valymo efektyvumą. Eksperimento metu tradicinio ciklono vidutinis valymo efektyvumas siekia – 87,2 proc., tuo tarpu akustinio ciklono – 97,5 proc. Ciklono didžiausias efektyvumas pasireiškia veikiant užterštą oro srautą 8 kHz dažnio akustiniu lauku.

Trumpos žinios apie autorių

Darius Ozarovskis gimė 1978 m. balandžio 27 d. Vilniuje.

2000 m. įgijo mechanikos inžinerijos bakalauro laipsnį Vilniaus Gedimino technikos universiteto Mechanikos fakultete. 2002 m. tame pačiame fakultete įgijo mechanikos inžinerijos mokslo magistro laipsnį. 2000–2002 m. dirbo konstruktoriumi metalo frezavimo staklių gamykloje UAB „Vultus“, 2002–2007 m. skardos gaminių cecho viršininku UAB „Vilpra“, nuo 2007 m. – direktorius UAB „Vilpros pramonė“. 2008–2012 m. Vilniaus Gedimino technikos universiteto doktorantas.

Darius OZAROVSKIS

THE RESEARCH OF ACOUSTIC CYCLONE

Summary of Doctoral Dissertation
Technological Sciences, Mechanical Engineering (09T)

Darius OZAROVSKIS

AKUSTINIO CIKLONO TYRIMAS

Daktaro disertacijos santrauka
Technologijos mokslai, mechanikos inžinerija (09T)

2012 12 21. 1,5 sp. l. Tiražas 70 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
http://leidykla.vgtu.lt
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius