Efficiency Increase of the Dust-extraction Plant By High-intensity Ultrasonic Action

Vladimir N. Khmelev, *Senior Member*, *IEEE*, Andrey V. Shalunov, Roman S. Dorovskikh,
Roman N. Golykh, Viktor A. Nesterov
Biysk Technological Institute (branch) of Altay State Technical University named after I.I. Polzunov, Biysk, Russia
Center of Ultrasonic Technologies, Biysk, Russia

Abstract **– The article presents the results of the studies aimed at the ways of efficiency increase of the dust-extraction unit operation on the base of Venturi pipe due to action of high-intensity ultrasonic vibrations. Carried out theoretical analysis of dust-extraction unit operation let determine the possibility of efficiency increase and dust reduction of gas at the output of the plant at the application of ultrasonic action.**

Index Terms **– Dust-extraction installation, Venturi pipe, ultrasonic action.**

I. INTRODUCTION

AT PRESENT wet dust-collecting apparatuses are widely used as a part of gas-cleaning unit, among which Venturi turbulent apparatuses (scrubbers) are the most efficient [1,2]. They provide efficiency of collecting of dispersed ash particles up to 94…96%. However such efficiency of dust collecting is insufficient due to the modern environmental requirements of protection from harmful industrial waste. At that further efficiency increase of such types of the dust-collectors due to changes of the construction and modes of movement of gas-dispersed and liquid phases does not produce needed results. The reason is that it is impossible to increase probability of collision of dispersed particles with the particles of sprayed water.

To increase the probability of collision of collecting dispersed particles with sprayed water drops is possible due to providing of vibrating motion to dispersed particle relative to heavier water particles. It can be realized the most effectively by acoustic action on gas-dispersed flow – i.e. due to ultrasonic coagulation of dispersed particles [3].

For estimation of efficiency of dispersed particle coagulation in Venturi pipe at the use of additional action of high-intensity ultrasonic vibrations there is a need to study the coagulation mechanisms in the analyzed device and determine optimum modes and conditions, at which ultrasonic action is able to provide maximum efficiency increase of dust-collecting.

As existing procedures of calculation of gas-cleaning equipment do not take into consideration the possibility of ultrasonic action for the decrease of residual dust content of smoke in the dust-extraction installation, we use universal methods of mathematical modeling of current and interaction of multiphase flows realized by numerical calculations on the computer with the application of special programs based on finite-element method. They let take into account a large number of determining factors, minimize assumptions and perform numerical calculations with high accuracy and at rather short period of time.

II. METHODS AND APPROACHES APPLIED AT THE DEVELOPMENT OF THE MODEL OF DUST-EXTRACTION INSTALLATION

It is known, that flows of gas, ash particles supplied to the input nozzle of the dust-extraction plant and sprayed water drops injected to Venturi pipe from the injector are multiphase dispersed system.

For the description of gas-dispersed flows with gas phase different mathematical models taking into consideration various mechanisms of interaction of flow with surrounding objects and having a number of assumptions are used.

At that the choice of mathematical model fully describing studied process (in this case it is the interaction of solid particles of ash with water drops) is the base for obtaining of adequate solution of stated problem.

In multiphase dispersed flows, which occur in the dust-extraction plant on the base of Venturi pipe, there is one continuous phase (purifying gas) and also one or several dispersed phases (for instance, ash and water). Dispersed phases contain a lot of discrete drops or particles, which are distributed in continuous phase. The size of the particles is much smaller than the size of cells in the mesh of finite element model, their large number does not let model the motion of each particle separately.

In this case it is necessary to solve the main equation for each phase considering the cloud of dispersed particles as a certain continuous medium (Euler approach) or replacing each group from fixed amount of particles (usually $10^4…10^6$) by one particle (Lagrange approach) having physical properties (diameter, mass, speed, etc.) equal for all group. Between different phases force interaction, heat and mass transfer should be taken into account.

Carried out analysis of the multiphase flow model showed, that Lagrange model considers fully the main factors influencing on the process efficiency of dispersed particles collecting in the dust-extraction plant (both at the presence and absence of ultrasonic action).

According to the model of discrete phases in polydisperse flow containing particles of various sizes coagulation effect occurs due to particle speed differential (orthokinetic coagulation), which influences on intensity of particles collision.

At the absence of ultrasonic action under the influence of inertial forces large particles move slower than little ones, and thereby probability of collision increases. At the presence of ultrasonic action large water drops are not involved into vibrational motion retaining initial trajectory, and small particles of ash (no more than 10 μm) vibrate on a large scale (i.e. with doubled amplitude) up to 100 μm increasing the space of effective interaction with water drops [4].

III. DETERMINATION OF OPERATION EFFICIENCY OF THE DUST-EXTRACTION PLANT

At the design of calculated model of Venturi scrubber it is assumed that:

– there is a laminar flow, i.e. gas moves in layers without mixing and pulsations(irregular and quick changes of speed and pressure);

– friction and adhesion of the particles on walls of Venturi pipe are not taken into consideration, at that inelastic reflection of the particles (ash and water drops) from the wall of Venturi pipe is assumed;

– settling of ash and drop particles on the wall of the drop catcher;

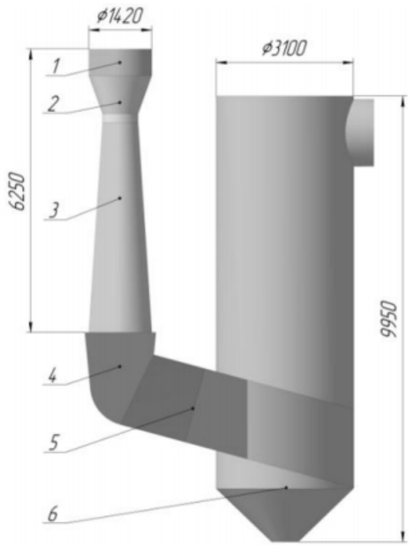
– absence of heat transfer between the phases and as a consequence absence of water drop evaporation;

– one-way interaction of continuous and dispersed phases (influence of dispersed particles on gas flow does not take into account).

To calculate efficiency of the plant we take following initial data corresponding to the operating parameters of the most dust-extraction plants exploited at present:

1. The temperature of smoke before the installation is 170ºC, that corresponds to the density of gas flow of 0.78 kg/m^3;
2. Mean size of the drops of sprayed water is 150…250 μm;
3. The volume of output smoke is 100000 m³/h that corresponds to speed of gas flow at the input of Venturi pipe equal to 17.4 m/sec.
4. Dust content before the plant is 17.0 g/Nm³ that corresponds to mass flow of ash of 0.35 kg/sec;
5. Speed of smoke in the confuser of Venturi pipe is 50…70 m/sec;
6. Water mass flow rate on the spraying of Venturi pipe is 10 t/h;
7. Size of ash particles formed at combustion of coal is defined according to scientific-technical data [5,6] and it can be of 2 to 90 μm.

For modeling of the motion of gas flow we designed 3d geometric model of the dust-extraction plant consisting of Venturi pipe and cyclone-drop catcher (see Fig.1).



1 – input nozzle; 2 – confuser; 3 – diffuser; 4 – curved part of the air pipe (pipe bend); 5 – connecting pipe; 6 – cyclone-drop catcher

Fig. 1. 3D model of the dust-extraction plant on the base of Venturi pipe.

Geometry and standard size of the model correspond to existing constructions of the dust-extraction plant applied in industry [2]. The results of modeling of gas flow motion are shown in Fig. 2.

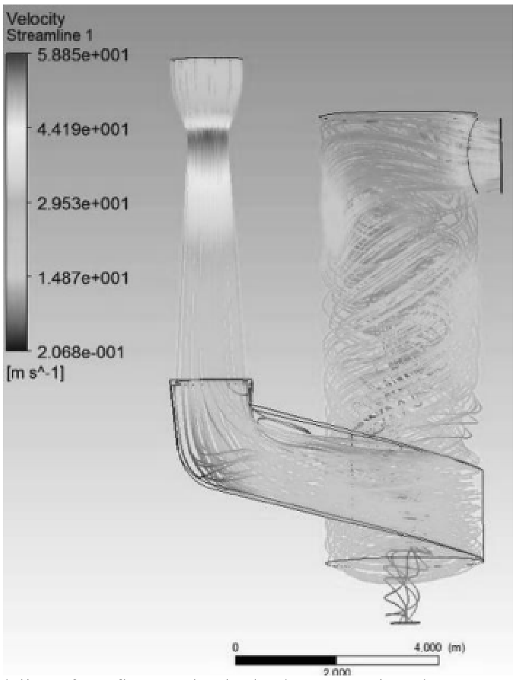


Fig. 2. Modeling of gas flow motion in the dust-extraction plant.

As it follows from obtained results, speed of gas flow in the opening of Venturi pipe achieves 58.8 m/sec. In turn in the papers [1,2] the range of values is 50…70 m/sec that proves adequacy of used model of gas flow motion.

The presence of ultrasonic vibrations in Venturi pipe is taken into consideration as additional force acting on individual particle located in the ultrasonic field, which is defined by disturbance of gas medium speed arising at the propagation of acoustic waves. At the calculation of force addition deviation of the form of ash particle from the spheric one is considered:

$$\Delta F = 3\pi d\mu\left(k_B \cos^2\theta + k_n \sin^2\theta\right)\times$$
$$\times\left(U_1 + U_2\right)\sin\left(2\pi f t\right),$$

where d is the largest diameter of the ellipsoid particle, m; μ is the viscosity of gas flow, Pa·sec; θ is the angle between smaller semi-axis of the particle and the direction of ultrasonic field, rad; k_B is the streamlining coefficient of the particle at flow motion along smaller semi-axis; k_N is the streamlining coefficient of the particle at flow motion along larger semi-axis; f is the frequency of vibrations (22 kHz); U_1 is the amplitude of disturbance of gas flow speed from the side of initial ultrasonic field, m/sec; U_2 is the amplitude of disturbance of gas flow speed from the side of water particles, m/sec; t is the time, sec.

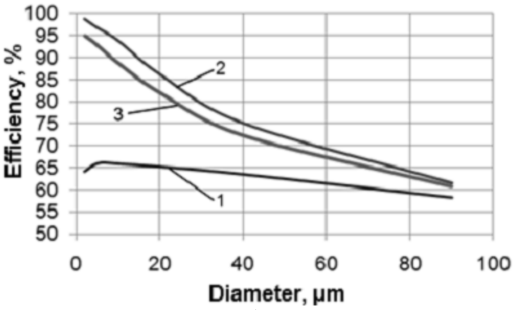
The force addition from the side of gas flow at the calculations is taken into account only at the presence of the particles in the volume of Venturi pipe.

According to the results of carried out calculations the dependences of efficiency and residual dust content of gas flow of Venturi pipe on the size of ash particles were obtained (see Fig. 3).

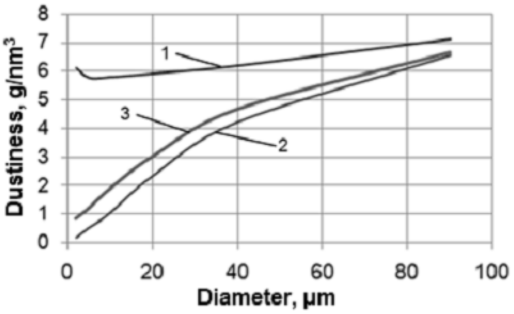
From presented results (see Fig.3) it follows, that the application of ultrasonic vibrations with the level of acoustic pressure of

150 dB provides no less than twofold dust reduction at the output of Venturi pipe for the particles with the size of up to 20 µm and in 1.5 times for the particles with the size of more than 20 µm.

It proves high efficiency of the application of ultrasonic vibrations for coagulation of suspended particles and mainly thin-dispersed ones (2 – 5 µm), for which six fold dust content reduction is provided.



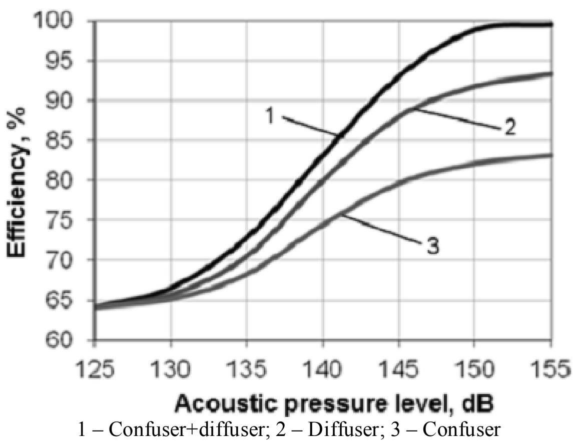
a)



b)

1 – without ultrasound, 2 – with ultrasound 150 dB; 3 – with ultrasound 145 dB
Fig. 3. Dependence of efficiency (a) and residual dust content (b) of Venturi pipe on the size of ash particles at different levels of acoustic pressure.

Further the calculations of determination of optimum zone of ultrasonic action at different levels of acoustic pressure were carried out (see Fig. 4).



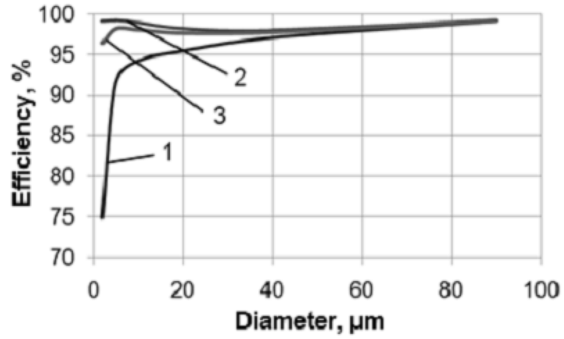
1 – Confuser+diffuser; 2 – Diffuser; 3 – Confuser
Fig. 4. Dependence of Venturi pipe on the level of acoustic pressure at different zones of ultrasonic action.

From obtained results it can be concluded, that to provide maximum efficiency of the coagulation process it is necessary to achieve uniform ultrasonic field in all volume of Venturi pipe (simultaneous ultrasonic action on the confuser and the diffuser).

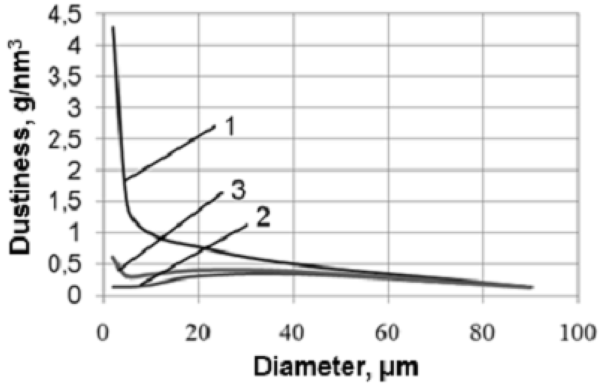
Fig. 5 shows the dependences of efficiency and residual dust content of the gas flow of all dust-extraction plant on the size of the ash particles.

From the dependences, shown in Fig. 5, it follows, that the application of ultrasonic action provides essential efficiency increase of the operation of the dust-extraction plant especially in the zone of high-dispersed particles. So for the particles of 2 µm efficiency of the plant rises from 75 % to 99.2 %.

Thus the use of ultrasonic action with frequency of 22 kHz is the most efficient for the particles of less than 20 µm. Larger particles are influenced by ultrasonic vibrations to a lesser degree, however for the particles of 20 µm to 40 µm the efficiency of the dust-extraction plant increases from 95.4 % to 98.2 %.



a)



b)

1 – without ultrasound; 2 – with ultrasound 150 dB; 3 – with ultrasound 145 dB
Fig. 5. Dependence of efficiency (a) and residual dust content (b) on the size of ash particles at different levels of the acoustic pressure.

Efficiency decrease after the application of ultrasound for large particles is leveled by high starting efficiency (without ultrasonic action) of collecting of such particles.

That is why, it can be concluded that the application of ultrasonic action for the efficiency increase of the dust-extraction plant on the base of Venturi pipe is expedient to reduce the content of high-dispersed ash fraction in smoke coming to the atmosphere after cleaning.

IV. Determination of Ash Powder at the Output of the Dust-Extraction Plant

At the final stage of the analysis theoretically achieved gas dust content at the output of the dust-extraction plant at known powder of ash at the input was determined.

Residual dust content of the gas was calculated on the base of obtained data on fractional efficiency of the dust-extraction plant (see Fig.5) by the following expression:

$$\eta_p = \frac{\sum_{i=1}^{N} \eta(d_i) W_i}{\sum_{i=1}^{N} W_i}$$

where η_p is the collecting efficiency of polydisperse ash, %; $\eta(d_i)$ is the dependence of collecting efficiency of monodisperse ash on the diameter d_i, %; i is the amount of the groups of sizes of ash particles; d_i is the size of the particles of i- group, m; W_i is the mass fraction of ash particles of i- group.

For objective efficiency estimation of the application of ultrasound the data on powder of flue ash obtained from reliable free sources [6] were used.

Fig 6 shows the results of calculation for ash obtained after burning of brown coal of Kharanor deposit ground by the mill MV 50–160 in the boiler BKZ 210–240 of Vladivostok heat station-2.

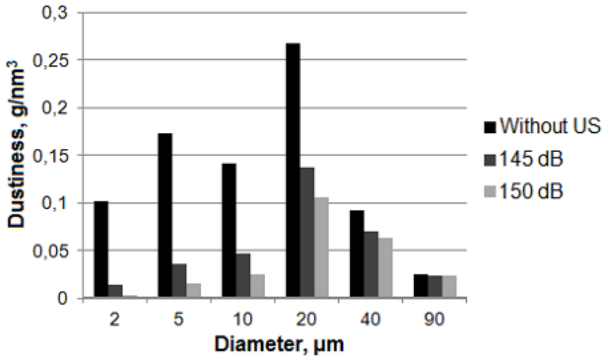


Fig. 6. Ash powder at the output of the dust-extraction plant.

From obtained data it follows, that at the output of the dust-extraction plant with the application of ultrasonic action with the level of acoustic pressure of 150 dB fractions with the size of particles of 2 – 5 μm are not observed (less than 0.05 g/m^3). Total dust content at the output of the dust-extraction plant is: Суммарная запыленность на выходе ЗУУ при этом составляет: without ultrasonic action – 0.802 g/Nm^3 (the efficiency is 95.253 %); at the acoustic pressure level of 145 dB – 0.329 g/Nm^3 (the efficiency is 98.065 %); at the level of acoustic pressure of 150 dB – 0.237 g/Nm^3 (the efficiency is 98.611 %).

Thus obtained results prove efficiency and prospects of the application of ultrasonic vibrations for efficiency increase of the dust-extraction plants on the base of Venturi pipes.

V. CONCLUSION

After carrying out the studies we obtained following results:

– it was determined, that the application of ultrasonic action provided essential efficiency increase of the operation of the dust-extraction plant, especially at collecting of high-disperse particles. For the particles with the size of 2 μm the efficiency of the plant rose from 75 % to 99.1 %;

– it was shown, that the use of ultrasonic action with the frequency of 22 kHz is the most efficient for the particles with the size of less than 20 μm. Larger particles were influenced by ultrasonic vibrations to a lesser degree; however for the particles with the size of 20 μm to 40 μm the efficiency growth of the dust-extraction plant was up to 3% (from 95.4 % to 98.2 %). At that efficiency decrease of the application of ultrasonic action for large particles was leveled by high starting efficiency (without ultrasonic action) of the dust-extraction plant at collecting of such particles;

– it was theoretically determined, that for ash obtained after burning of brown coal of Kharanor deposit the total dust content at the output of the dust-extraction plant without ultrasonic action was 0.802 g/Nm^3 (the efficiency was 95.2535 %), at ultrasonic action with the level of acoustic pressure of 145 dB it achieved 0.329 g/Nm^3 (the efficiency was 98.065 %); at ultrasonic action with the level of acoustic pressure of 150 dB it was 0.237 g/Nm^3 (the efficiency was 98.611 %).

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REFERENCES

[1] Uzhov, V.N. Purification of industrial gases from dust [Text] / A.U. Waldberg, B.I. Myagkov, I.K. Reshidov.– M.: Chemistry, 1981. – 392 p.

[2] Kropp, L.I. Dust-extractors with Venturi pipes at the thermal power stations [Text] / L.I. Kropp, A.I. Akbrut.– M.: Energy. – 1977. – 160 p.

[3] Khmelev, V.N. Ultrasonic coagulation of aerosols: monograph [Text] / V.N. Khmelev, A.V. Shalunov, K.V. Shalunova, S.N. Tsyganok, R.V. Barsukov, A.N. Slivin; Altai State Technical University, BTI. – Biysk, 2010. – 241 p.

[4] Khmelev, V.N. Acoustic coagulation of aerosol [Text] / V.N. Khmelev, A.V. Shalunov, R.V. Barsukov, S.N. Tsyganok, D.S. Abramenko // Polzunovskiy vestnik. – 2008. – №1-2. – P.66-74.

[5] Chernov, N.N. Acoustic methods and means of settling of suspended particles of industrial smoke: dissertation of Doctor of Technical Sciences: 01.04.06 / Chernov Nikolay Nikolaevich.– Taganrog, 2004. – 317 p.

[6] Skryabina, L.Ya. Industrial and sanitary gas cleaning. Atlas of industrial dusts. Part I. Flue ash of the thermal power stations [Text] / Central Institute of scientific-technical information and technical-economic studies of chemical and oil machine-building.– M., 1980. – 47 p.

Vladimir N. Khmelev (SM'04) is deputy director for scientific and research activity at Biysk technological institute, professor and lecturer, Full Doctor of Science (ultrasound), honored inventor of Russia, laureate of Russian Government premium for achievements in science and engineering, IEEE member since 2000, IEEE Senior Member since 2004. His scientific interests are in field of application of ultrasound for an intensification of various technological processes.

Andrey V. Shalunov has got engineer's degree at 2003 and Philosophy degree (Doctor of Engineering Sciences) at 2013. He is leading specialist in designing of interface systems of ultrasonic technological equipment and other devices, docent and lecturer in Biysk Technological Institute, laureate of Russian Government premium for achievements in science and engineering. His research interests are in designing of ultrasonic technological equipment and in applying of ultrasonic vibrations of high intensity for intensifying of technological processes and for changing of materials and substances properties, constructing of technological assemblies for ultrasonic technologies realization.

Roman S. Dorovskikh has got a higher education on information measuring engineering and technologies from Altay State Technical University at 2013. He is postgraduate student of Biysk Technological Institute.

Roman N. Golykh (S'10) is postgraduate student of Biysk Technological Institute now, IEEE Student Member since 2010. His research interests are in field of ultrasonic equipment and technologies, mathematical modeling of technological processes under the influence of ultrasonic oscillations in various media.

Viktor A. Nesterov has got a higher education on information measuring engineering and technologies from Altay State Technical University. He is engineer in Biysk Technological Institute. His research interests is finite-element modeling and designing ultrasonic oscillation system.