

SOLVING COAGULATION PROBLEMS IN EXTRACTION OF WATER FROM THE GROUND IN THE CONDITIONS OF EXTRATERRESTRIAL OBJECTS

Khmelev Vladimir Nikolaevich



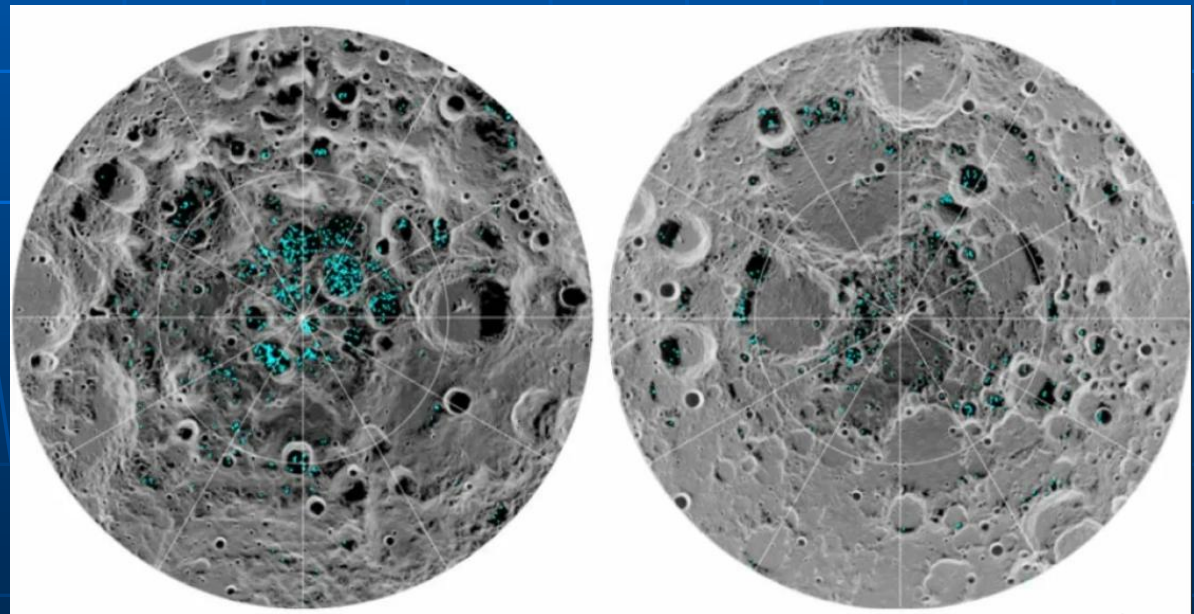
Doctor of Technical Sciences, Professor, Honored Inventor of the Russian Federation, Senior Member IEEE. Laureate of the Russian Government Award in the field of science and technology, author of more than 900 scientific publications (including more than 100 patents, more than 20 monographs and textbooks), Deputy Director for Scientific Work of the Biysk Technological Institute of the Altai State Technical University.

+7 9039925120
vnh@u-sonic.ru

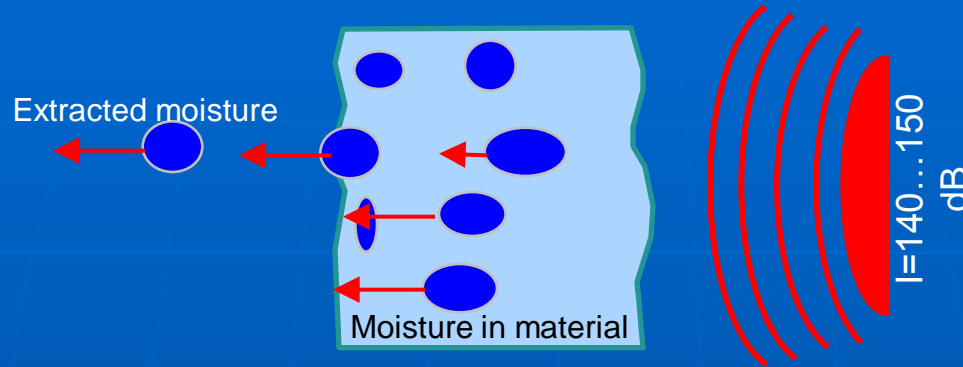
The purpose of water extraction on the Moon

- Great scientific interest (possible existence of life, conducting experiments impossible on earth);
- Possibility of colonization (extraction of oxygen, cultivation of plants, survival of mankind in case of global catastrophes on Earth);
- Extraction of hydrogen for fuel (launching spacecraft from the Moon for deep space exploration).

The estimated presence of ice at the poles of the Moon based on the results of data processing from the NASA Moon Mineralogy Mapper (M3) instrument (reflective properties, the ability of molecules to absorb infrared light)



Process of ultrasonic extraction of water



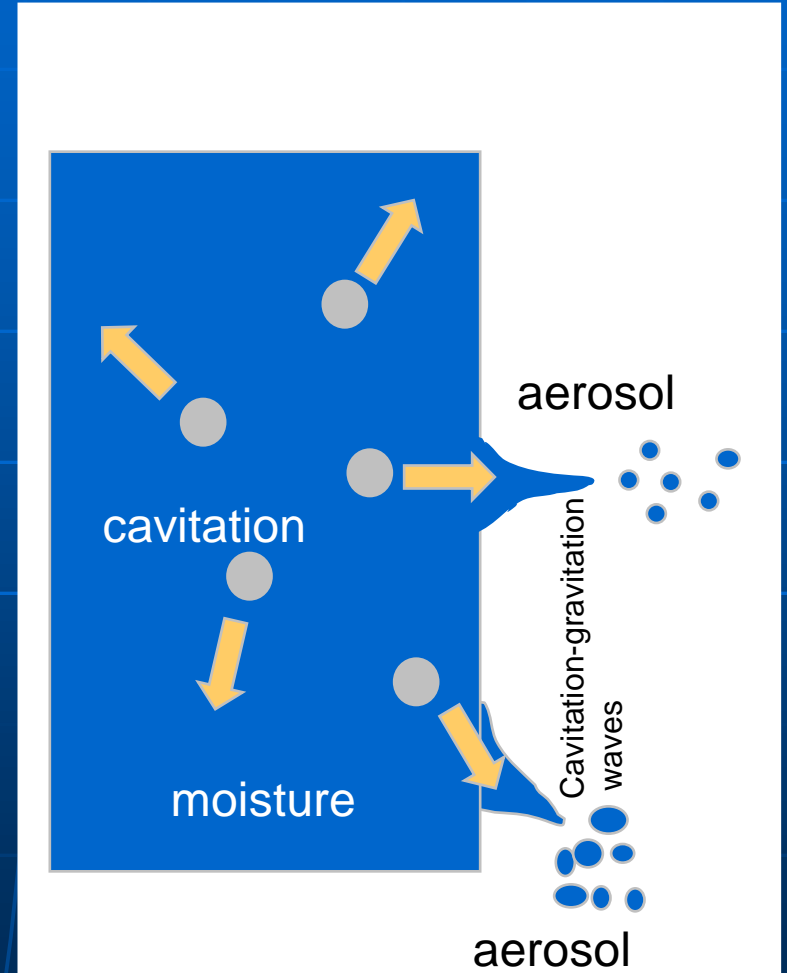
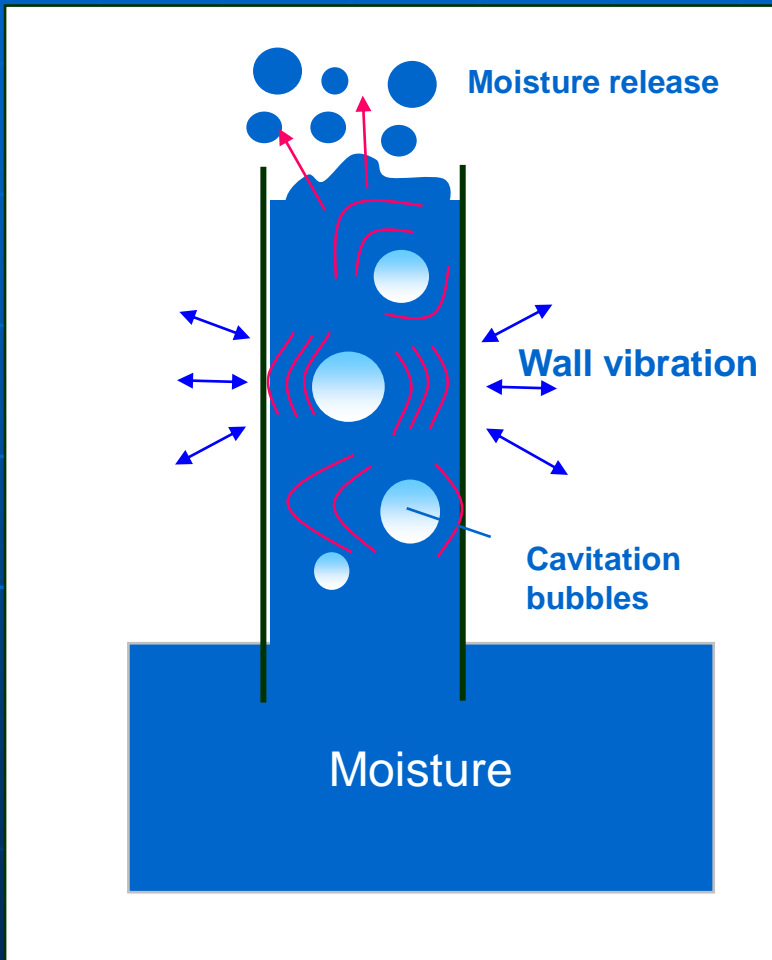
Advantages of ultrasonic extraction

1. Increasing of efficiency.
2. Decreasing of power consumption.
3. Extraction at low temperature.

Ultrasonic vibrations provides maximum effective exposure on the soil for the water extraction process.

Ultrasonic vibrations can extract moisture from porous soil at low temperatures

Mechanisms of cavitation liquid extraction



Catching of fine particles of liquid

Filtering devices

Regeneration difficulties, high hydraulic resistance, insufficient chemical and thermal resistance

Wet catchers

It is possible to change the physico-chemical properties of the captured particles, the need for corrosion protection

Inertial gas cleaning equipment

Types of equipment

Electrofilters

The capture efficiency is limited by the particle size

Sensitivity to maintaining cleaning parameters

Air conditioning

Ways to improve the efficiency of particle capture

Ultrasonic method

Gas heating

Gas cooling

Particle size enlargement using various coagulation mechanisms

Humidification of gases

Ionization

Turbulence of the flow

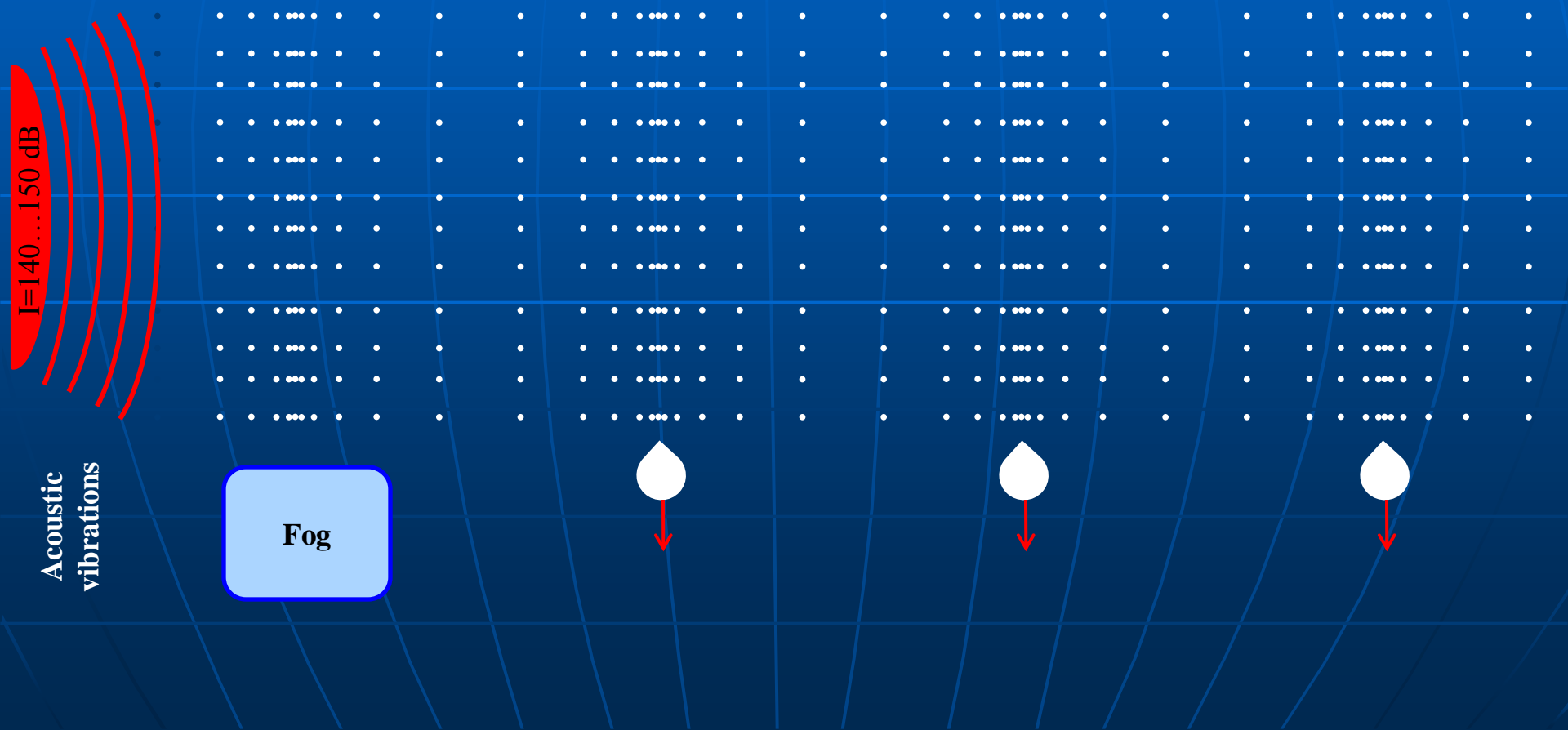
Using the condensation effect

The task of creating specialized ash-collecting equipment capable of increasing the efficiency of capturing highly dispersed particles from gaseous media due to exposure to high-intensity ultrasonic vibrations is urgent and requires a solution

Advantages of ultrasonic method

1. The ability to coagulate aerosols of various dispersities
2. Can be applied for aggressive and combustible environments.
3. Does not change the physico-chemical properties of the initial liquid media
4. Low overall size of equipment
5. Low power consumption.
6. High efficiency

Mechanism of acoustic coagulation



Object of studies

Gas jet radiators

Advantage:

- constructive simplicity;
- small dimensions;
- good agreement with the air.

Factors limiting the application:

- high consumption of compressed air;
- low efficiency;
- wear of mechanical components;
- inability to operate at high frequencies.



Alternative ???

Ultrasonic vibrating system

Advantage:

- the ability to work at frequencies over 20 kHz;
- high efficiency;
- low energy costs.

Factors limiting the application:

- the absence of studies aimed at determining the effectiveness of the use of ultrasonic vibratory systems with a disk radiator for aerosol coagulation.

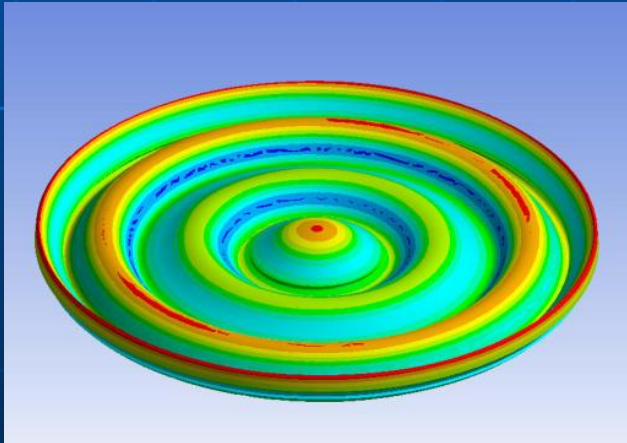


Advantages of ultrasonic radiators

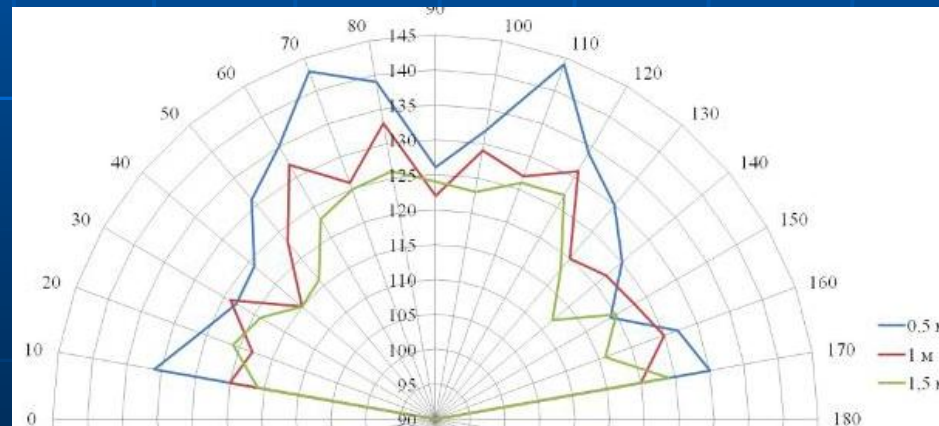
1. High efficiency (more than 60%).
2. Wide radiation pattern with high sound pressure level (more than 150 dB).
3. Small weight and size characteristics.
4. Ease of use.
5. The wide prevalence of materials used in the production of radiators.
6. Frequency–stable radiation, which allows providing the most effective vibration mode - the standing wave mode.



ultrasonic disk radiator

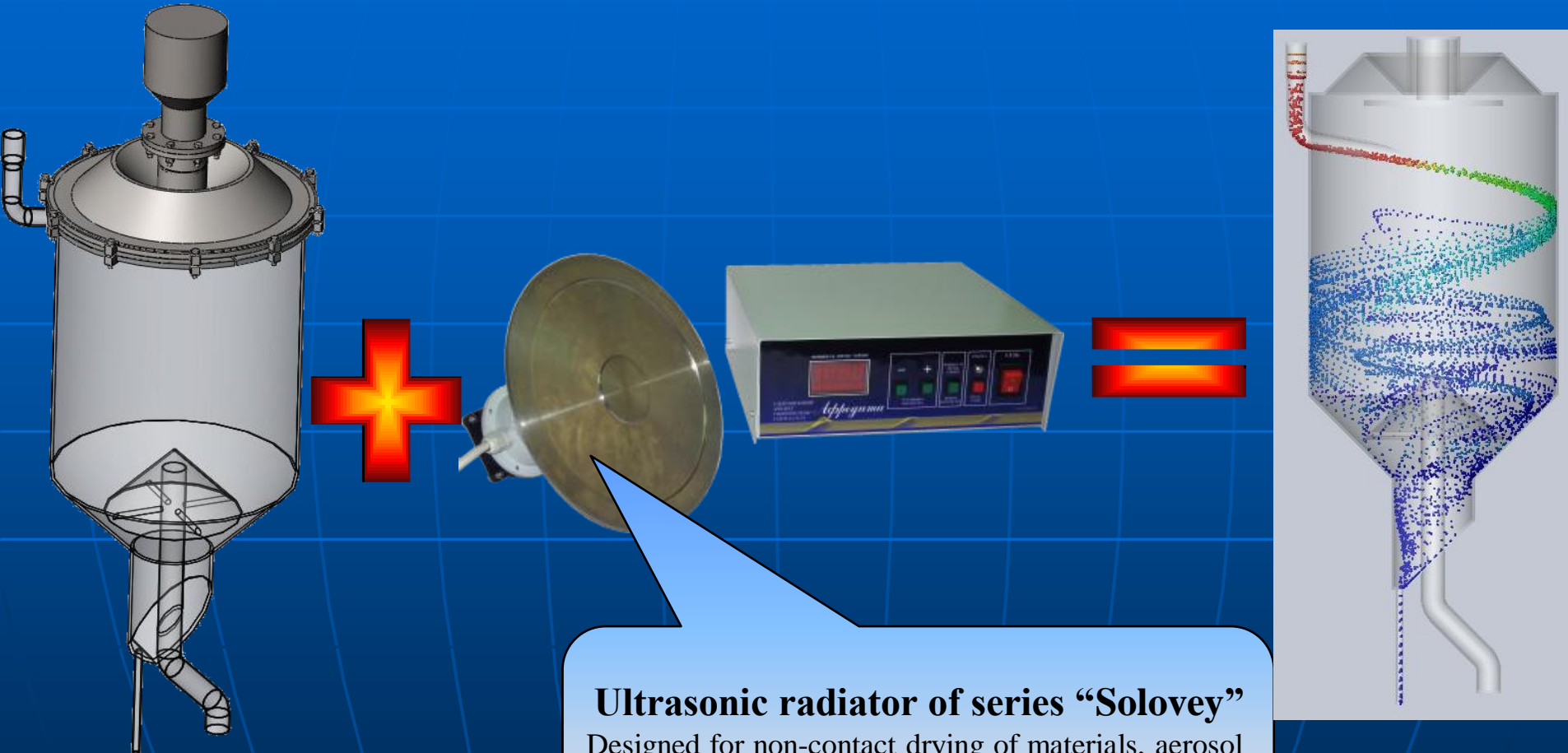


Distribution of vibrations of the disk radiator



Radiation pattern for a disk radiator at a distance of 0.5 m; 1 m; 1.5 m

Capture of dispersed particles in gaseous media



Ultrasonic radiator of series “Solovey”

Designed for non-contact drying of materials, aerosol coagulation, foam quenching, etc. The maximum intensity of acoustic vibrations is up to 153 dB.

Preliminary studies of the coagulation process

Block diagram of the stand

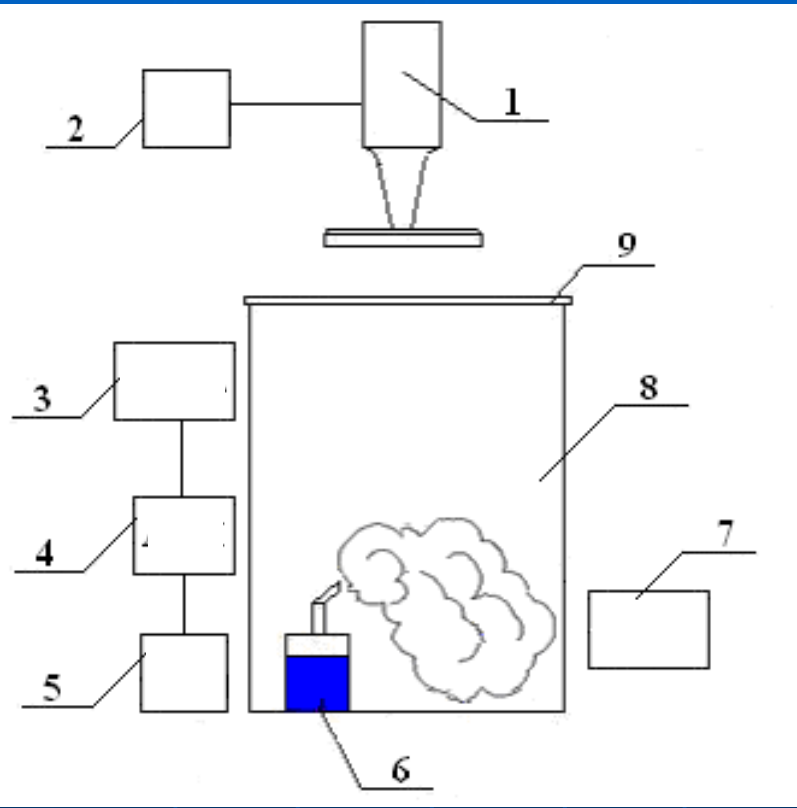


Photo of the stand



1 – ultrasonic vibratory system; 2 – ultrasonic generator; 3 – aerosol density measurement system (ADMS); 4 – ADC; 5 – personal computer; 6 – aerosol generator; 7 – sound pressure level meter; 8 – technological volume; 9 – air flow cut-off

Coagulation process

The sequence of photos that illustrating the dynamics of the coagulation process



1s

5s

10s

13s

15s

It should be noted that with simple mixing of the aerosol, both with the help of ultrasonic vibrations (at a sound pressure level insufficient for coagulation) and with the help of air flows generated mechanically (with the help of a fan placed in the process volume), aerosol deposition was not observed.

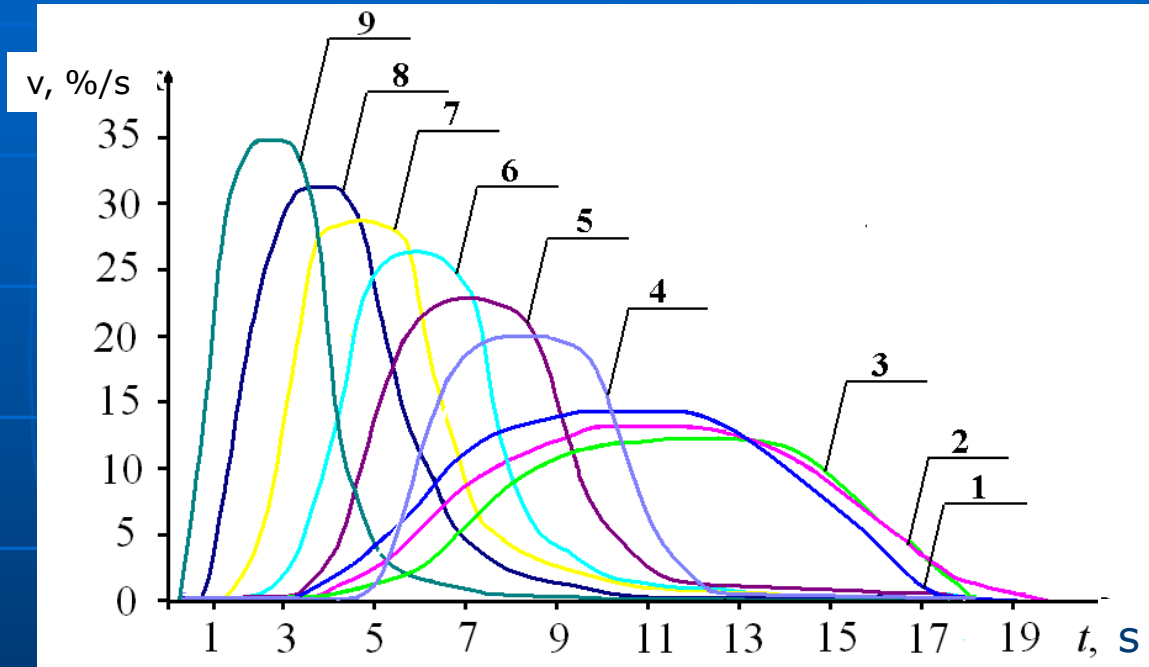
The experiment was carried out with the following parameters of the disk radiator: sound pressure level – 130 dB; frequency of sound vibrations – 20.5 kHz; ultrasonic exposure time - 15 seconds.

As a result of ultrasonic exposure, the aerosol almost completely coagulated. The walls of the technological volume were covered with droplets of coagulated liquid.

It should be noted that with simple mixing of the aerosol, both with the help of ultrasonic vibrations (at a sound pressure level insufficient for coagulation) and with the help of air flows generated mechanically (with the help of a fan placed in the process volume), aerosol deposition was not observed.

Investigation of the dependence of the maximum coagulation rate on the sound pressure level

Dependence of aerosol coagulation rate on time for different sound pressure levels



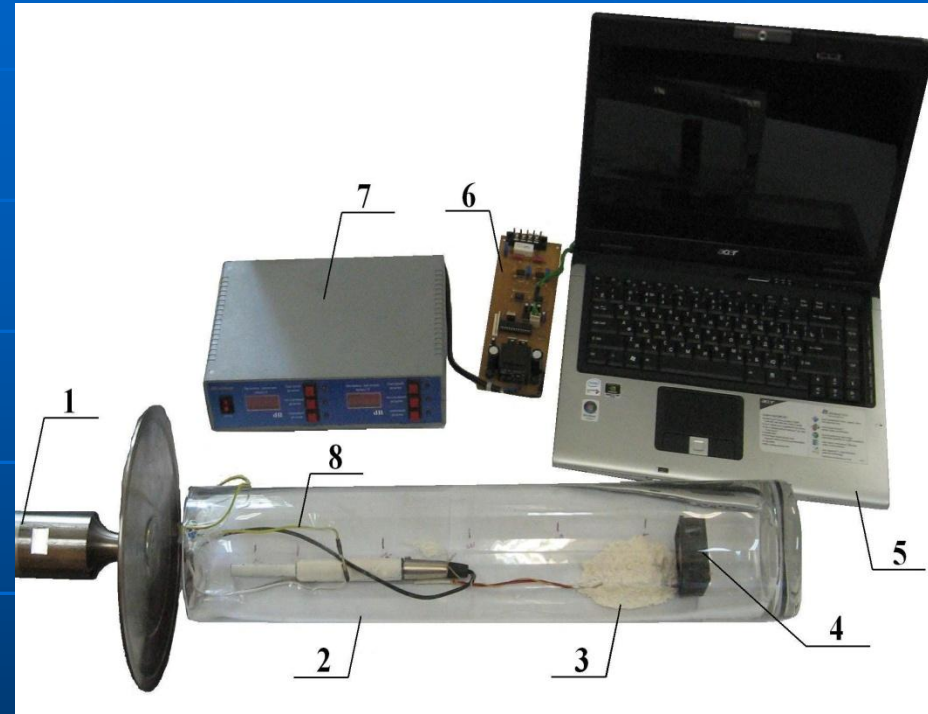
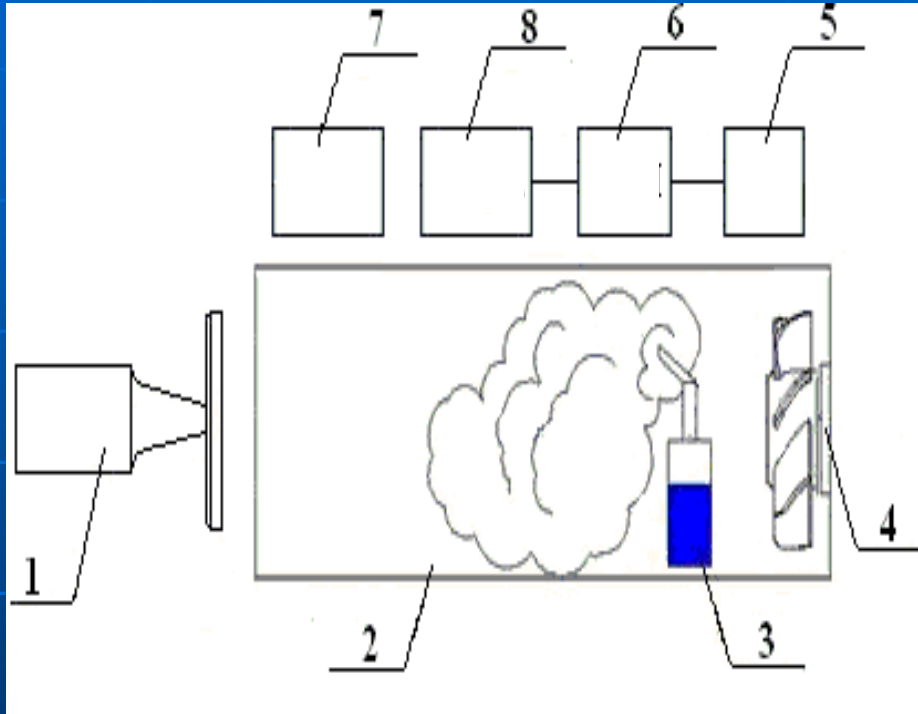
Sound pressure levels:
1 – 100 dB; 2 – 115 dB; 3 – 120
dB; 4 – 125 dB; 5 – 130 dB; 6 –
135 dB; 7 – 140 dB; 8 – 145 dB; 9
– 150 dB

The coagulation rate increases sharply, starting from the level of ultrasonic exposure corresponding to 125 dB. With a further increase in the level of ultrasound exposure, the maximum values that the coagulation rate reaches continue to increase, without reaching any limitation or maximum value.

Installation for the study of the coagulation process in the air flow

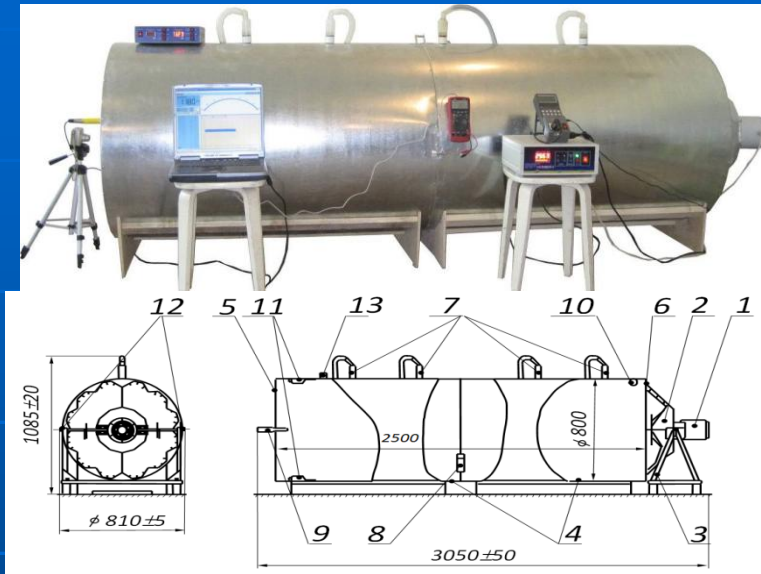
Block diagram of the stand

Photo of the stand

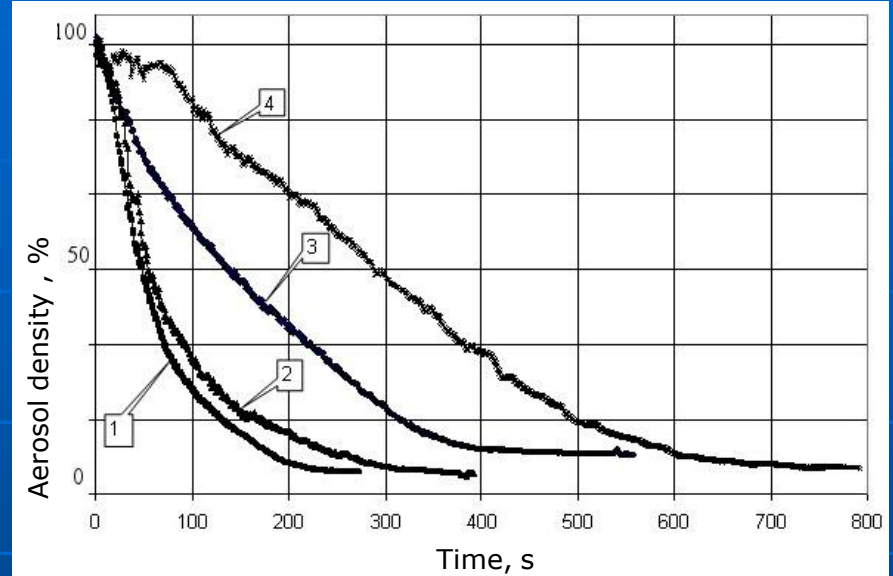


1 – ultrasonic vibratory system; 2 – technological chamber; 3 – aerosol source; 4 – fan; 5 – personal computer; 6 – ADC; 7 – aerosol density measurement system (ADMS); 8 – sound pressure level measurer (SPLM)

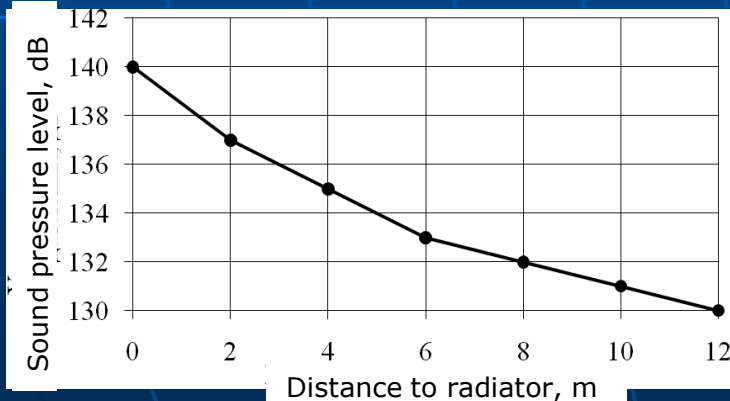
Results of experimental studies of the water coagulation process



Coagulation chamber with measuring equipment

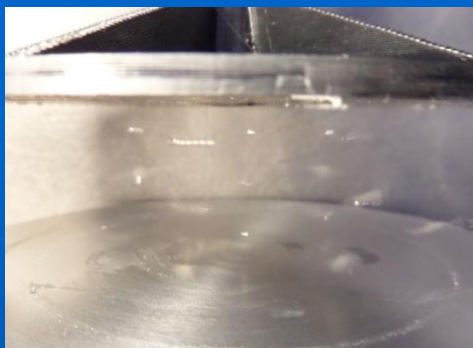


Change in aerosol density during experiments:
 1 – with forced circulation of aerosol flows and with ultrasonic exposure; 2 – without forced circulation of aerosol flows and with ultrasonic exposure; 3 – with forced circulation of aerosol flows and without ultrasonic exposure; 4 – without forced circulation of aerosol flows and without ultrasonic exposure



Dependence of the sound pressure level on the distance to the radiator

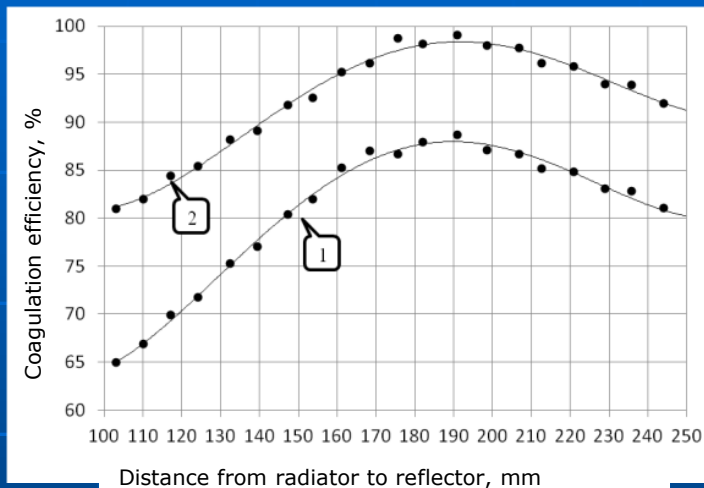
Aerosol coagulation in a standing wave



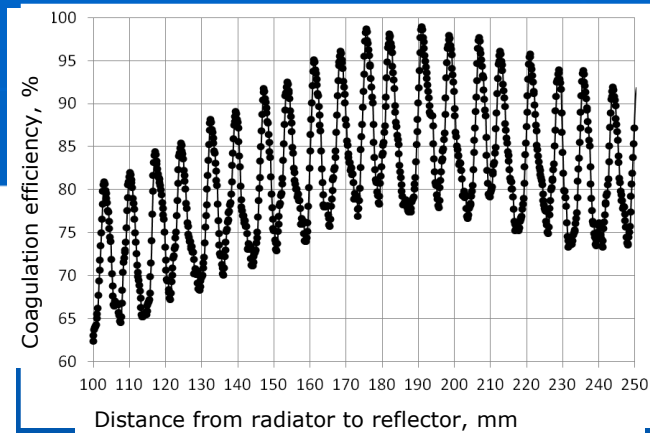
Aerosol drops (0.5 – 2 mm)



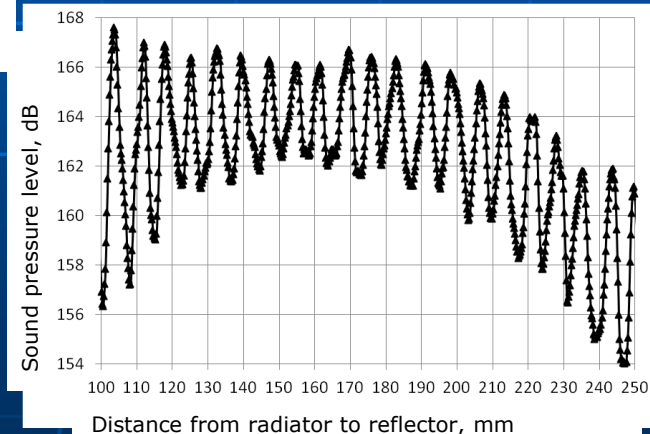
1 – ultrasonic disk radiator; 2 – aerosol generator;
 3 – ultrasonic generator to supply disk radiator;
 4 – coagulation chamber; 5 – reflector
 Stand for study of ultrasonic coagulation in standing wave mode



Dependences of coagulation efficiency (envelopes) from the distance between the longitudinally vibrating radiator and the reflector; 1 – flexibly vibrating radiator; 2 – longitudinally vibrating radiator

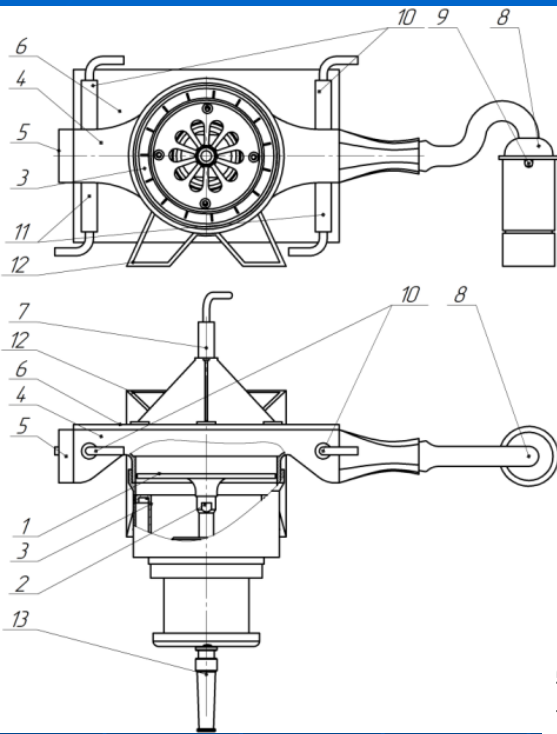


The dependence of the coagulation efficiency on the distance between the longitudinally vibrating radiator and the reflector



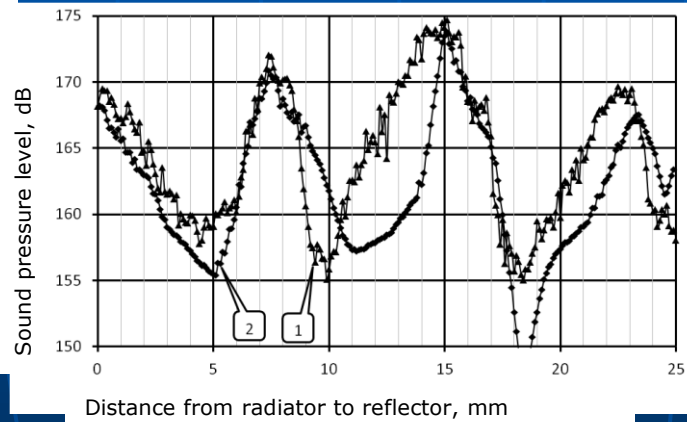
The dependence of the sound pressure level on the distance between the longitudinally vibrating radiator and the reflector

Coagulation in thin layer



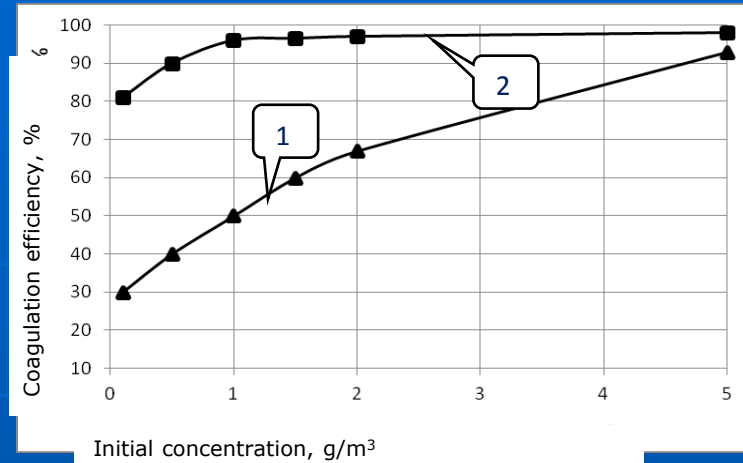
- 1 – ultrasonic disk radiator;
- 2 – piezoelectric transducer; 3 – flange of ultrasonic vibratory system;
- 4 – coagulation chamber housing;
- 5 – exhaust fan; 6 – reflector;
- 7 – microphone; 8 – inhaler; 9 – hole;
- 10 – infrared LEDs; 11 – photodiodes;
- 12 – stand; 13 – power cable of the ultrasonic disk radiator

Sketch of the developed stand for the study of coagulation in a thin layer



- 1 – longitudinally vibrating radiator;
- 2 – flexibly vibrating radiator.

Dependence of the sound pressure level on the distance between the radiator and the reflector



The dependence of the coagulation efficiency on the initial concentration:

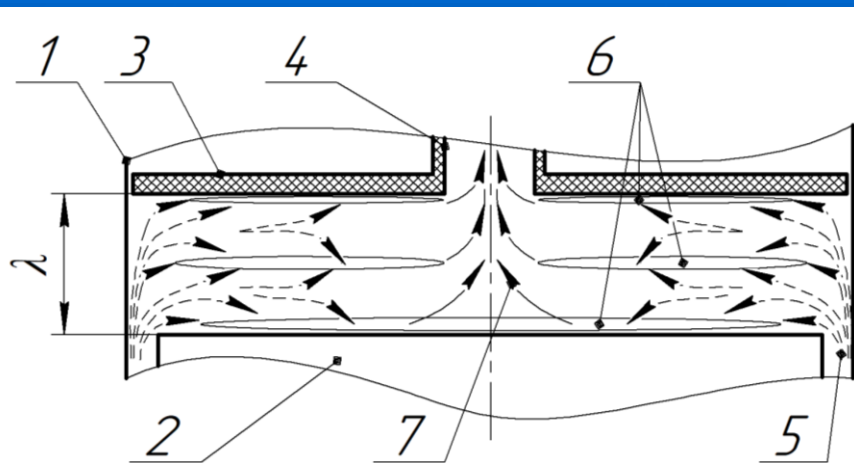
- 1 – longitudinally vibrating radiator; 2 – flexibly vibrating radiator;

$$\eta = \left(1 - \frac{N_{outlet(less15)}}{N_{inlet}}\right) \cdot 100\%$$

N_{outlet} – aerosol concentration with particles less than 15 microns at the outlet, g/m³;

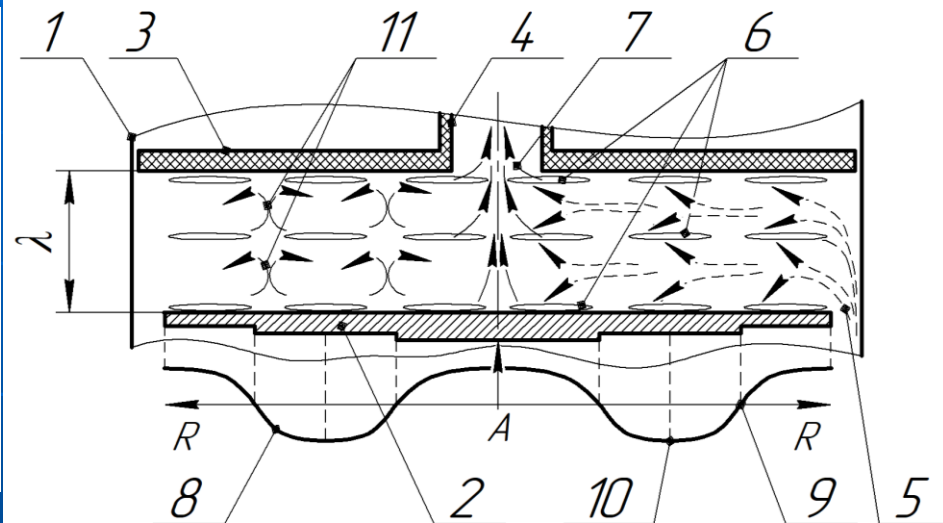
N_{inlet} – aerosol concentration at the inlet, g/m³.

Schemes of movement of liquid particles in the coagulation chamber



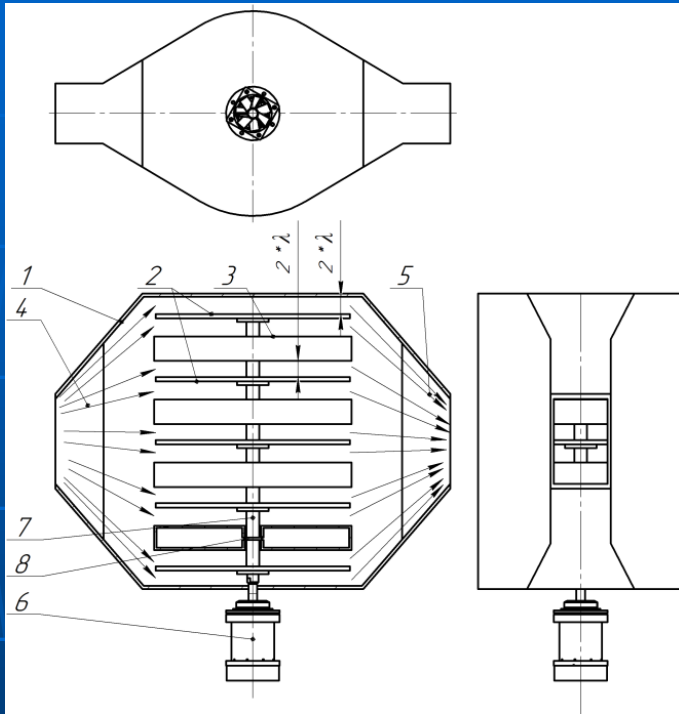
1 – radiator; 2 – reflector; 3 – gas–dispersed flow;
4 – nodal areas; 5 – flow separation area; 6 – agglomerate
formation areas; 7 - outlet pipe;

The scheme of movement of particles in the coagulation
chamber when using a longitudinally vibrating radiator

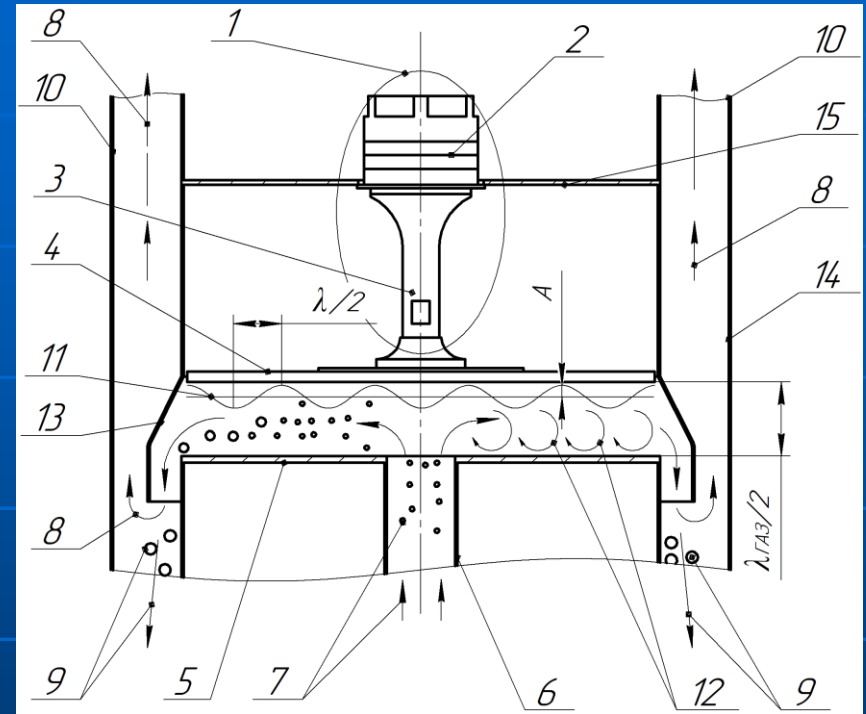


1 – radiator; 2 – reflector; 3 – gas–dispersed flow;
4 – nodal areas; 5 – flow separation area; 6 –
agglomerate formation areas; 7 - outlet pipe;
8 –vortex regions; 9 –amplitude zeros of disk radiator
The scheme of movement of particles in the coagulation
chamber when using a bending-vibrating radiator

Construction of ultrasonic coagulation modules

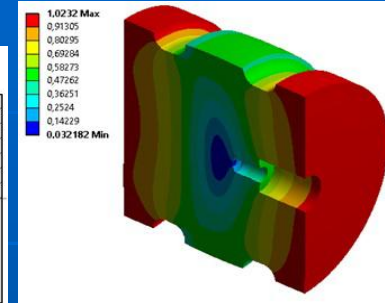
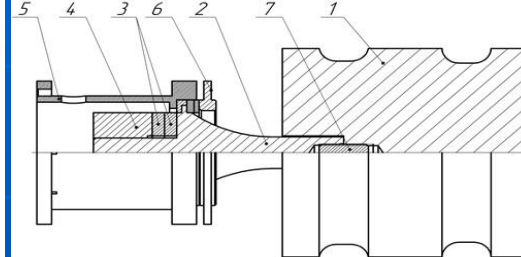
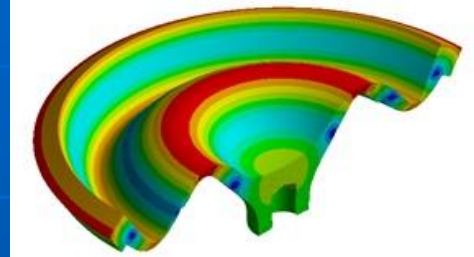
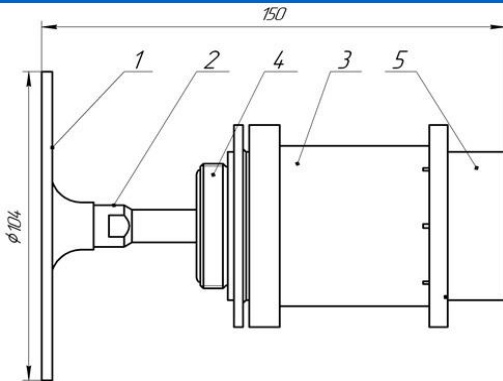


1 – case; 2 – ultrasonic bending-vibrating radiator;
 3 – reflector; 4 – direction of incoming flow; 5 – direction
 of outgoing flow; 6 – ultrasonic piezoelectric transducer; 7 – half-
 wave waveguide; 8 – flange (zero vibration); λ – wavelength



1 – piezoelectric vibratory system; 2 – piezoelectric transducer;
 3 – concentrator; 4 – ultrasonic radiator; 5 – reflector; 6 – inlet pipe;
 7 – gas-dispersed flow (gas and particle flow); 8 – purified gas flow;
 9 – agglomerates of particles; 10 – outlet pipes of purified gas;
 11 – distribution vibrations amplitudes of the ultrasonic radiator;
 12 – vertex currents; 13 – partition; 14 – case; 15 – mounting flange;

Type of ultrasonic radiator



Sketch of the ultrasonic vibratory system with a bending-vibrating radiator

The shape of the vibration of the disk radiator

Sketch of the ultrasonic vibratory system with a longitudinally vibrating radiator

The waveform of the ultrasonic radiator

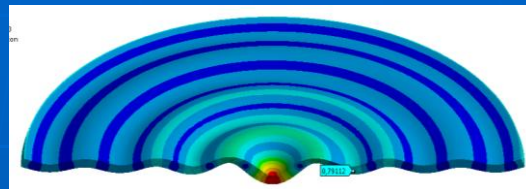


Photo of the ultrasonic vibratory system:
1 – disk radiator; 2 – piezoelectric transducer; 3 – case;
4 – flange; 5 – fan

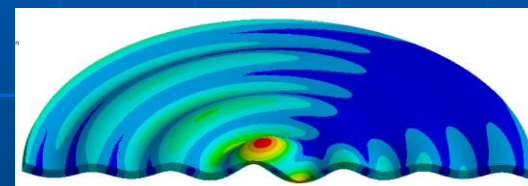
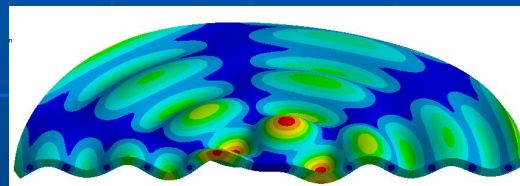
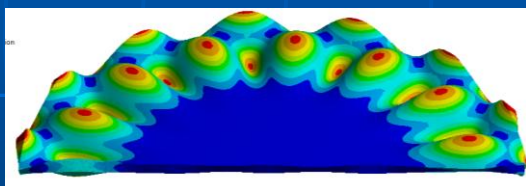
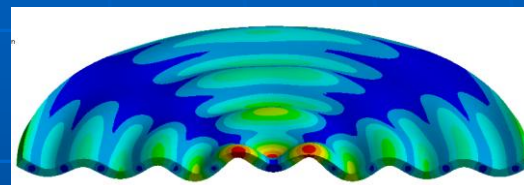
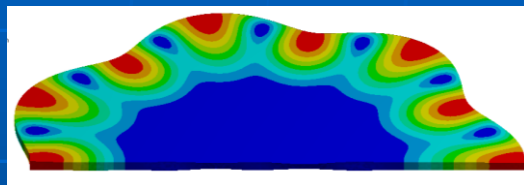


Photo of the ultrasonic vibratory system:
1 – ultrasonic radiator; 2 – concentrator of piezoelectric transducer; 3 – piezoceramic elements; 4 – reflective overlay;
5 – case; 6 – flange; 7 – pin

Problems in the development of ultrasonic disk radiators



Vibration form of flat disk

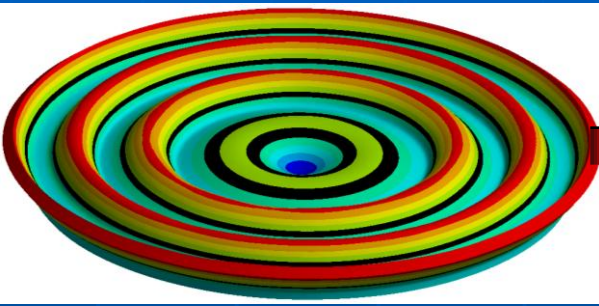


Various modes of vibrations of disk radiators

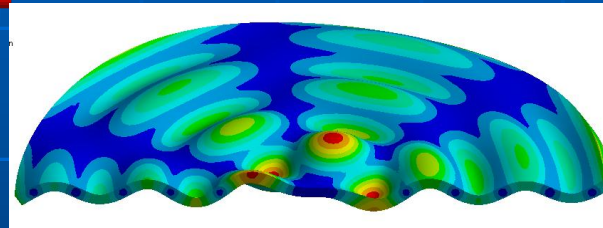
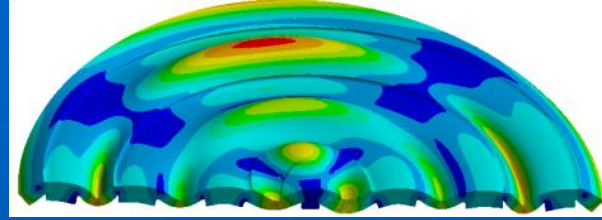
Design problems:

1. Ensuring uniformity of vibration amplitudes, both within the annular sections and between the annular sections.
2. The appearance of secondary vibrations modes having frequencies close to the frequency of the ring mode of vibrations (the difference is less than 500 Hz) leads to deformation of the vibrations form of the ring mode. .
3. Anisotropy of the mechanical properties of the material leads to deformation of the vibration form of the ring mode.
4. Relatively low sound pressure level to realize rapid coagulation
5. Small area of radiation

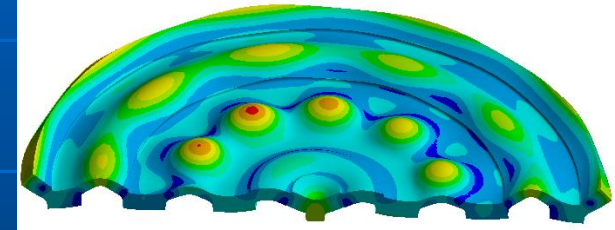
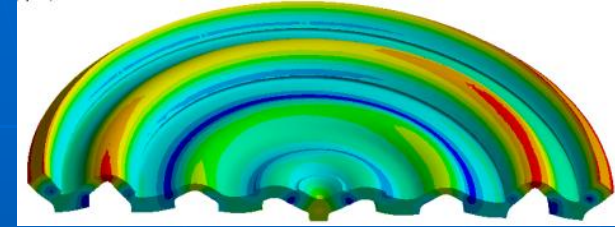
Superposition of secondary vibration modes on the ring mode



The desired vibrations
shape of the disk
radiator



Waveforms of a disk
radiator operating on a
secondary mode

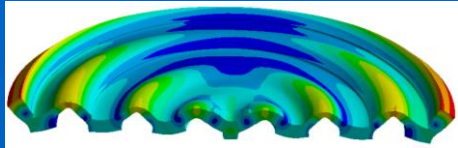


The resulting waveform of
the disk radiator

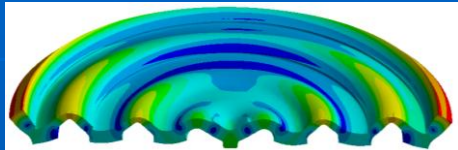


Appearance of the
ultrasonic disk
radiator

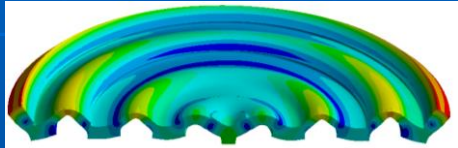
The anisotropy effect of the mechanical properties of the material on the vibration shape of the disk radiator



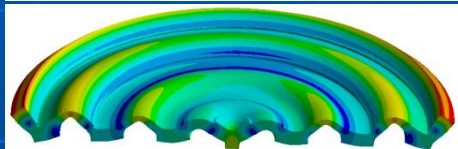
a) $E_x=1,13 \cdot 10^{11}$ Pa; $E_y=1,13 \cdot 10^{11}$ Pa;
 $E_z=1,08 \cdot 10^{11}$ Pa



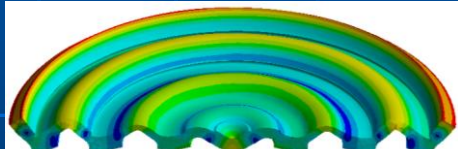
b) $E_x=1,13 \cdot 10^{11}$ Pa; $E_y=1,13 \cdot 10^{11}$ Pa;
 $E_z=1,1 \cdot 10^{11}$ Pa



c) $E_x=1,13 \cdot 10^{11}$ Pa; $E_y=1,13 \cdot 10^{11}$ Pa;
 $E_z=1,11 \cdot 10^{11}$ Pa



d) $E_x=1,13 \cdot 10^{11}$ Pa; $E_y=1,13 \cdot 10^{11}$ Pa;
 $E_z=1,12 \cdot 10^{11}$ Pa



e) $E_x=1,13 \cdot 10^{11}$ Pa; $E_y=1,13 \cdot 10^{11}$ Pa;
 $E_z=1,13 \cdot 10^{11}$ Pa



The distribution corresponds to the model



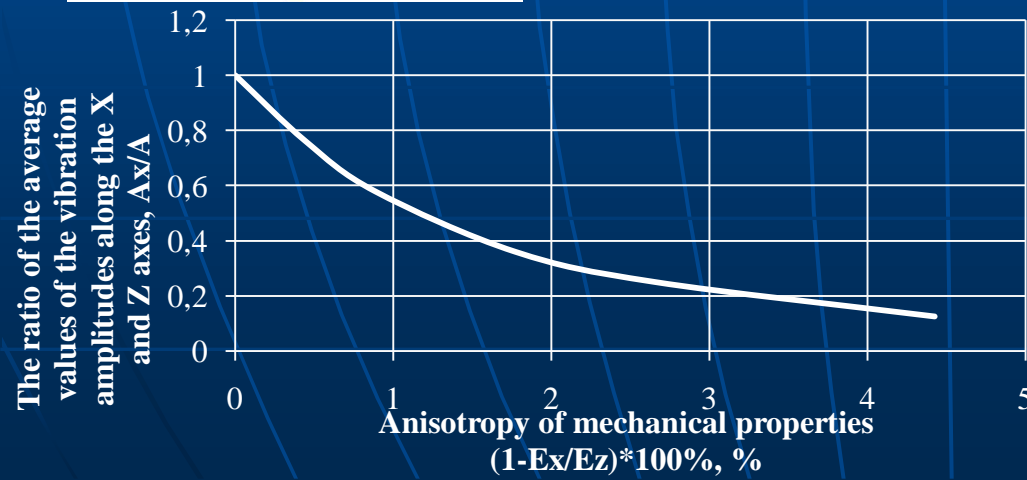
The location of the "Zero vibrations" on the surface of the axisymmetric radiator



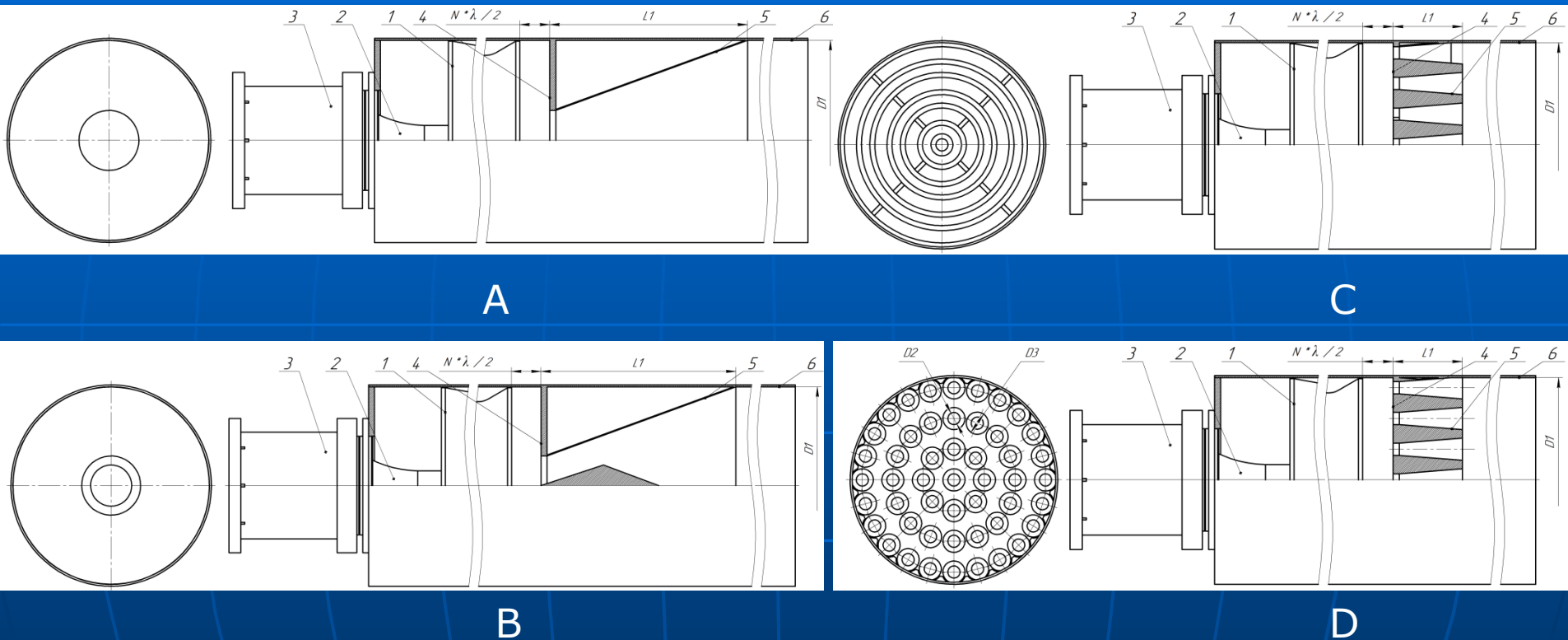
Radiator modernization (completion)



The location of the "Zero vibrations" on the surface of the modernized radiator



Increasing of ultrasonic radiator efficiency

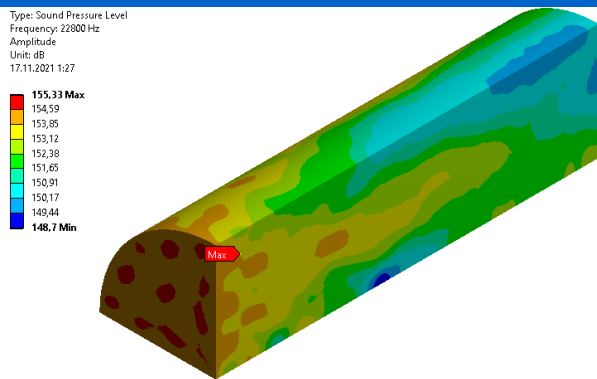


Sketches of a longitudinally vibrating radiator with various configurations of horns

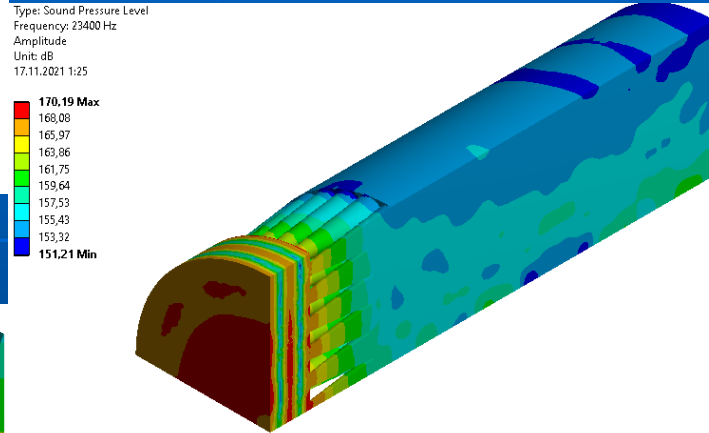
1 – longitudinally vibrating radiator; 2 – ultrasonic piezoelectric transducer; 3 – transducer case; 4 – reflector;
5 – horn structure; 6 – outer shell;

A – radiator with a single horn; B – radiator with a single horn with a Vente body; C – radiator with concentrically mounted ring horns; D – radiator with an array of horns

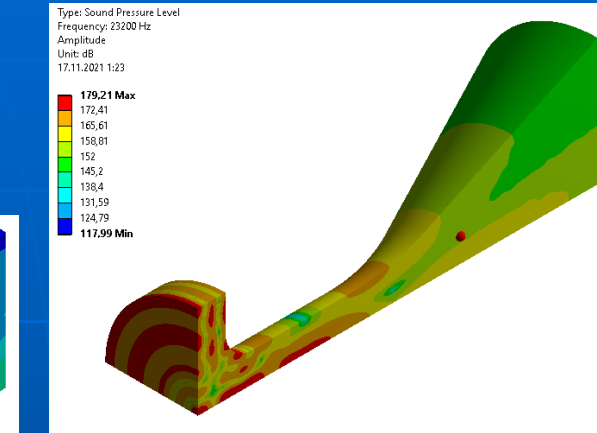
Radiators with different horn configurations



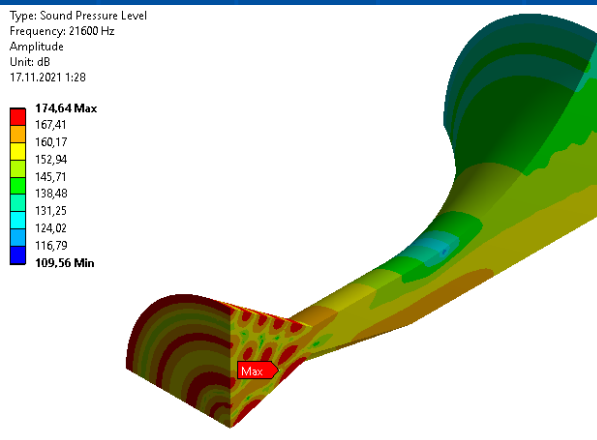
A



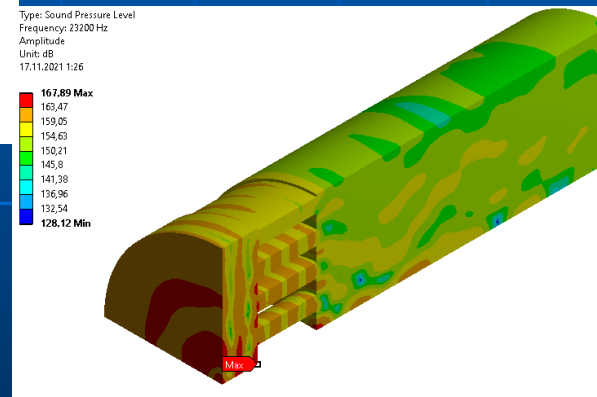
E



C



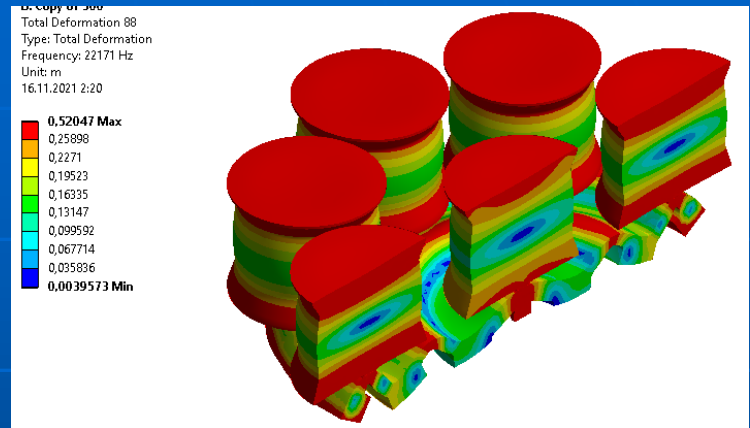
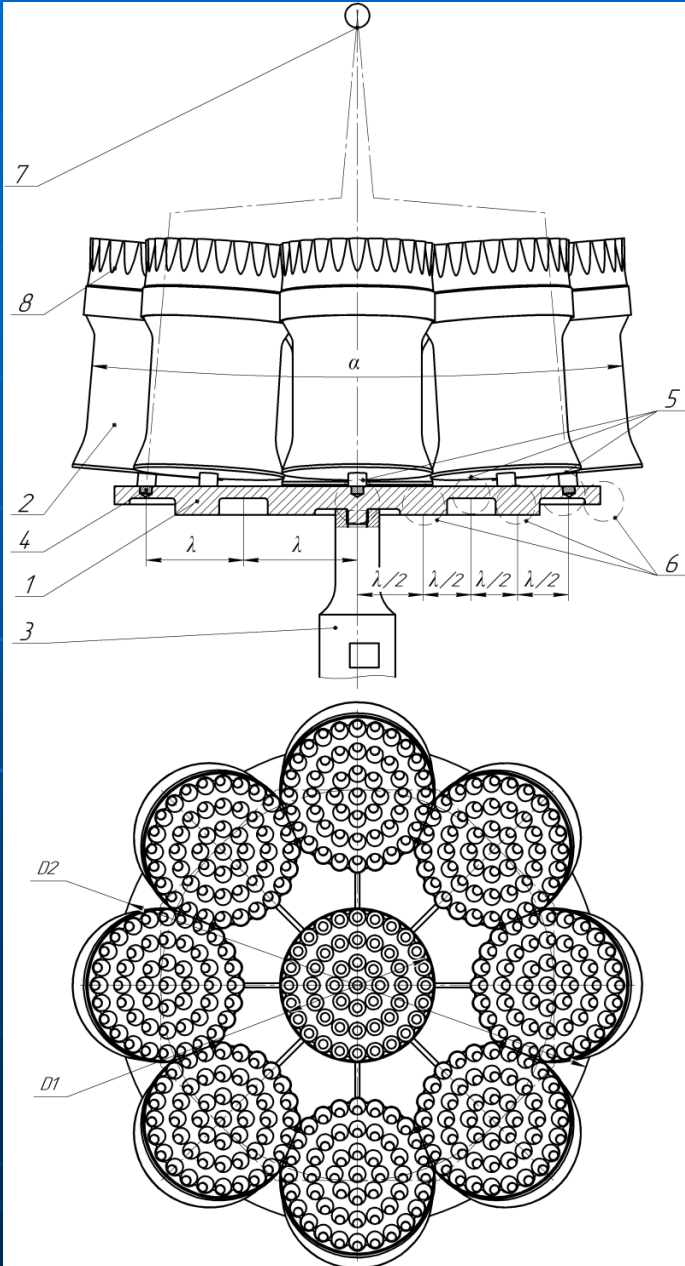
B



D

A – without a horn, without a resonant chamber; B – a narrow-mouthed horn with a Venturi body, with a conical pre-valve chamber; C – a narrow-mouthed horn with a resonant chamber in front of the radiator; D - ring horns with a resonant chamber in front of the radiator; E - an array of conical horns with a resonant chamber in front of the sound pressure level distribution radiator for various configurations of horns (only the gas medium limited by the horn structure is presented)

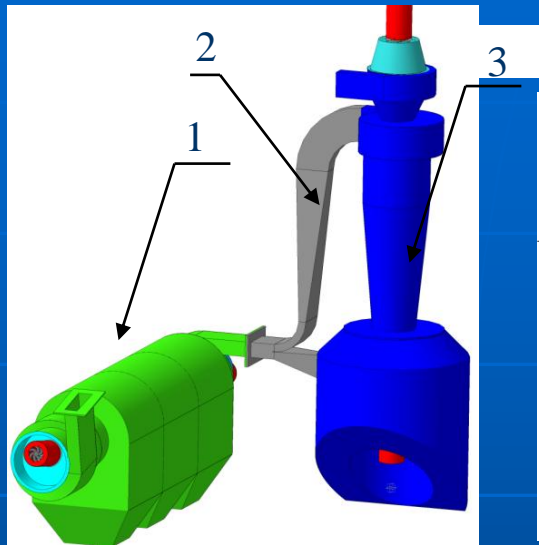
Increasing the radiation area



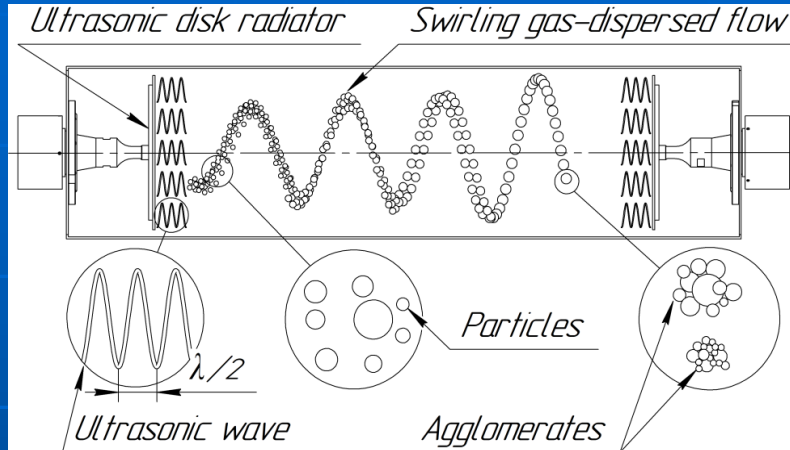
Distribution of vibrations of the array of longitudinally vibrating radiators

- 1 – vibration distributor in the form of a flexibly vibrating disk radiator with a flat frontal surface;
- 2 - longitudinally vibrating radiators;
- 3 – concentrator; 4 - threaded attachment unit of a longitudinally vibrating radiator to the distributor;
- 5 – distributor areas vibrating with a high amplitude of vibrations; 6 – booster areas of the distributor; 7 – focus area; 8 – arrays of horns. Installation diagram of a two-dimensional array of radiators.

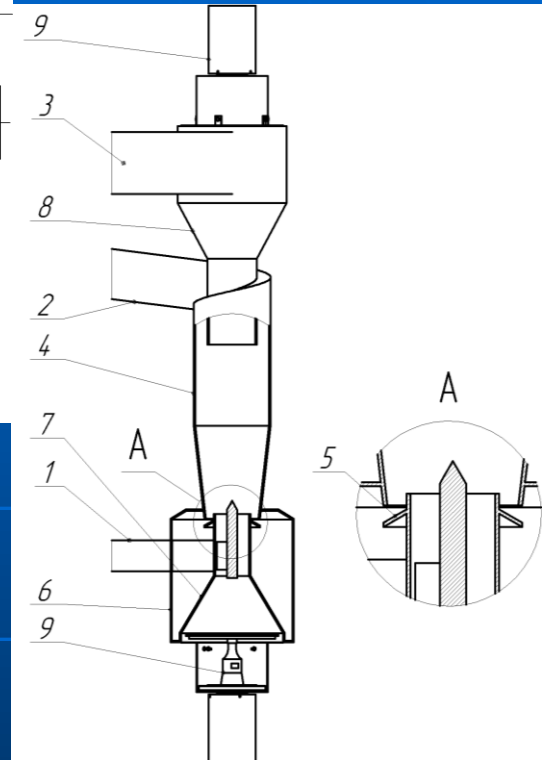
Centrifugal acoustic equipment



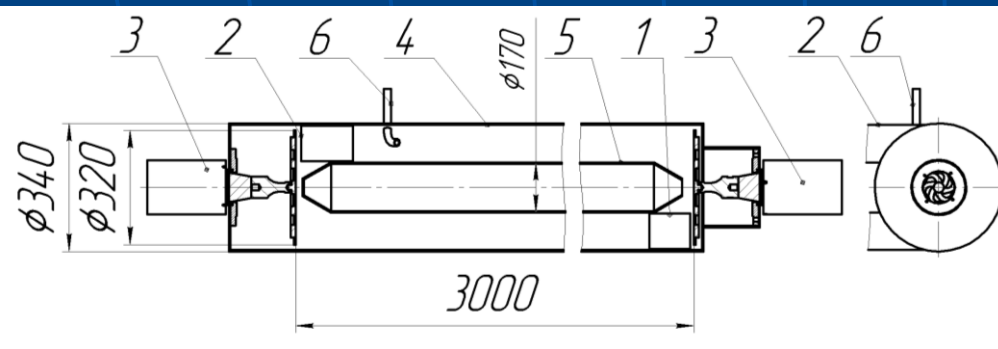
1 – the first stage is a pre-coagulation device; 2 – flues; 3 – second stage – devices for highly efficient particle capture
Scheme of gas cleaning equipment



The principle of operation of the centrifugal acoustic coagulation chamber

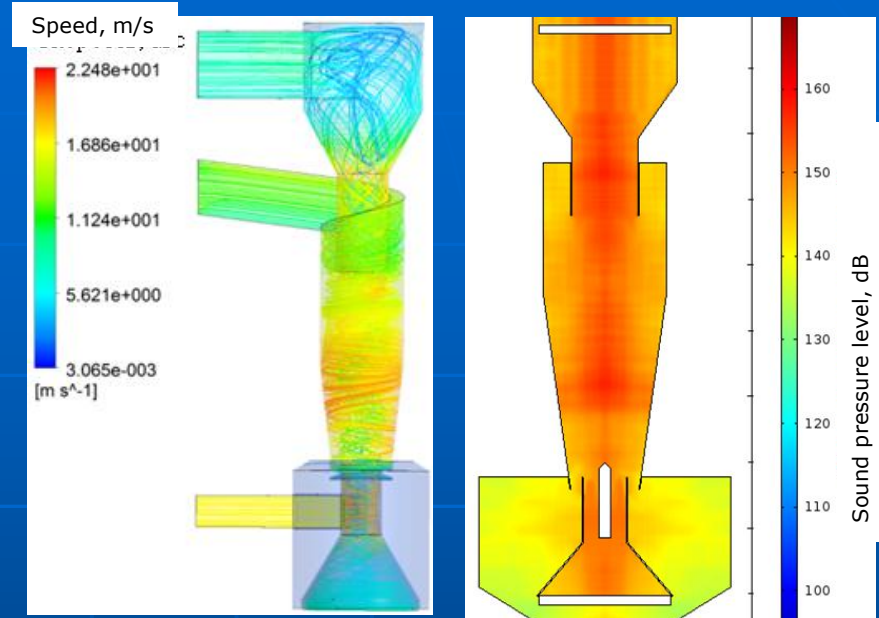
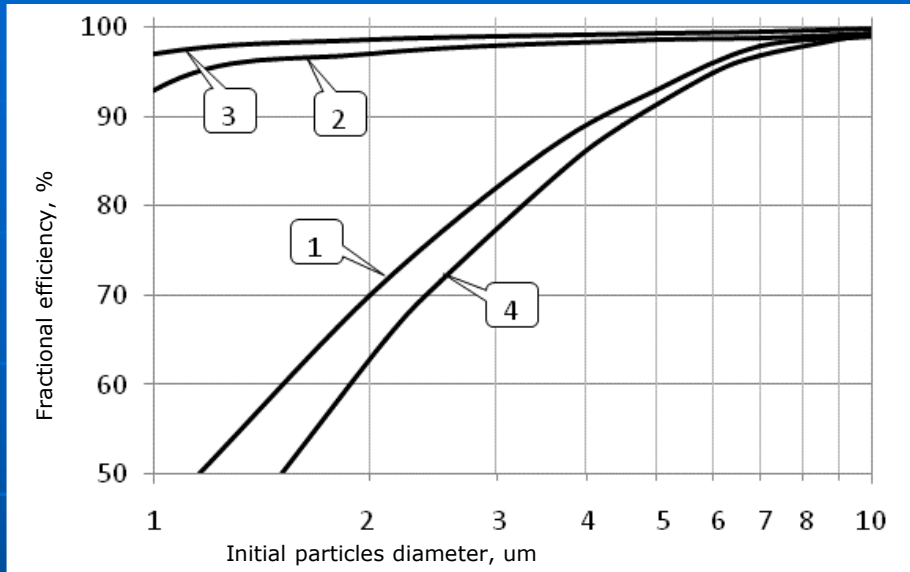


1 – primary flow pipe; 2 – secondary flow pipe; 3 – outlet pipe; 4 – separation part; 5 – chipping washer; 6 – hopper; 7, 8 – cones; 9 – ultrasonic radiators;
Sketch and 3D model of the device with counter swirling flows



1 – inlet pipe; 2 – outlet pipe; 3 – ultrasonic disk radiator; 4 – coagulation and separation chamber; 5 - displacer; 6 – sampling tube
Sketch of a stand for the study of coagulation in a swirling stream

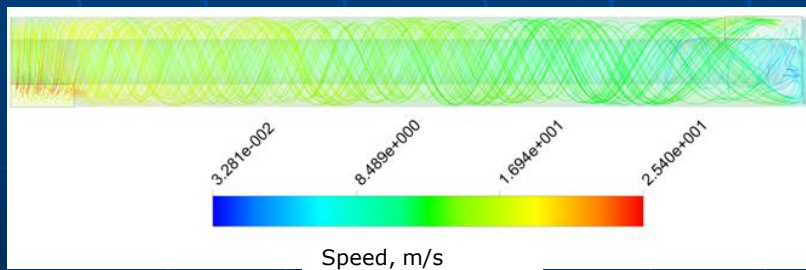
Calculated fractional efficiency of the equipment



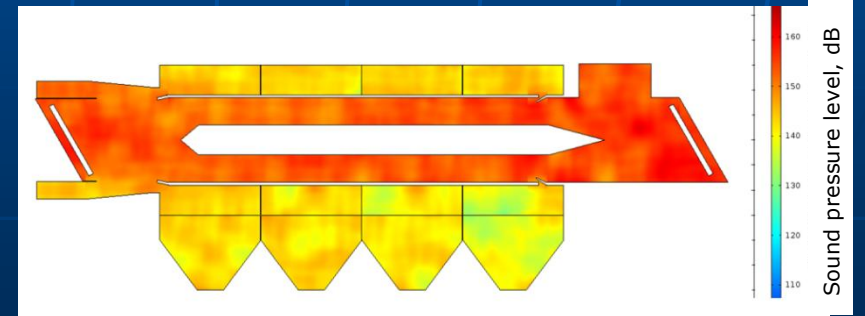
The gas flow in the volume of the device with counter swirling flows

Sound pressure level distribution

- 1 – agglomerator and device with counter swirling flows;
 - 2 – agglomerator (+US) and device with counter swirling flows;
 - 3 – agglomerator (+US) and device with counter swirling flows (+US);
 - 4 – literary effectiveness of device with counter swirling flows
- Fractional efficiency of centrifugal acoustic gas cleaning equipment

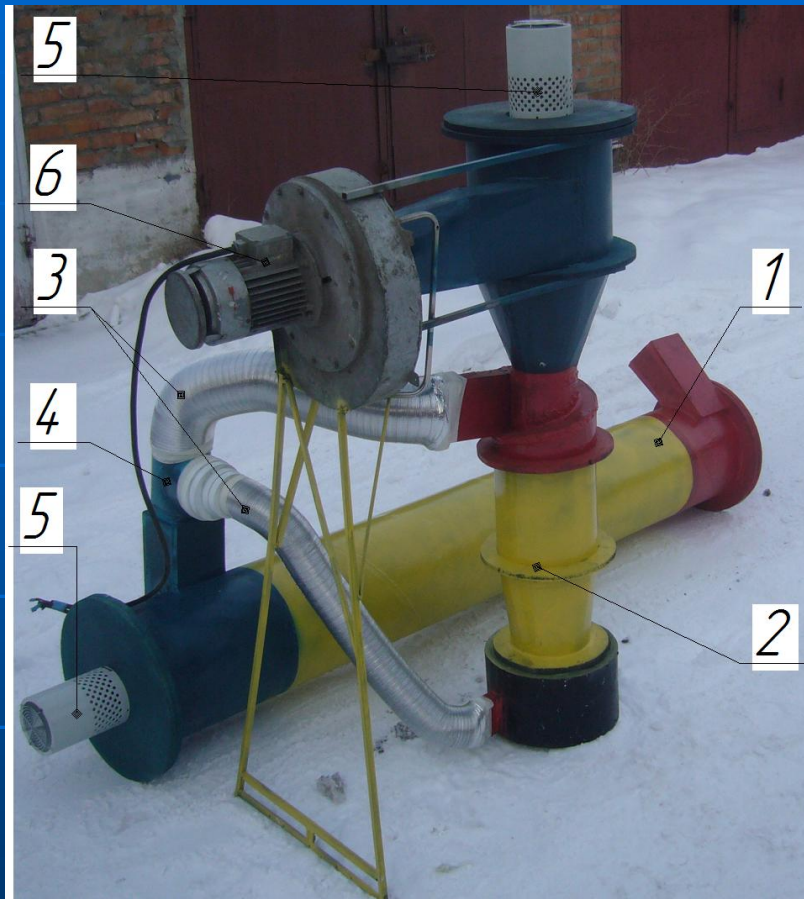


The gas flows in the volume of the agglomerator

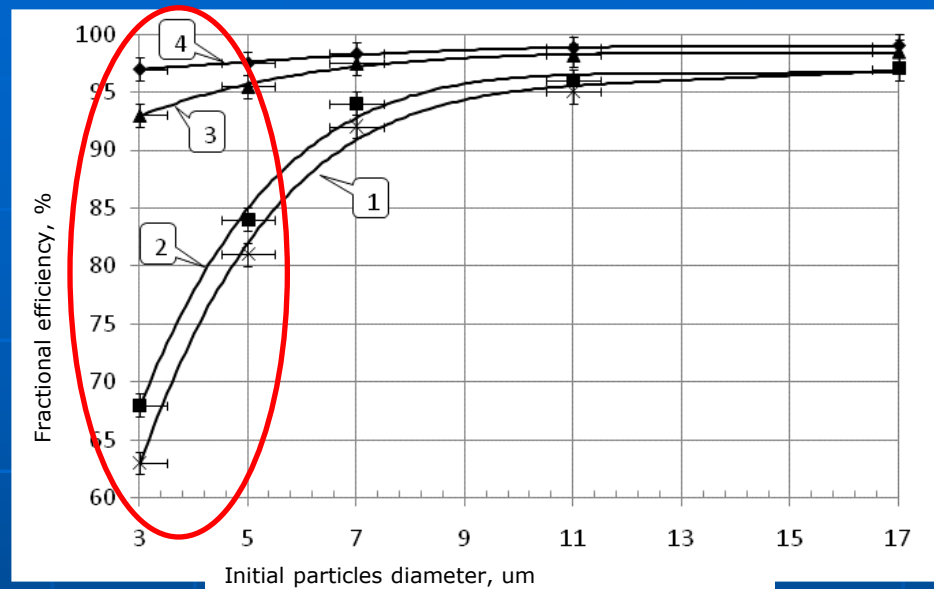


Distribution of the sound pressure level in the agglomerator

Centrifugal acoustic gas cleaning equipment



1 – agglomerator; 2 – device with counter swirling flows; 3 – air ducts; 4 – flow divider; 5 – ultrasonic disk radiators; 6 – centrifugal fan
Experimental sample of a centrifugal acoustic dust collector



1 – only device with counter swirling flows;
2 – agglomerator and device with counter swirling flows;
3 – agglomerator (+US) and device with counter swirling flows;
4 – agglomerator (+US) and device with counter swirling flows (+US);
Fractional efficiency of designed equipment

Technical characteristics of the developed centrifugal acoustic gas cleaning equipment

Parameters	Value
Gas consumption, m^3/h ;	1000
Concentration of dispersed particles, g/m^3	5-50
Hydraulic resistance, Pa	2500

Reasons for limiting of possibilities of ultrasonic coagulation

1. During the formation of a standing wave, the particles almost do not interact with each other within the nodal region. At low concentrations, the coagulation efficiency will be minimal. This is due to the fact that due to the large distance between the particles, significantly exceeding their size, the interaction forces of the particles and the amplitude of the vibratory motion are insufficient to bring them closer to a distance sufficient for collision.

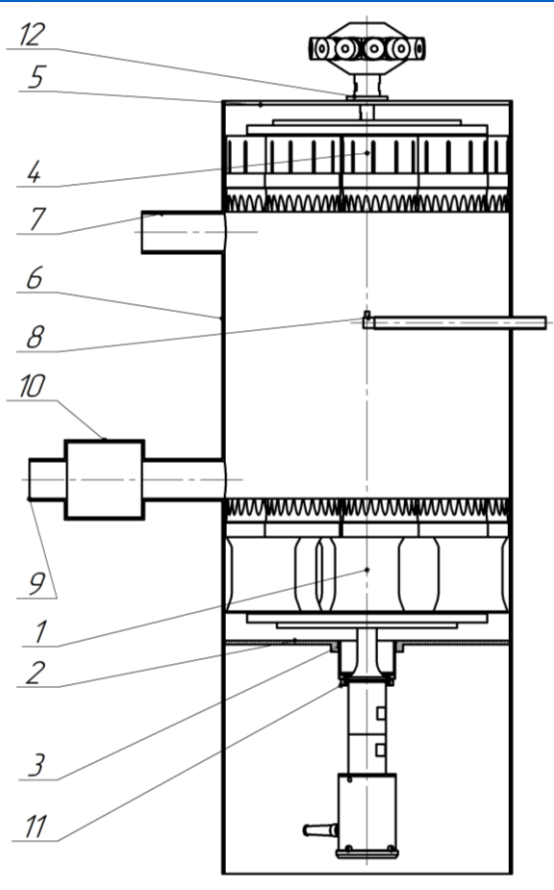
2. The use of a low frequency of ultrasonic exposure, at which all particles smaller than 2.5 μm are involved in vibratory motion. This does not contribute to their convergence and collision, which allow creating local pressure differences of different shapes and values in local areas during the required exposure time.

3. The absence of conditions for the occurrence of secondary effects that increase the effectiveness of ultrasound coagulation.

4. No interaction between the particles during the implementation of the standing wave mode due to their retention by the ultrasonic field in the nodal regions.

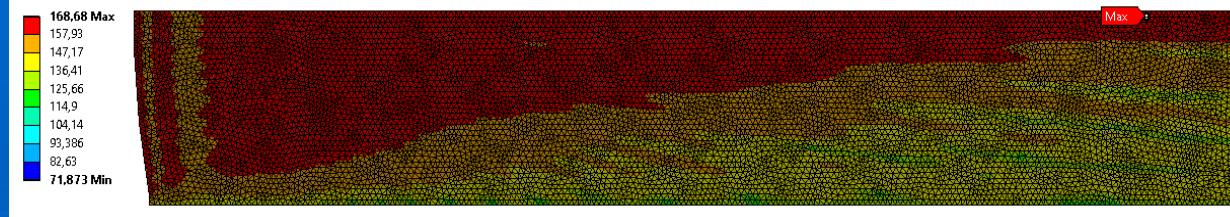
5. Low probability of particle collisions at low concentrations, even at high sound pressure levels, due to the large distances (larger than the size of the particles themselves) between the particles.

Nonlinear wave ultrasonic effect on gaseous media for coagulation of particles less than PM 2.5

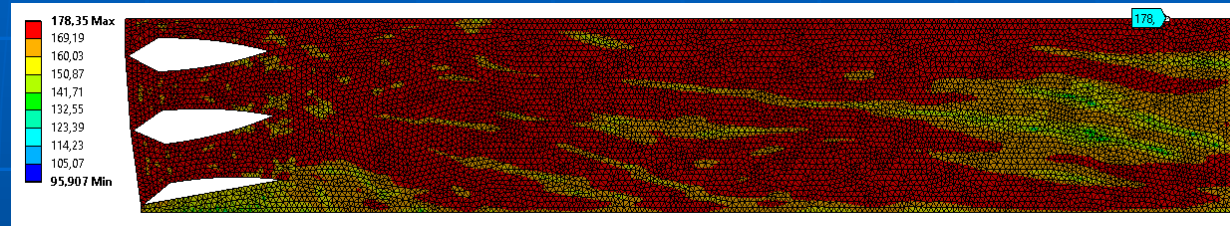


- 1 – array of radiator on a disk distributor (22 kHz); 2 – flange;
- 3 – threaded mechanism for adjusting the vertical position of the radiator array; 4 – radiator array on a disk distributor (44 kHz); 5 – flange;
- 6 – agglomeration chamber; 7 – nozzle for the introduction of aerosol;
- 8 – spray nozzle; 9 – purified gas outlet pipe; 10 – sampling chamber;
- 11, 12 – acoustic isolation

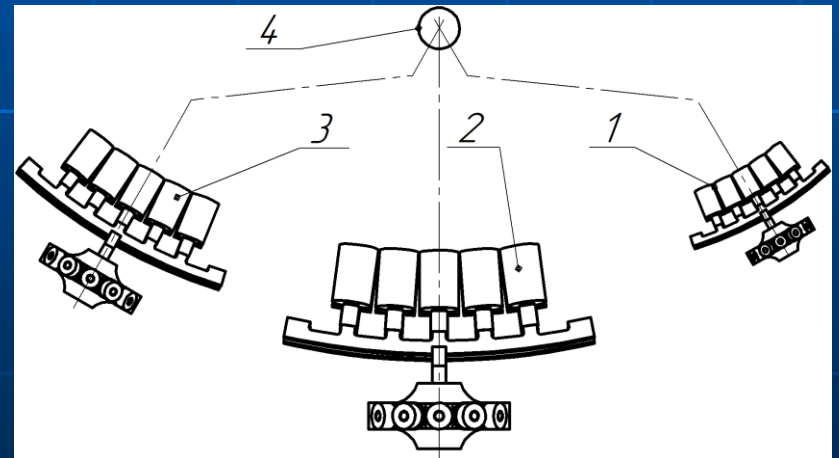
The stand sketch for the study of the agglomeration process



An example of the distribution of the sound pressure level created by a one-dimensional array (5 pcs) of longitudinally vibrating radiators



An example of the distribution of the sound pressure level created by a two-dimensional array (25 pcs) of longitudinally vibrating radiators



- 1 – 15 kHz radiator; 2 – 30 kHz radiator; 3 – 60 kHz radiator;
- 4 – focus area

Arrangement of arrays of piston-type radiators with multiple frequencies for exposure to open spaces (horns are not shown)

