Застосовано тривимірне моделювання сепараційних градієнтних аерозольних технологій. Створено тривимірні моделі для чисельного експерименту вдосконаленого масловіддільника для систем суфлювання газотурбінних двигунів з контактними ущільненнями. Виконано дослідження в діапазоні витрат 100...200 м³/год. На основі розрахунків створений дослідний зразок масловіддільника і виконані його експериментальні дослідження на спеціальному стенді. Визначено коефіцієнт сумарної ефективності очищення, який досягає 99,9 %

Ключові слова: масловіддільник, градієнтні аерозольні технології, тривимірна розрахункова сітка, статичний тиск, температура нагрівача

Применено трехмерное моделирование сепарационных градиентных аэрозольных технологий. Созданы трёхмерные модели для численного эксперимента усовершенствованного маслоотделителя для систем суфлирования газотурбинных двигателей с контактными уплотнениями. Выполнены исследования в диапазоне расходов 100...200 м³/ч. На основе расчетов создан опытный образец маслоотделителя и выполнены его экспериментальные исследования на специальном стенде. Определен коэффициент суммарной эффективности очистки, который достигает 99,9 %

Ключевые слова: маслоотделитель, градиентные аэрозольные технологии, трехмерная расчетная сетка, статическое давление, температура нагревателя

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EMPLOYING THE SEPARATION GRADIENT AEROSOL TECHNOLOGIES FOR DESIGNING THE OIL SEPARATORS OF VENTING SYSTEMS IN GAS TURBINE ENGINES (G=200 m³/h)

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1. Introduction

The introduction of new power plants (atomic, gas- and gas-steam turbine), a growth in the number of power plants and the development of industries contributed to an increase in the interest in the problems of two-phase dispersed media. Especially important is the task to remove a liquid phase out of gases, since its increased concentration reduces the efficiency and operational lifecycle, as well as deteriorates the operating characteristics of plants. For example, when drops and dust particles enter, along with air, the flowing area of gas-turbine engines of the gas-pumping units, it leads to the formation of deposits and strengthening of the processes of high-temperature corrosion. Similar changes also occur in the gas-turbine power stations and compressors of compressor plants. In winter time, the freezing of air-intake devices occurs, their aerodynamic drag increases, as well as the wear of cylinder-piston groups, etc. Creation of highly effective and economical heat- and mass-exchange apparatuses and separating devices is a significant reserve for improving the performance efficiency of power plants and more efficient use of fuel-energy resources. The relevance of the application of a three-dimensional modeling of separation gradient aerosol technologies for creating an oil separator is predetermined by the task to ensure effective removal of harmful liquid admixtures from industrial wastes. This issue is an important national-economic problem in coping with the environmental pollution.

2. Literature review and problem statement

In the studies of gas dynamics, heat and mass transfer, there are widely-known articles of foreign authors and by a number of the scientific Ukrainian schools, the result of which are the designs of separation equipment with a wide scope of application.

Thus, paper [1] presents theoretical studies into gas purification in the nano-porous graphite membranes. The given technology makes it possible to capture liquid and solid particles with diameter to 1 μm; however, separation cartridges with the nano-porous graphite membranes are limited by the operating time and their replacement leads to additional expenditures. This technology is not applicable for catching the highly dispersed particles of oil for the venting systems of a gas turbine engine. In article [2], authors propose to use membrane technologies for cleaning the non-stationary flows. This technology makes it possible to intensify the settling of a liquid phase in the gas flow through the additional pulsations of medium. In paper [3], authors propose to intensify the deposition through the introduction of the significant temperature gradients in the deposition channels and confirm this technology by calculating different designs of the elements of a separator. In article [4], authors performed the CFD modeling of behavior of particles in the super-fast deposition channels and determined the effectiveness of deposition. In paper [5], authors studied different membrane channels and determined the optimum ones for the deposition of particles. They developed a model for mixed flows, which can be used to calculate the deposition in the separator designs. In article [6], authors examined technologies for catching the oil aerosol in separation channels. A special feature of that work is that the authors studied the processes of enlarging and crushing the drops in separation channels. The models are developed that will make it possible to understand in more detail the processes of catching the oil aerosol. In article [7], authors proposed a development of the separation technology for the gas turbine engine produced by IGCC. In paper [8], authors investigated the influence of temperature differential on the deposition of highly dispersed particles in smooth channels. It was experimentally established that the temperature differential makes it possible to increase deposition in a separator by 10–20 %. In article [9], authors designed a turbo-impact separator for the closed cycle of the venting system in a gas-turbine unit. A generalized mathematical model was developed based on the previously-conducted studies for determining the intensity of the purification process of dispersed polyphase flows in the systems of power plants [10].

The development of separators of gas-turbine engines for the flow rate of gaseous medium at 200 m^3/h based on the separation gradient aerosol technologies with purification factor 99.9 % is predetermined by the start of the creation of the new generation of engines at the gas-turbine enterprises of C.P.R.

3. The aim and tasks of the study

The aim of present study is develop an oil separator of the venting systems of gas turbine engines for the flow rate of gaseous medium at 200 m^3/h based on the separation gradient aerosol technologies.

In order to achieve the aim, the following tasks were set:

– to develop section-by-section design concept and a three-dimensional model of the oil separator;

– to perform calculations of the hydrodynamic situation and particle trajectory in the flow area of an oil separator;

– to prepare working drawings and a prototype;

– to carry out bench tests of the oil separator.

4. Materials and methods of examining the design of a gas scrubber and estimating its effectiveness

In order to work out the design of a gas scrubber and to estimate its effectiveness, we constructed a test bench (Fig. 1), which is an open type wind tunnel, equipped with the tools for measurement, adjustment and control.

The modeling dispersed medium was created as follows. Air through flow-meter collector 1 entered measuring section 19 and streamlined heater 2, where its temperature rose to 100 °C. Next, the air got mixed with the highly dispersed aerosol, which was supplied from generator with sprayer 3. Consumption of highly dispersed aerosol (minimum $D_{particle}$ – 3 μm; medium $D_{particle}$ – 10 μm; maximum $D_{particle}$ – 15 μm) was regulated by the amount of supplied compressed air from compressor 21 and by autotransformers 20. The air flow rate through the section was regulated by shutter 12, located after supercharger 11. In section 19, there is thermocouple 4, sampler in the form of a tube of total pressure 5. Next, there was a gas scrubber with flat coagulator 13, whose inlet and outlet branch pipes were connected to measuring section 19. Micromanometers 18 and 6 measured pressure differentials on collector 1 and resistance of the gas scrubber. To measure the oil concentration in air, we employed aspirator 9 with allonges and torsion analytical balance 17 [7].

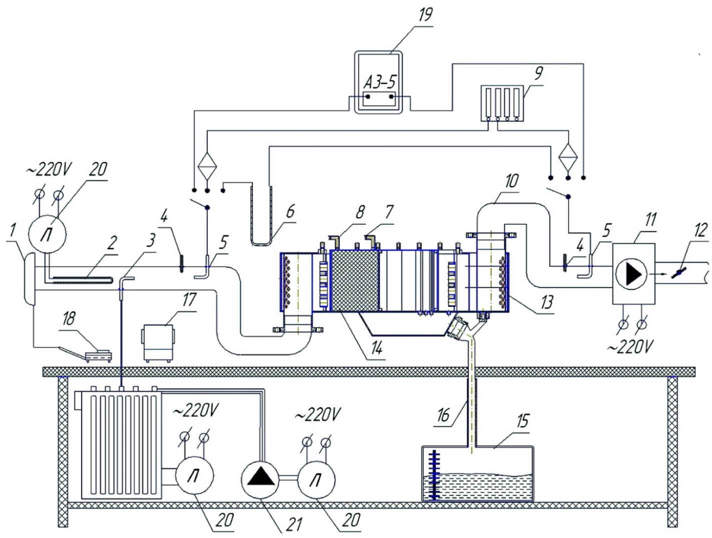


Fig. 1. Schematic of the test bench

Pulsation generators 7, 8 are installed into separation module 14. It consists of two stages of composite coagulators. The first stage of a separation module consists of a coagulator with the set of corrugated mesh from 0.1...0.5 mm. The second step of the separation module consists of a coagulator with the set of corrugated mesh from 0.05...0.2 mm.

Acoustic vibrations of low-frequency range were created by vibrating the walls (source of ultrasound) with appropriate frequency:

$$u_y = 2 \cdot A \cdot \pi \cdot э \cos(2\pi \cdot э), \quad (1)$$

where A=0.00002 mm is the amplitude; э=10000 Hz is the frequency of vibrations.

5. Results of examining an oil separator for the venting systems of GTE

Based on the developed in [10] methods for the intensification of mass transfer in the dispersed two-phase media, we designed a section-by-section structural scheme of oil separator for the venting systems of GTE (Fig. 2).

The proposed design of oil separator operates in the following way. A purified medium through the inlet branch pipe enters the gas distributor, from where, after the acceleration in a system of nozzles, it is sent in the form of jets onto the perforated U-shaped plate. Similar to the described mechanism, there occurs the inertial deposition of drops at the internal surface of the housing and the plate, their fusion with the formation of a film. The film under the action of gravity force and the flow is transported downward and along the porous plate. The fluid is removed from the lower part of an outlet chamber through the discharge branch pipe. Low-inertia particles enter the grid coagulator, where they are deposited based on the separation gradient aerosol technologies. The enlarged drops carried by the flow fall into the package of wavelike profiles with straight input and output plates. Output plates of the profiles contain vertical abducting grooves, which remove the fluid, captured on the wavelike part of the profiles. Using a package of profiles significantly decreases overall size of the gas scrubber and expands the interval of gas consumption. The captured fluid flows down into the pan of a gas scrubber and is removed from its housing through the branch pipe. Purified gas is sent to the outlet chamber, and, from it, into the outlet branch pipe [13].

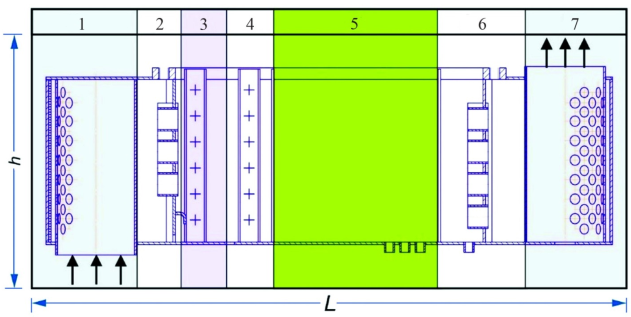


Fig. 2. Structural scheme of oil separator based on the separation gradient aerosol technologies: h — height of gas scrubber; L — length of oil separator; 1 — inlet branch pipe with the system of inertial nozzles; 2 — system of inlet nozzles into coagulator; 3 — the first stage: coagulator with the set of corrugated mesh from 0.1...0.5 mm; 4 — the second stage: coagulator with the set of corrugated mesh from 0.05...0.2 mm; 5 — package of the optimized profiles for deposition; 6 — system of inlet nozzles; 7 — exhaust branch pipe with a system of inertial nozzles

The research into oil separator was conducted by the computational methods when examining its three-dimensional model at the range of consumption 100...200 m^3/h (Fig. 2) and on the test bench, as well as in actual conditions in the engines. We explored gas dynamics of the flow and investigated coefficients of deposition at different consumption.

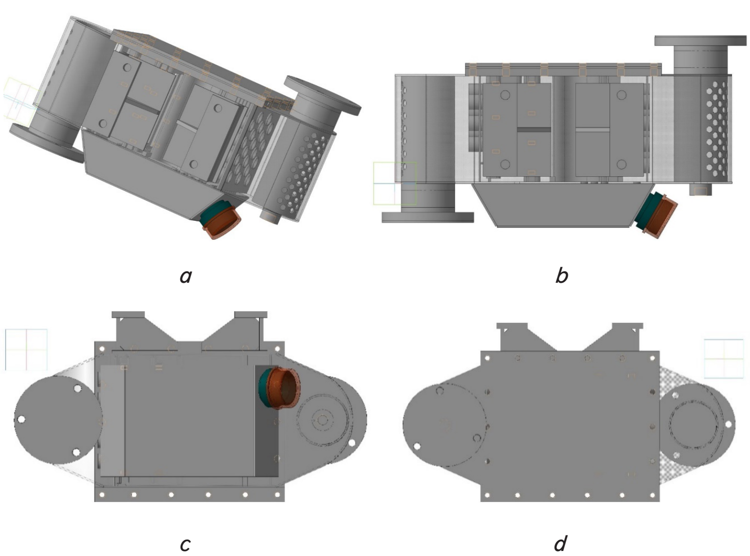


Fig. 3. Oil separator at the range of consumption G=100...200 m^3/h based on the separation gradient aerosol technologies: *a* — isosymmetry; *b* — side view; *c* — bottom view; *d* — top view

6. Mathematical model for examining the separation gradient aerosol technologies

The utilized thermophysical model of the processes of particle transfer in a channel is based on the transport equation of Reynolds stresses with the calculation of individual stresses $(u'_i u'_j)$ and took the form:

$$\frac{\partial}{\partial t}(\rho\overline{u'_i u'_j})+\frac{\partial}{\partial x_k}(\rho u_k\overline{u'_i u'_j})= =\frac{\partial}{\partial x_k}\left[\frac{\mu_g}{\sigma_g}\frac{\partial\overline{u'_i u'_j}}{\partial x_k}\right]+\frac{\partial}{\partial x_k}\left[\mu_L\frac{\partial}{\partial x_k}(\overline{u'_i u'_j})\right]- -\rho\left[\overline{u'_i u'_k}\frac{\partial u_j}{\partial x_k}+\overline{u'_i u'_k}\frac{\partial u_i}{\partial x_k}\right]-2\mu_L\overline{\frac{\partial u'_i}{\partial x_k}\frac{\partial u'_j}{\partial x_k}}. \quad (2)$$

By analogy with the transport equation of Reynolds stresses, in order to consider the nonisothermic parameters of the process, we performed calculation of convective heat transfer with the help of energy equation:

$$\frac{\partial}{\partial t}(\rho E)+\frac{\partial}{\partial x_i}\left[u_i(\rho E+P)\right]= =\frac{\partial}{\partial x_i}\left[\left(k+\frac{C_P\mu_T}{Pr_T}\right)\frac{\partial T}{\partial x_i}+u_i(\tau_{ij})_{eff}\right], \quad (3)$$

where τ was computed as:

$$\tau=\mu_{eff}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)-\frac{2}{3}\mu_{eff}\frac{\partial u_i}{\partial x_i}\delta_{ij}, \quad (4)$$

where

$$\mu_{eff}=\mu_T+\mu_L. \quad (5)$$

In order to model trajectories of the dispersed particles of a two-phase medium, we solved equation of motion [3], which considered the force of inertia of a particle and other basic forces acting on it. In the Cartesian coordinates, this equation was written in the following way:

$$\frac{\partial u_p}{\partial t}=F_D+\frac{g_x(\rho_p-\rho)}{\rho_p}+F_i, \quad (6)$$

where F_D is the resistance force for the unit of mass of the particle:

$$F_D=\frac{18\mu}{p_p d_p^2}\frac{C_D}{24}Re, \quad (7)$$

$$Re=\rho d_p\frac{|u_p-u|}{\mu}, \quad (8)$$

where F_i are the additional forces acting on the particle.

Specific resistance C_D was calculated in the following way:

$$C_D = \frac{24}{Re}\left(1 + b_1 Re^{b_2}\right) + \frac{b_3 Re}{b_4 + Re}, \quad (9)$$

where b_i are the polynomially assignable coefficients.

The equation considers additional forces F_i, which act on the particle. To account for the deposition of particles under the action of inertial force, it is necessary to consider the acceleration of flow that streamlines the particle. The inertial force is calculated in the following way:

$$F_1 = \frac{1}{2}\frac{\rho}{\rho_k}\frac{\partial}{\partial t}\left(u - u_k\right). \quad (10)$$

The transverse displacement of particles can be caused not only by the gradient of the averaged gas velocity, but also by the heterogeneity of the field of its pulsating velocities. The nonuniformity of velocity profile leads to the directed particle displacement to the side of the decrease in the intensity of pulsations. This effect, usually called turbulent migration or turbophoresis, is calculated by formula:

$$F_2 = -0{,}5 m_k \frac{\partial \overline{u_k'^2}}{\partial y}. \quad (11)$$

The additional force of particle transfer occurs in the case of a pressure differential and is called the diffusion-phoretic force, which can be calculated by formula:

$$F_3 = \left(\frac{P}{P_w}\right) u_k \frac{\partial u}{\partial x}. \quad (12)$$

The acoustic vibrations of low-frequency range were considered by modeling the vibration of walls (source of ultrasound) at appropriate frequency. The harmonic law of variation in the translational speed along the y axis is described by equation:

$$u_y = 2\cdot A\cdot\pi\cdot\text{э}\cos(2\pi\cdot\text{э}), \quad (13)$$

where A=0.00002 mm is the amplitude; э=10000 Hz is the frequency of vibrations.

7. Calculation experiment

We conducted a study into gas dynamics in the flow area of the channel (Fig. 4) and obtained values for the coefficients of deposition at different concentrations of a liquid phase.

In the process of calculation, the following parameters were assigned:

– a three-dimensional geometry is built on a real scale (length is 80 mm and height is 5...25 mm);

– computational grid is built of the triangular segments with area $S=30*10^{-8}$ m^2; parameters of a medium – standard conditions;

– gas density ρ_g=1.225 kg/m^3;

– viscosity μ_g=1.79·10^{-5} kg/(m*s);

– material of the wall of a channel – aluminum with roughness 0.1 mm and density ρ_{al}=2690 kg/m^3;

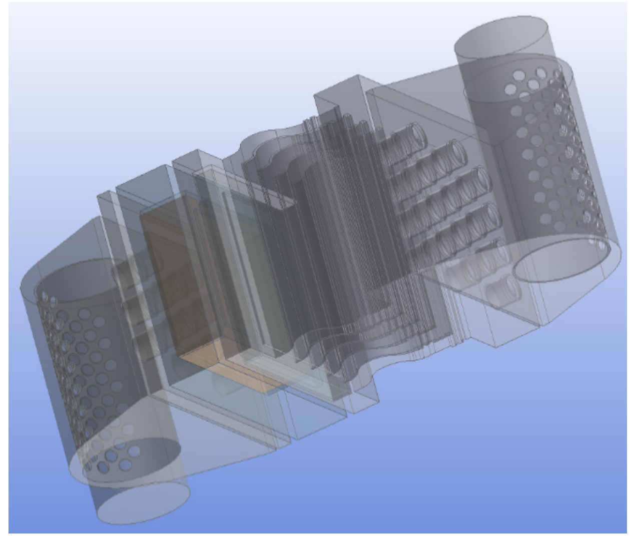
– minimum diameter of the particles: d_{min} – 3 µm;

– mean particle diameter: d_{mid} – 10 µm;

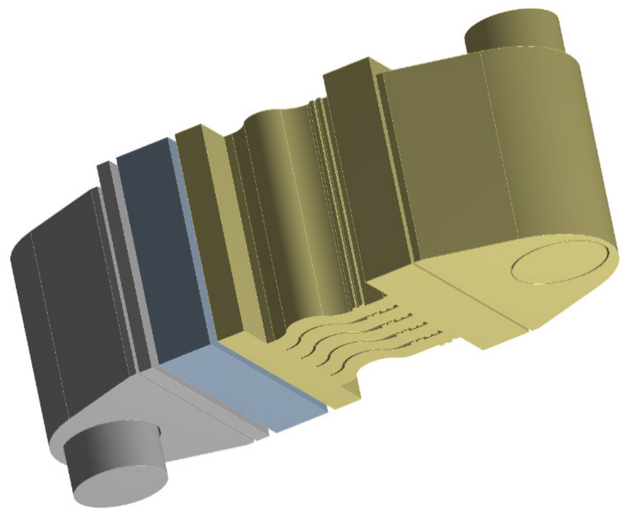
– maximum diameter of the particles: d_{max} – 15 µm;

– concentration of the liquid phase C_{input}=0,6 kg/m^3;

– range of consumption – G=100...200 m^3/h.



a



b

Fig. 4. A three-dimensional model of gas scrubber G=100...200 m^3/h based on the separation gradient aerosol technologies: *a* — a three-dimensional view for constructing the computational grid; *b* — a three-dimensional computational grid of finite elements

The diagrams of static pressure distribution (Fig. 5) show that a pressure differential for G=100 and 200 m^3/h in the separating coagulators reaches 2.5...3.9 kPa, respectively.

The trajectory calculation of particle motion in the channel showed that a particle flies through the entire channel in 0.8 s and its trajectory coincides with the flow line of gaseous medium in the working channel. Fig. 6 shows speed distribution in the oil separator at G==100 m^3/h and G=200 m^3/h.

From the calculated distribution of speed in the oil separator at G=100...200 m^3/h we determined that velocity in the coagulation profile does not exceed 10 m/s.

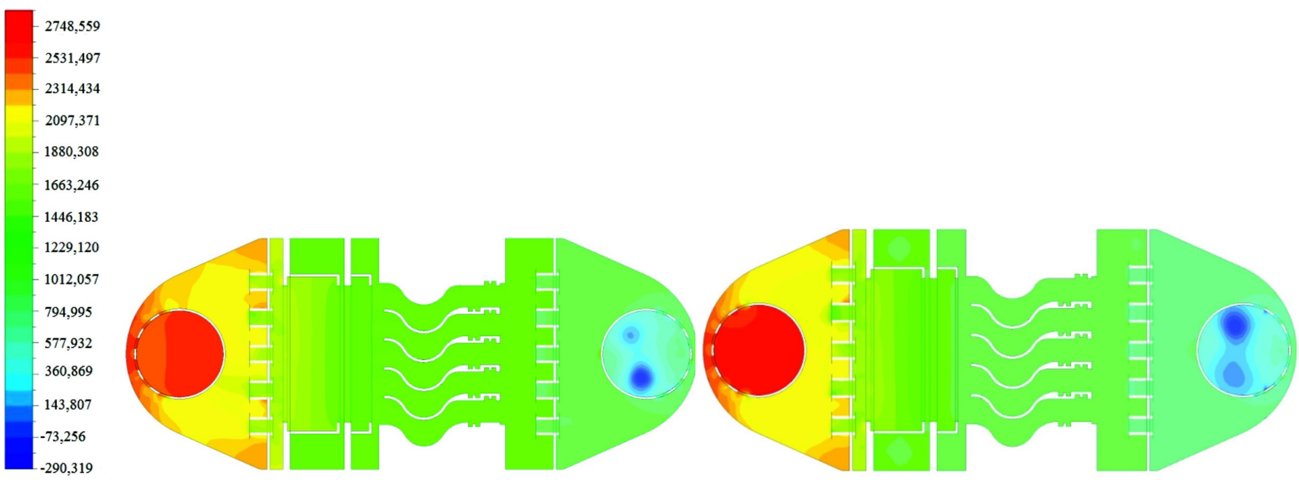
The calculation of particle deposition in the oil separator at G=100...200 m^3/h is given above in Table 1.

Results of calculation at G=100...200 m^3/h demonstrated that the summary pulsation effect of the deposition of highly dispersed particles reaches 25.1 %.

Table 1

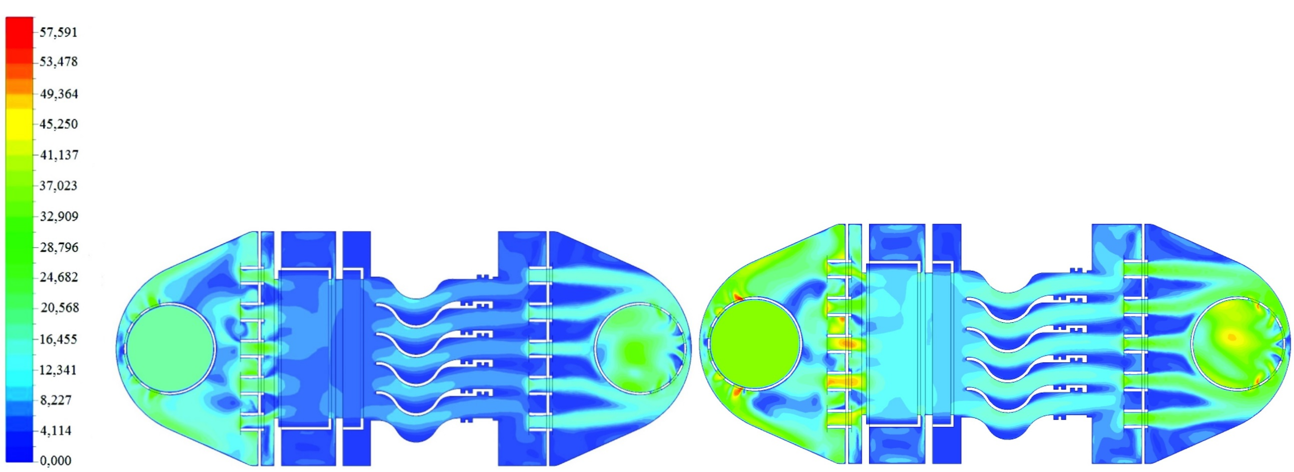
Calculation of deposition in the oil separator at G=100...200 m^3/h

Starting conditions						Without grid pulsation			With grid pulsations			ΣPLE (plant life extention) %
G_{input}, m^3/h	T_{input} cm, °C	C_{input}, kg/m^3	d_{min}, μm	d_{mid}, μm	d_{max}, μm	d_{min}, g_{output}, g/h	d_{mid}, g_{output}, g/h	d_{max}, g_{output}, g/h	d_{min}, g_{output}, g/h	d_{mid}, g_{output}, g/h	d_{max}, g_{output}, g/h	
100	80	0.6	3	10	15	6.2	1	0	4.1	1	0	41.1
120	80	0.6	3	10	15	9.3	1	0	7.2	1	0	25.6
140	80	0.6	3	10	15	12.5	1	1	10.7	1	0	23.9
160	80	0.6	3	10	15	16.3	1	0	13.2	0	1	21.8
180	80	0.6	3	10	15	18.8	1	1	16.4	1	1	13.0
200	80	0.6	3	10	15	22.4	2	1	17.3	2	1	25.1
Averaged value												25.1



a *b*

Fig. 5. Static pressure distribution in the oil separator: *a* – at G=100 m^3/h; b – at G=200 m^3/h



a *b*

Fig. 6. Distribution of speed in the oil separator: *a* – at G=100 m^3/h; *b* – at G=200 m^3/h

8. Procedure for the examination of oil separators in the venting systems of GTE

Optical measurements of the particle dispersiveness and concentration were conducted using the photoelectric counter of aerosol particles AZ-5 (Russia) and the photometer of aerosols FAN-U4.2 UHL (Russia). Error of measurement by these instruments did not exceed 5 %. The sampling was carried out by the sampling tubes, which simultaneously served as the tubes of total pressure 5 (Fig. 7). Isokinetic conditions were maintained during measurements. Mass particle concentration in the flow was determined by sampling the dispersed two-phase medium with aspirator and its passage through the analytical filters AFA. The AFA filters were weighed on the analytical balance with error ±0.1 mg prior to and after the sampling. By the increase in the weight of the filter, taking into account the time and consumption of the gas sample, we determined particle concentration using formula:

$$C_{mid}=1000(m_b-m_a)/g_{sample}\tau, \quad (14)$$

where m_b, m_a are the mass of filters before and after the sampling, mg; g_{sample} is the air consumption over the period of taking the sample through the aspirator, l/min; τ is the time of the sampling, min.

Consumption of the oil-air medium was determined by the pressure differential on the flow-meter collector, made in the form of a lemniscate profile:

$$G=\alpha_k S_k\sqrt{\frac{2}{\rho}9{,}81(p_1-p_2)}, \quad (15)$$

where α_k is the coefficient of consumption, $\alpha_k=0{,}99$; S_k is the flow area of collector, m^2; ρ is the density of medium, kg/m^3; p_1 and p_2 is the static ambient pressure and in the collector, mm Hg.

The effectiveness of capturing the aerosols by the examined elements was determined by formula:

$$\eta_{\Sigma 0}=\left(1-\frac{C_{вых}}{C_{вх}}\right)100\ \%, \quad (16)$$

where C_{input} and C_{output} are the input and output concentration of the oil aerosol, mg/m^3. Weighing of the AFA filters was carried out on analytical balance 17. Coefficient of the total effectiveness of purification was calculated by formula:

$$\eta_{\Sigma 0}=\left(1-C_{output}G_{в}/g_{ул}\right)100\ \%. \quad (17)$$

The test procedure implied the estimation of effectiveness in the range of gas consumption from 100 to 200 m^3/h, with and without cooling the coagulator.

9. Results of bench studies of the design of a gas scrubber and the estimation of its effectiveness

In order to conduct studies, we designed and assembled the prototype of a gas scrubber with capacity of 100–200 m^3/h, which corresponded to the consumption of an oil-air medium in the venting systems of GTE of the fourth generation DN 80 and DG 90 (Ukraine). Results of the bench tests are given in Table 2, 3.

Table 2

Study of oil separator. G=100 m^3/h

G_{input}, m^3/h	T_{input} cm, °C	C_{input}, kg/m^3	η_Σ	ΔP, kPa	C_{output}, g/m^3	G_{output}, g/h	C_{output}, g/m^3 PLE	G_{output}, g/h PLE	Σ PLE
100	80	0.6	99.9	2.5	$70\cdot10^{-3}$	7	$54\cdot10^{-3}$	5.4	29.6
100	80	0.6	99.9	2.5	$83\cdot10^{-3}$	8.3	$61\cdot10^{-3}$	6.1	36.0
100	80	0.6	99.9	2.5	$75\cdot10^{-3}$	7.5	$55\cdot10^{-3}$	5.5	36.3
100	80	0.6	99.9	2.5	$83\cdot10^{-3}$	8.3	$60\cdot10^{-3}$	6.0	38.3
100	80	0.6	99.9	2.5	$78\cdot10^{-3}$	7.8	$54\cdot10^{-3}$	5.4	44.4
100	80	0.6	99.9	2.5	$84\cdot10^{-3}$	8.4	$59\cdot10^{-3}$	5.9	42.3
100	80	0.6	99.9	2.5	$75\cdot10^{-3}$	7.5	$53\cdot10^{-3}$	5.3	41.5
100	80	0.6	99.9	2.5	$78\cdot10^{-3}$	7.8	$52\cdot10^{-3}$	5.2	50.0
Averaged value					$78.25\cdot10^{-3}$	7.825	$56\cdot10^{-3}$	5.6	39.8

Table 3

Study of oil separator. G=200 m^3/h

G_{input}, m^3/h	T_{input} cm ,°C	C_{input}, kg/m^3	η_Σ	ΔP, kPa	C_{output}, g/m^3	G_{output}, g/h	C_{output} г/м^3 PLE	G_{output}, g/h PLE	Σ PLE
200	80	0.6	99.9	3.9	$140\cdot10^{-3}$	28.0	$110\cdot10^{-3}$	22.0	27.27273
200	80	0.6	99.9	3.9	$144\cdot10^{-3}$	28.8	$114\cdot10^{-3}$	22.8	26.31579
200	80	0.6	99.9	3.9	$135\cdot10^{-3}$	27.0	$110\cdot10^{-3}$	22.0	22.72727
200	80	0.6	99.9	3.9	$139\cdot10^{-3}$	27.8	$108\cdot10^{-3}$	21.6	28.7037
200	80	0.6	99.9	3.9	$148\cdot10^{-3}$	29.6	$115\cdot10^{-3}$	23.0	28.69565
200	80	0.6	99.9	3.9	$142\cdot10^{-3}$	28.4	$113\cdot10^{-3}$	22.6	25.66372
200	80	0.6	99.9	3.9	$144\cdot10^{-3}$	28.8	$117\cdot10^{-3}$	23.4	23.07692
200	80	0.6	99.9	3.9	$138\cdot10^{-3}$	27.6	$110\cdot10^{-3}$	22.0	25.45455
Averaged value					$141\cdot10^{-3}$	28.2	$112\cdot10^{-3}$	22.4	25.98879

Table 2 shows that the coefficient of total effectiveness of removing the drops of oil for the coagulator reached 99.9 %. This coefficient is obtained at the input concentration of drops to 1.5 kg/m^3, gas consumption from 100 to 200 m^3/h and at temperature 90 °C. In this case, the aerodynamic drag of separator was from 2.5 to 3.9 kPa, and the output concentration of oil in the purified air was up to 13.2 mg/m^3. An increase in the input temperature of gas-oil medium decreased the effectiveness of capturing the highly dispersed aerosol due to an increase in the vapor phase of oil and the amount of the smallest particles. Thus, at t_{input}=90 °C, an increase in the output concentration of highly dispersed aerosol was 5 times higher than that at 30 °C (Table 2, 3).

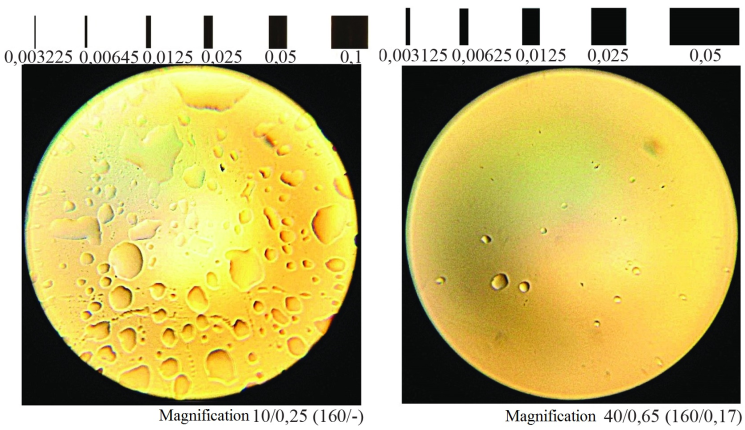
Studies into effectiveness of a separator at the pulsation of grid coagulator with the appropriate frequency:

$$u_y=2\cdot A\cdot\pi\cdot \text{э}\cos(2\pi\cdot \text{э}), \tag{18}$$

where A=0.00002 mm is the amplitude; э=10000 Hz is the vibration frequency, revealed a positive influence on the quality of purification. Thus, the pulsation of coagulator decreased the output concentration of oil by almost three times (Table 3). The total losses of oil in the presence of pulsation coagulator are reduced by approximately ΣPSE=30 % (summary pulsating separation effect) with an increase in the aerodynamic drag by 10 %. Thus, by using the pulsation coagulator it is possible to capture the vapors of oil before their saturated state at the temperature of feeding cold oil.

Fig. 7 shows images of the dispersed composition of gaseous medium, obtained with the help of an inertial probe and a digital microscope.

It is established that the coefficient of total effectiveness exceeds 99.9 %. The output concentration of oil aerosol under conditions of air consumption from 100 to 200 m^3/h amounted to $56\cdot10^{-3}$ and $112\cdot10^{-3}$ g/m^3, respectively. Aerodynamic drag is from 2.5 to 3.9 kPa.



a *b*

Fig. 7. Images of the dispersed composition of gaseous medium at G=200 m^3/h: *a* — inlet; *b* — outlet

10. Discussion of results of examining oil separators of the venting systems in GTE

As a result of the studies, we carried out a three-dimensional modeling of the oil separator of the venting systems of a gas turbine engine at gas consumption to 200 m^3/h based on the separation gradient aerosol technologies. In the process of constructing a mathematical model for the investigation of separation gradient aerosol technologies, all forces and effects were considered, which influence the processes of particle deposition in the channels of separators. In order to calculate the proposed design of an oil separator, we built a computational grid of finite elements on a real scale, which made it possible to analyze the separation equipment as a whole and to identify the most effective zones of deposition. Results of the bench tests confirmed the methods proposed. Deposition coefficient in the oil separator reaches 99.9 %, removal of the highly dispersed phase at consumption 200 m^3/h does not exceed 23 g/h.

However, in the performed study we did not calculate the deposition of solid particles of different diameters. The deposition at the elevated concentrations of a liquid phase to 10–90 % was not considered. We did not explore the processes of deposition for different types of gases at different pressures. The application of the given approach for the implementation in all types of separation devices requires additional research.

Nevertheless, the new designs we created, as well as the modernization of existing set-ups of purifiers, will differ by the application of pulsation separation elements, which will make it possible to increase coefficients of purification from the highly dispersed aerosol to 30 %. This is the obvious advantage of our design. It should be noted that the development of separators for the gas turbine engines with consumption of gaseous medium at 200 m^3/h based on the separation gradient aerosol technologies with the purification factor 99.9 % is predetermined by the start of creation of the new generation of engines at the gas-turbine enterprises of C.P.R. The studies conducted make it possible to develop in the future a range of separators with gas consumption from 20 to 2000 m^3/h.

The modernization of purifiers for capturing the aerosols in the following systems is possible based on the separation gradient aerosol technologies:

– the venting of gas turbine engines;

– the ventilation of crankcase of internal combustion engines;

– comfortable and technical conditioning;

– the ventilation of reducers of main turbine gear units, compressed air purification;

– drying of food and medical preparations.

11. Conclusions

1. We calculated a hydrodynamic situation and particle trajectory in the flow area of an oil separator, which showed that a particle flies through the entire channel in 0.8 s and its trajectory coincides with the flow line of gaseous medium in the working channel.

2. Using the calculated distribution of speed in the oil separator at G=100...200 m^3/h, it was determined that velocity in the coagulation profile does not exceed 10 m/s.

3. It is established according to the results of static pressure distribution for G=100, 200 m^3/h

that a pressure differential in the separation coagulators reaches 2.5...3.9 kPa, respectively.

4. Results of the calculation at G=100...200 m^3/h revealed that the summary pulsation effect from the deposition of highly dispersed particles reaches 25.1 %.

5. Based on the calculations, we assembled the prototype of an oil separator and tested its experimentally on the test bench in the form of an open type wind tunnel. Coefficient of the total effectiveness of purification was determined, which amounts to 99.9 %.

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