Journal of Siberian Federal University. Engineering & Technologies 2023 16(2): 198–210
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Technosphere Safety
Техносферная безопасность

EDN: KSKCJY

УДК 66.074.1

Cleaning of Industrial Emissions from Gas and Dispersive Particles

Mukhtor J. Makhmudov*[a] and Tashmurza R. Yuldashev[b]
*[a]Bukhara Institute of Engineering and Technology
Bukhara, Republic of Uzbekistan*
*[b]Karshi Engineering Economics Institute
Karshi, Republic of Uzbekistan*

Received 05.11.2022, received in revised form 04.02.2022, accepted 21.02.2023

Abstract. This article presents the results of experimental and theoretical studies of the effective purification of dispersed-ring two-flow industrial gases from gaseous and dispersed particles, hydrodynamics and mass transfer. The devices are designed to reduce the harmful emissions of the established threshold permissible (ChRET) at relatively low energy costs.

Keywords: natural gas, amine, cleaning gas, adsorption, absorption, adsorber, absorber.

Citation: Makhmudov, M.J., Yuldashev, T.R. Cleaning of industrial emissions from gas and dispersive particles. J. Sib. Fed. Univ. Eng. & Technol., 2023, 16(2), 198–210. EDN: KSKCJY

Очистка промышленных выбросов от газообразных и дисперсных частиц

М. Дж. Махмудов[а], Т.Р. Юлдашев[б]
*[а]Бухарский инженерно-технологический институт
Республика Узбекистан, Бухара*
*[б]Каршинский инженерно-экономический институт
Республика Узбекистан, Карши*

Аннотация. В данной статье представлены результаты экспериментальных и теоретических исследований по эффективной очистке дисперсно-кольцевых двухпоточных технических газов

* Corresponding author E-mail address: makhmudov.mukhtor@inbox.ru

от газообразных и дисперсных частиц, гидродинамики и массообмена. Установки предназначены для снижения вредных выбросов до установленного порога, допустимого (ЧРЭТ) при относительно небольших энергозатратах.

Ключевые слова: природный газ, амин, газ очистки, адсорбция, абсорбция, адсорбер, поглотитель.

Цитирование: Махмудов, М. Дж. Очистка промышленных выбросов от газообразных и дисперсных частиц / М. Дж. Махмудов, Т. Р. Юлдашев. Журн. Сиб. федер. ун-та. Техника и технологии, 2023, 16(2). С. 198–210. EDN: KSKCJY

Introduction

Purification of industrial gases from gaseous and dispersed particles due to worsening environmental problems has become a common national problem in the world and on the scale of our republic. In our republic, these problems are of great importance, and due to the lack of attention paid by nature drying enterprises, the level of pollution of nature and atmospheric environment is increasing.

Based on this, North Shu'artan, Harmiston, Kumchuq and Shakarbulok fields are connected to one block in "Shortanneftgaz" UShK. A project on the disposal of satellite gases has been drawn up and a large amount of work has been carried out [1].

The greenhouse effect changes the composition of gases in the earth's atmosphere. As a result of increasing the concentration of gas in the atmosphere, it absorbs the «infrared» rays that enter the earth and retains part of the heat in the atmosphere, and in turn, this situation leads to global warming of the climate on the planet.

CO_2 are considered greenhouse gases (carbon dioxide,) and about 80 % of the CO_2 greenhouse effect occurs due to it, and about 20 % due to the effect of methane, while the greenhouse effect of other gases has little effect on climate change. CH_4 During the last ten years, the amount of methane in the earth's atmosphere CO_2 has increased more than 3 times, and methane – 2.5 times more [2].

Today, economical use of industrial gases remains one of the problematic issues in global practice. Every year, 170 billion cubic meters of industrial gas is burned into the atmosphere. It is natural that such a situation causes great damage to the ecology and economy of mining countries (Table 1) [3, 4].

Among the countries of the world, Nigeria and Russia have the highest share of waste gas burning. Due to the release of wastes due to the burning of flare gases into the atmosphere, there is a danger to

Table 1. The volume of industrial gas that is burned or released into the atmosphere distribution by world regions

№	Regions	Volume, billion m ^{3} /year
1	North America	17
2	Central and South America	10
3	Africa	37
4	Near and Middle East	16
5	Asia	20
6	CIS	32
7	Europe	3
Total		135

human health, harmful substances are increasing in a very large amount, harmful metals in its content are causing various types of serious diseases [5].

Of gas is produced in Uzbekistan for a year, 58.4 % of it is used for domestic use, 6.5 % is sent to underground storages, 12.5 % is sent to the cycling process, and 22.5 % is sent to export. If we consider that 3 % of the total extracted gas is released into the atmosphere through flares, this value is a large indicator [6].

If 1000 m^3 we take into account that 3 tons of carbon dioxide is released into the atmosphere when industrial gas is lit, 1.5 billion 4.5 mln. m^3 of gas is burned. t carbonic acid is released into the atmosphere [7].

This scientific article examines the issues related to the cleaning of industrial gases of the hydrolysis industry enterprises, which are considered as sources of increasing environmental risk, that is, they are associated with the problems of overcomplicating environmental requirements for the network and a sharp increase in the size of payments for emissions.

Accumulation of gases released into the atmosphere due to the lack of improvement of technological processes and equipment in the hydrolysis industry, the presence of various harmful gases in its composition, organic vapors, small dispersed droplets of liquid, solid particles of primary raw materials (dust), lignin, solids, soot, etc. will be available.

First of all, the cleanliness of the atmosphere is affected by emissions from the main production facilities:

– air produced from yeast containing sour carbon dioxide, nutrient medium and live microorganisms, heat carrier, dryer discharges containing water vapor and sizes 3–16 µm. particles of dry microorganisms;

– the ecological danger of disposal of hydrolysis devices, equipment and clarifiers is primarily related to the presence of furfural in the gas;

– the discharge of uncondensed gases from the rectification column contains methanol and a whole range of organic acids.

This includes the removal of boiler rooms and auxiliary units. For example, when the discharge volume of a limestone kiln is 30,000 m^3 /hour, it emits 2.5 tons of solid particles, 7.7 tons of nitrogen dioxide, 8.5 tons of sulfur dioxide, and 0.6 tons of carbon dioxide into the atmosphere. The amount of harmful emissions from the Krasnoyar Biochemical Plant alone is hundreds of tons per year [8, 9].

The complexity of the organization of gas cleaning in the hydrolysis industry is achieved by simultaneously maintaining the gaseous and dispersed (solid or liquid) components from the gas, as well as the optimal temperature of the process.

The implementation of the reduction of emissions to the limited permissible norm (ChREM) is related to the acceleration of new technologies and existing technological cleaning processes.

A comparative analysis of the main known cleaning methods (absorption, adsorption, catalytic and thermal) shows that the absorption (wet) method is the most necessary method in the implementation of complex gas cleaning [10].

Wet cleaning does not require additional gas cleaning and the use of expensive catalysts or adsorbents, and at the same time provides an opportunity to carry out cleaning of gas emissions and dispersed particles in the optimal temperature regime.

A comparative analysis of the main characteristics of known "wet" types of apparatus (Table 2) shows that among them, high-speed Venturi, foam apparatus, pseudo -hydrogen layer apparatus, and curtain tube apparatus have the greatest efficiency [11].

The curtain devices between them work in the dispersed-ring mode. They have a number of additional advantages: these devices have the possibility of simultaneous cleaning of gaseous and dispersed particles, it is possible to ensure the optimal temperature in the zone of contact phases, they work stably in gas and liquid over a wide range of loadings, they have small dimensions and their structural equipment is relatively simple, for a long time provides contact (100 times greater than in venturi tubes) [12].

In this case, scaling problems in curtain apparatuses are easily solved, and data obtained in individual tubes in laboratory and experimental-industrial conditions can be quickly transferred to industrial apparatuses. In addition, it is possible to easily organize several accelerated cleaning zones, bring in natural gas at the expense of the energy of the irrigated liquid, that is, transportation of contaminated gas is provided without additional mechanical equipment, and in practice the total energy costs are reduced.

In the tube curtain apparatus nozzles (Fig. 1), the gas contacts the liquid in the form of a curtain on the surface of the pipe and in the form of drops in the flow core.

Table 2. The main indicators of the devices in the "wet" cleaning of gases

Indicators	Ventur a tube	SP type hollow Scrubber	Foam hardware	Ball Nozzle Scrubber	Curtained – tubular (decre-asing direct current)
Dimensions:					
height, m;	4.99	17.4;	8.8;	8.3;	4.8;
diameter, m;	2.8x1.9	0.9;	1.6;	1.2;	1.7;
mass, t	1.26	6.8	2.5	2.3	1.5
Pressure loss in the liquid transmission line, mm water us.	80,000	80,000	8,000	8,000	3000
Hydraulic k resistance, mm of water him	300–3000	100–220	100–350	100–500	10–350
Comparative energy costs, kW · h / thousand.m ^{3}	2–4	0.99–1.7	0.6–2.8	0.6–2.82	0.23–2.12
Coefficient of mass transfer to liquid, m/s	(1–2.5) · 10–4	10–5–10–4	(0.6–5.5) · 10–2	(0.5–5) · 10–2	(0.2–1) · 10–1
Velocity of gas on the cross-section surface, m/s	1.4–7.7	5–9	0.9–4	6–15	1–30
Amount in concentration, g/l	< 0.5	–	–	< 10	–
Minimum diameter of the captured particle, µm	1–3	5–10	2	1–6	1–3
Time of entering the contact zone, sec.	0.01	1.5–4	0.03	0.05	0.16–5
Efficiency, %: SO_2 according to according to po NO_2 dispersed particle	 50–86 - 90–100	 50–99	76 (fluorine) - 90	73 69 95	90 89 95–100

Explanation. The table shows the indicators of the device with gas consumption of 20,000 m3 /h and liquid consumption of 20 m 3 /h.

The capture of gaseous components is provided by physical or chemical absorption, the increase in efficiency is achieved by increasing the mass transfer coefficient of liquid and gas turbulization, for example, by installing an artificial swirl on the membrane surface [2]. In addition, the twist provides a reciprocating movement of the fluid in the turbulent membrane and, at the same time, stabilizes its flow due to centrifugal forces, maintaining a stable membrane flow when the pipes deviate from verticality and in the deposits of membrane formations on the surface of the pipe.

Another way to effectively trap gaseous emissions is related to the creation of additional surfaces in the contact phases.

The main advantages of direct-flow centrifugal separators are the possibility of effective separation of a wide range of gas consumption and concentration of dispersed phase (solid or liquid aerosol particles) with relatively small hydraulic resistance, reliability and simplicity of structural equipment [13]. At approximately the same cost of energy, and the performance of direct flow centrifugal separators exceeds that of ordinary cyclones in terms of effective separation (especially when the particle size is smaller than 5–10 μm) [14].

They are close to wet electric filters in terms of overall efficiency, and in terms of fractions – wet (wet) dust traps (particle size 0.5–1.0 μm – or fiber filters [15]). In order to capture the particles smaller than 1 μm, steam is introduced into it, their size is increased and it is cooled by giving a cold flow through the wall of the channel, and at the same time, it condenses under the influence of centrifugal force in the dispersed ring mode, and the particles are deposited on the surface.

Experimental part

In the investigation of the dispersed-annular regime in the curtain apparatus, the velocity of the gas on the cross-sectional surface of the pipe is measured using a Pitot-Prandtl tube, and the temperature of the gas is measured using thermocouples. Research work was carried out on smooth and bumpy surfaces of pipes. The roughness of the twisted surfaces is created by means of 3 mm wires on the inner surface of the pipe with very small slits of 0.4–0.8 mm, the distance between the windings of the wires is 30 mm [16].

Liquid consumption is varied from 1 to 15 m^3/hour, and gas speed is varied from 6 to 50 m/sec. The average thickness of the liquid film was determined using the source shear method (continuous blocking). The minimum and maximum thickness of the membrane is determined by contact needles, and its free end is attached with a microscrew and a transparent capillary. The change of the pressure difference in the pipe during strong interaction is carried out in piezometric pipes, and the air consumption is determined by means of normal diaphragms [16].

The study of mass transfer to liquid was carried out on the example of isothermal absorption of a liquid layer from air [16]. Cleaning of gas emissions from NO_2 and SO_2 was carried out by experimental-industrial research chemical methods. Primary gas contains 10 to 18 mg/m ^{3} of dispersed particles, 23 to 73 mg/m^3 of nitrogen dioxide NO_2 and 38 to 80 mg/m^3 of sulfur dioxide SO_2 at 140 °C condensation mode, air dusting is carried out using artificial dispensers. Steam transmission to the device is carried out using electric steam generators. The temperature in the air, in the steam-gas mixture and in the refrigerant is measured using a thermocouple. Air pollution is monitored using an AZ-5M aerosol particle counter [9]. The efficiency of separation of the dispersed phase is evaluated by the amount of condensate, and the efficiency of general dust removal – dry mass residues in the concentrate, fractionation – dry mass residues in paper filters of different sizes and with the help of the AZ-5M aerosol particle counter. In separate experiments, the results on the amount of particles retained after the tissue apparatus with filtering material FPP-15–1.7 of the FP type (Petryanov's filter) are monitored [10, 11].

In the laboratory experimental device, the dependence of the main parameters on the hydraulic resistance, the heat exchange description of the apparatus and the separation efficiency of the dispersed phase from the initial composition of the gas, the consumption of steam mixing, the speed of the flow and the swirling speed, the dispersion composition, the main parameters, the concentration of dust and the change in its physicochemical properties were determined in the following intervals: initial air temperature – 20 ÷ 80 °C; initial air humidity – 40 ÷ 80 %; volume consumption of air – 0.003 ÷ 0.03 m^3/s; specific consumption of mixed steam – 0.01 ÷ 0.1 kg/kg; mass concentration of solid particles – 0 ÷ 0.005 kg/$m^{3;}$ temperature of the refrigerant (initial) – 2 ÷ 10 °C; consumption of refrigerant – 0.002 ÷ 0.02 kg/s. *In the experiments, powders with a bulk density of 1000 to 2000 kg/*m^3 and a particle size of 0.1 to 10 μm and different formations are used as the dispersed phase [17–18].

Discussion of results

Disperse-annular flow research. The hydrodynamic representation of the dispersed annular flow is carried out under complex conditions. Spraying on the surface of the curtain leads to the fact that the share of the liquid at a distance of 1.5–2.0 m reaches 20–80 % compared to the total consumption in the dispersed phase, while the thickness of the curtain decreases and the structure of the wave on its surface changes.

The pressure loss in tubular nozzles in the flow of the dispersed-annular mode of the apparatus is calculated by the following known relation:

$$\Delta P = \lambda \frac{\rho L (w-u_s)^n}{2(D-2h_{o'r})}, \tag{1}$$

(where Δ P is the pressure loss; L is the length of the pipe; r is the gas density; w – average consumption rate of gas; $u_s = 1{,}15 u_{parda}$ – surface velocity of liquid film; u_{parda} – the average flow rate of the liquid curtain; $h_{o'r}$ – the average thickness of the liquid film; D – pipe diameter; л – coefficient of hydraulic resistance; n – phase indicator), problems arise in determining the coefficient of hydraulic resistance on the surface of the phase interval.

It is not correct in principle to rely on Lockcart-Martinell model [19], homogeneous flow [20], in determining the coefficient of hydraulic resistance in the dispersed-annular flow regime, as well as separate flows of the curtain, gas and liquid [14]. At the same time, the expression of the hydraulic resistance coefficient by the parameters of the waves on the surface of the curtain is an ineffective relationship [21].

It is optimal to determine the coefficient of hydraulic resistance by the most commonly used methods of calculating the experimental values of the pressure gradient. It is established that the total value of the test voltage in the channel does not change along its length. The empirical relationship for the hydraulic smooth surface of the pipe in the calculation of the coefficient of hydraulic resistance gi at the phase intervals of the surfaces in the dispersion-ring mode is obtained in the following form:

$$\lambda = 6{,}5 \left(Re_0 \frac{u_{qat}}{w} \frac{v}{v_s} \right)^{-1{,}3} Re_{qat}^{1{,}24}, \tag{2}$$

where Re_0 is the relative Reynolds number of the gas: $Re_{qat} = 4\Gamma/\nu_s$ – the Reynolds number of the liquid film; ν and ν_s coefficients of kinematic viscosity of gas and liquid.

A similar equation is derived for pipes with a constant artificial diameter. The value of the coefficient of hydraulic resistance varies from 0.08 to 2, depending on the load of gas and liquid and the condition of the surface (surface) forming the curtain.

The velocity of the film is calculated through the average thickness of the liquid film, or it can be calculated according to the equations presented in the general work of [17] (other known equations do not take into account the removal of liquid from the surface of the film, which is especially important for the surface with artificial roughness at high gas loading leads to an increased value of the thickness of the curtain during the flow of the curtain according to).

n in equation (1) varies from 1.4 to 1.8, depending on the concentration of the droplet in the core of the flow, in contrast to single-phase flow (*n = 2).* It is characterized by the quenching of the turbulent pulsation flow of dispersed particles as a partial «laminarization» state.

Permeability in the cleaning of gaseous emissions in the curtain is $2 \cdot 10^{-3} – 5 \cdot 10^{-2}$ m/*s* depending on the consumption of gas and liquid and the condition of the surface forming the curtain in the isothermal absorption of poorly soluble gases [8].

In the dispersed ring mode, the mass transfer at the greatest speed is achieved in the movement of the curtain on the lumped surface of large-scale undulations. In the nonisothermal process, the value of mass permeability decreases by 20–50 % in the case of liquid evaporation from the membrane. The presence of a solvent surface-active substance, which reduces the surface attraction forces of the liquid, leads to a decrease in the coefficient of mass transfer by 10–30 %.

The surface of the curtain leads to an increase in absorption efficiency. It is determined that the presence of droplets in the dispersed ring flow (on the surface) is not taken into account in the current approaches that lead to the determination of the experimental value of the mass transfer coefficient, which leads to serious errors in a number of cases and does not provide an opportunity to establish the true value of the process parameters.

Separation efficiency research. A large number of theoretical and experimental studies of direct flow centrifugal separators show that the efficiency of centrifugal separation in general depends on the initial concentration of the dispersed phase, the flow rate, the design features and the main parameters of the separator, and the characteristics of the separation in terms of particle size. The performance of direct flow centrifugal separators is determined by the degree of removal of the dispersed phase by vapor or gas streams, as is the case with heat and mass transfer devices with various centrifugal separation elements. In some cases, extraction actually reduces the overall separation efficiency.

Without taking into account the secondary removal in the calculation equation of the efficiency of the retention of the gas flow with aerosol particles in the cylindrical channel in the state of lumped motion, the equation of the following form can be obtained (Fig. 1) [18]:

$$\lambda = 6{,}5\left(Re_0 \frac{u_{qat}}{w}\frac{\nu}{\nu_s}\right)^{-1{,}3} Re_{qat}^{1{,}24},$$

$$\eta = 1 - exp(-8tg^2\gamma \cdot St \cdot \bar{L}), \tag{3}$$

here $St = w_2\delta^2\rho_d/(18\mu D) = w_z\tau/D$ – Stokes' criterion; $\tau = \delta^2\rho_d/(18\mu D)$ particle velocity relaxation time [19], $\bar{L} = L/D$

– relative length of the separator channel; w_z – the average axial flow rate of the gas; δ – particle size; ρ_d – the density of the dispersed phase; μ – coefficient of dynamic gas viscosity; g is the turning angle of the current.

The complexity of the hydrodynamic processes in the turbulent swirling flow makes it difficult to solve the problems of centrifugation of dispersed particles, which is practically impossible when secondary entrainment is taken into account. For this purpose, experimental research data on the speed of removal of particles from the surface of the channel in turbulent flow can be used.

A view of the semi-empirical relationship obtained for the calculation of the separation efficiency of the analytical results of the centrifugal separation and secondary extraction processes:

$$\eta \approx \frac{1}{1+\beta\frac{w_z\rho L}{\mu\cos^2\gamma}}\left\{1-exp\left[-\left(1+\beta\frac{w_z\rho L}{\mu\cos^2\gamma}\right)\frac{\delta^2\rho_d}{9\mu}\frac{w_zL}{D^2}tg^2\gamma\right]\right\}, \tag{4}$$

here α ≈ 0,01 – the fraction of particles covered by the twisting turbulence from the surface of the channel [20, 21]; $\beta = \alpha/(270\cdot75) \approx 4{,}94\cdot10^{-7}$ – the coefficient.

Calculated relationship (4) corresponds to the data of experimental studies and shows the clear influence of structural and technological parameters on the efficiency of gas cleaning (Fig. 2).

In centrifugal separators, the main mode in the flow of two-phase flow is the dispersed-annular mode, the liquid film along the wall of the channel and the accompanying flow of gas or vapor, carrying droplets and solid particles are observed.

The separation process is carried out in several main stages: vapor saturation of the aerodisperse flow, condensation enlargement of the particles, separation of the dispersed phase.

In a vapor-gas mixture, aerosol particles play the role of active centers of condensation, upon reaching suitable conditions at the beginning of the process, a separate condensation nucleus is first formed on their surface (small droplets of a new phase), and then a single liquid layer continues to increase in thickness, causing the particles to become larger and heavier.

In this case, wetting and solubility of primary particles do not play any practical role, and condensation actually occurs on the surface of the liquid layer.

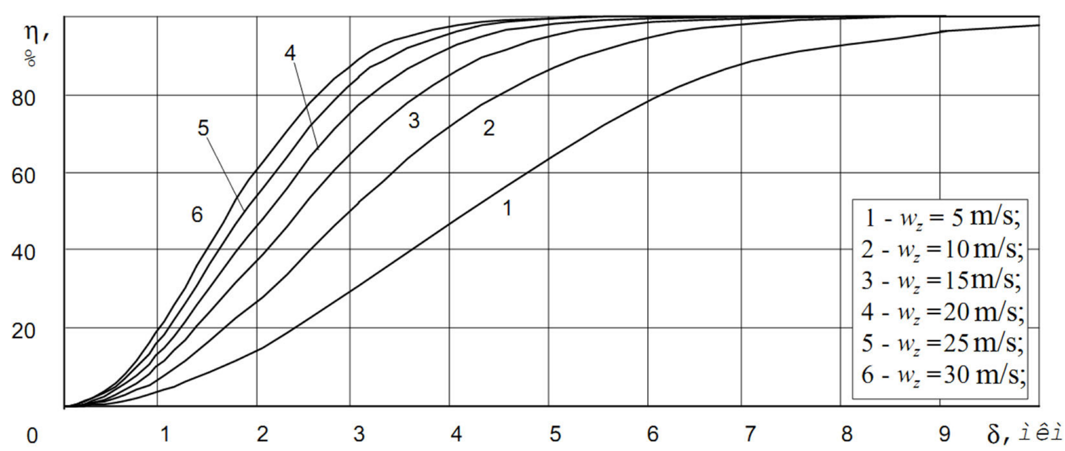

Fig. 1. Calculated fractional efficiency of centrifugal separation without secondary extraction: air-water 20 °C, D = 30 mm, L = 300 mm, g = 45 ° system when

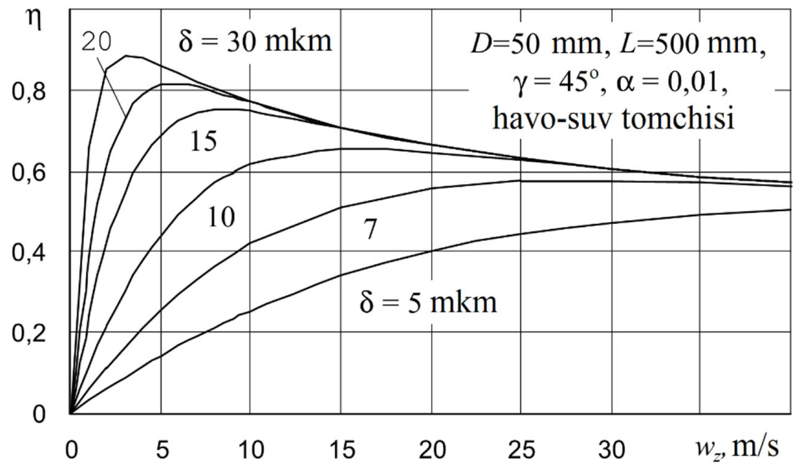

Fig. 2. A graph of the calculated dependence of the separation efficiency on the flow rate when taking into account the secondary removal

Steady-state condensation rate and droplet diameter (at constant temperature and pressure) and actual steam can be calculated from Maxwell's equation. When cooling a vapor-gas mixture moving over a very cold surface, heat transfer occurs through the boundary thickness of the adjacent gas, followed by condensation. If there is a mixture in the dispersed phase (liquid or solid aerosol particles), then condensation occurs not only on the surface, but also on the surface of the channel and on the particles.

The ratio between the mass of the condensate formed on the cooling surfaces of the channel v a depends on the supersaturation and concentration in the mixture of the dispersed phase. A large amount of condensation in the center of the flow condenses a very large amount of vapor relative to the wall of the channel [22]. The number of the particle is 10^{8} m^{-3} 99 % condensate is formed in total.

Calculations and experimental studies show that, under normal conditions, condensation enlargement can increase the size of particles from 1 to 10–15 μm. The ultimate particle size is largely determined by the magnitude of the heat flux surface density and is weakly dependent on velocity and initial size when the gas velocity is greater than 30 m/sec and the number concentration is greater than 10^{12} $m^{-3,}$ which means that the volume of condensate in each particle formed is itself becomes larger than its initial size. It is advisable to carry out the condensation enlargement of particles in a steam-gas stream at a relatively low concentration of the dispersed phase (up to 10^{12} $m^{-3)}$, high heat load and low flow speeds (up to 30 m/s).

It is not possible to carry out appreciable enlargement in each particle of the small liquid phase. Increasing the flow rate leads to an increase in energy consumption when the final particle size is not large enough to carry out the process.

In a condensing centrifugal separator, the mechanism of transferring particles to the walls of the channel is the same as in other direct flow centrifugal separators, so the basic law of the process is also similar.

In the general case, the axial component of the flow velocity is experimentally determined to decrease the total separation efficiency of the liquid phase, and the tangential one increases it, but its excessive increase can cause the separation of the liquid film from the seating surface and its removal in the secondary state. In fully inflow or outflow torsional (clumping) two-phase flow motion, the allowable loading on the gas and liquid differs over a wide range (compared to the axis), where the spray determines the full velocity of the gas at the boundary of the phase separation.

Fig. 3 presents an experimental graph showing the dependence of the spray size on the average axial velocity at different values of twist angles of the steam gas flow. For each curvature, the output corresponds to the optimal flow rate at which the work is minimal.

Its value depends on the turning angle and the variation of the parameters in the studied ranges is from 14 to 22 m/s. It lies in the limit, which completely corresponds to the normal values of centrifugal separators, i.e. the highest degree of clearance (minimum extraction accordingly) $\rho_g w^2$ value is from 150 to 600 kg /(m·s $^{2)}$ and the gas velocity is from 10 to 20 m/s (when the diameter of the cyclone is from 200 mm to 50 m/s).

Disperse phase does not have time to separate at low speed, and at high speed the secondary removal increases – at the boundary of the separation phases due to the increase of the full speed of the flow, the condensate film is broken. In practice, at optimal values of high speed (greater than 30–40 m/sec.), the amount of entrainment practically does not depend on the angle of rotation of the flow, that is, it can be seen that in the turbulent pulsation of the gas, the curtain is completely broken.

The separation efficiency of the dispersed phase is from 97.5 to 99.5 % at the value of the torsion angle in the range of the optimal speeds of the investigated flow.

The value of the minimum consumption of steam for mixing, which ensures the capture of aerosol particles, depends on its initial concentration and the temperature and humidity of the gas to be cleaned. The minimum consumption of steam is at a concentration of 10^{8} d and 10^{12} m $^{-3}$ up to, at the temperature of the gas up to 20 d and 80 °C and humidity is from 40 to 80 %, consumption is from 20 to 50 g/kg. Increasing the steam consumption to a very high minimum has practically no effect on efficiency.

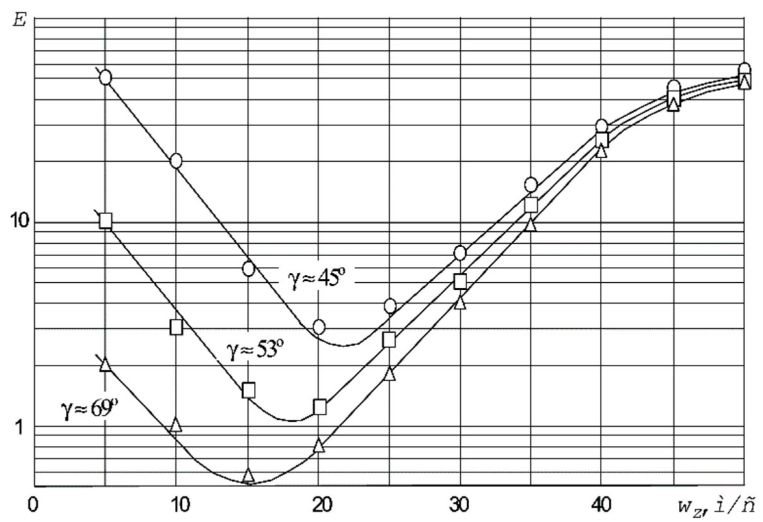

Fig. 3. Dependence of the displacement of the dispersed phase on the axial velocity and the angle of the twisting current: M-1 quartz powder at an ambient temperature of 80 °C; the concentration of the particle is 10^{10} m $^{-3}$; particle diameter 0.1 ÷ 5.0 µm; the temperature of the cooling agent is 10 °C; specific consumption of steam is 0.1 kg / kg

In optimal operating modes, the dispersed composition of the powder in the powder practically corresponds to the dispersed composition of the primary powder (independent of density and wettability). Thus, the efficiency of trapping particles with a size of 0.1 to 10 μm in the condensation centrifugal separator at a concentration of 10^{8} to 10^{12} m^{-3} does not depend on their primary diameter, which is confirmed by the conclusion of the theoretical analysis. In direct flow centrifugal separators with particle sizes of 5 ÷ 10 μm, retention is 95 ÷ 100 % even without condensation enlargement [23]. Thus, even small diameter particles of the condensing centrifugal separator are completely captured, and the fractionation efficiency of the separation limits the size of the spray-removal in the exceptional case.

Experience – industrial testing. Experiment – characteristics of the results of industrial research. Table 3 shows the data on the treatment of gaseous effluents in the limestone furnace of the biochemical plant with the height of the curtain apparatus with 3 mm twisting and the gas velocity is 10 m/s. It was found that changing the concentration of lime in water within the limit of 20 d and 100 g/l does not have a practical effect on the efficiency of gas purification. In the case where the gas velocity is relatively small, even with the low pressure of the industrial ventilator (up to 100 mm. water. *us.)*, the efficiency of cleaning of gaseous compounds was achieved, which ensured the marginal permissible emissions (ChRET).

Even when the liquid is artificially sprayed (sprayed), the dust retention efficiency has increased to 96 %.

Based on the received data, an industrial curtain pipe apparatus with a performance of 20,000 m^3/hour was calculated. Lime consumption is 4 kg/h, specific energy cost is 0.5 kW · h / thousand m^3 organized the The curtain pipe apparatus and technological scheme developed for the cleaning of gaseous wastes from the limestone kiln at "Krasnoyar BKZ" JSC enabled ChRET to be installed at very low energy costs and to reduce harmful wastes.

Of aerosol particles in a condensing centrifugal separator was carried out in the pilot-industrial experimental production of the All-Union Scientific Research Institute for the Designation of Technological Antibiotics and Medicinal Enzymes (VNITIAF, St. Petersburg). Trials were conducted in the production of inosine and actinomycete antibiotics.

Cultivated aeration fluid is used in crop cultivation processes and germ-free air is used in production fermentation. After fermentation (fermentation) in the volume of 0.5 m^{-3}, the air has a substance content of about 10 mg/m ^{3,} belonging to the first category of damage – mainly individual bacteria and their accumulation in sizes from 0.1 to 10 μm. When it gets into the environment, it causes unpleasant effects such as various types of allergic and poisoning in the human body.

In order to protect the environment, a single-chamber two-stage condensation centrifugal aerator with a working chamber diameter of 30 mm and a length of 250 mm is installed to clean the technological air leaving the fermenter. The consumption of air during drying was 350 to 450 l/min (at 0.0058 ÷ 0.0075 m^{3} /s) at a temperature of 30 ± 1 °C$^{. The}$ amount of steam is given to 0.1 kg/kg from the steam network of the sex. Water with a temperature of 2 to 15°C was used as a cooling agent.

As a screwing device, six-thread, screw (screw) pitch 96 mm (twisting angle 45 $^{0)}$ rammers were used. The numerical concentration of aerosol particles (bacteria) was determined by the number of columns before and after the separator in the gas test, after the release of the gas (medicinal substance) the formation of a saturation environment and for 24–72 hours it was kept under favorable conditions according to the VNITIAF methodology.

Table 3. Results of an experimental study

№	The name of pointers	Until it clears	After cleaning	Efficiency, %
1	Concentration of dust, mg / m ^{3}	19	7	63.2
2	NO_2 concentration, mg / m ^{3}	29	3	89.7
3	SO_2 concentration, mg / m ^{3}	80	8	90.0

Table 4. Experience – the results of industrial testing

Transmission scheme	Specific consumption of steam, g / kg		
	20	50	100
	Separation efficiency, %		
First step	30–50	50–80	70–100
The second step	0–30	20–50	40–80
Two steps together	40–80	80–100	100

Optimal conditions for the operation of the devices, and the parameters were found in laboratory studies. Steam transfer was carried out according to three schemes – only to the first stage, only to the second stage and equal amounts to both stages. The instability of the concentration of the dispersed phase in the gas made it difficult to reproduce the results of the experiments.

Table 4 shows the dependence of the separation efficiency of the dispersed phase on consumption and steam transfer schemes. As can be seen from the table, when transferring steam to both stages in the amount of 50–100 g/kg, the condensing centrifugal separator provides gas at a higher rate than aerosol particles, and complete purification is achieved when the steam consumption is 100 g/*kg.*

Has confirmed the possibility of using condensing centrifugal separators in the purification of process gases and industrial wastes of small mechanical mixtures from highly dispersed aerosol particles and achieving high efficiency.

Conclusions

Of curtain and centrifugal condensing devices, which implement the dispersed-ring mode that interacts with the phases, is considered the most effective for the simultaneous capture of gaseous and dispersed particles.

The developed devices provide high efficiency cleaning of gas from dispersed and gaseous wastes and provide the opportunity to clean up atmospheric pollution in practice.

The results obtained in the conducted research and industrial testing show the prospects of using the developed approaches in the improvement of the gas purification process.

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