ТЕХНИЧЕСКИЕ НАУКИ / TECHNICAL SCIENCE

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# HYDRODYNAMICS OF ABSORPTION BUBBLING APPARATUS

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# ГИДРОДИНАМИКА АБСОРБЦИОННОГО БАРБОТАЖНОГО АППАРАТА

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*Abstract.* The article proposes an improved design of the energy-saving, compact absorption bubbling apparatus, which cleans the particles and gas mixtures in the exhaust gases of industrial enterprises, has a high absorption efficiency. As a result of theoretical research, an equation has been proposed that calculates the value of the height of the gas cushion “h”, which provides equal distribution of purified gas to the mixing sections of the apparatus and operation in a stable hydrodynamic mode. As a result, depending on this value, it is possible to calculate the gas velocities and the gas consumption supplied to the apparatus.

*Аннотация.* В статье предлагается усовершенствованная конструкция энергосберегающего компактного абсорбционного барботажного аппарата, очищающего от частиц и газовых смесей выхлопных газов промышленных предприятий, обладающего высокой абсорбционной эффективностью. В результате теоретических исследований предложено уравнение, рассчитывающее значение высоты газовой подушки h, обеспечивающее равномерное распределение очищенного газа по участкам смешения аппарата и работу в стабильном гидродинамическом режиме. В результате, в зависимости от этого значения, можно рассчитать скорости газа и расход газа, подаваемого в устройство.

*Keywords:* gas cushion, resistance coefficient, liquid, bubbling, mixing zone, gas volume, gas velocity, liquid velocity.

*Ключевые слова:* газовая подушка, коэффициент сопротивления, жидкость, барботаж, зона смешения, объем газа, скорость газа, скорость жидкости.

## *Introduction*

Apparatus of various designs are used to carry out gas cleaning processes. Each of them is used to clean a specific polluted gas. One of the urgent tasks today is the creation and development of devices for the effective purification of multi-phase multi-component pollutants in the exhaust gases of industrial plants. Therefore, the following main tasks were set for the researchers [1, 2, 3, 9]. It is the development of methods for creating and calculating a promising, improved design of devices for the complex purification of gases from particles and gas mixtures, as well as solving the problem of their introduction into production.

*Material and research methods*

Based on these requirements, we have developed a new structure of the bubble absorption apparatus, which operates in an accelerated mode, with high efficiency of the mass transfer process. The structural structure and principle of operation of the device are given below (Figure 1).

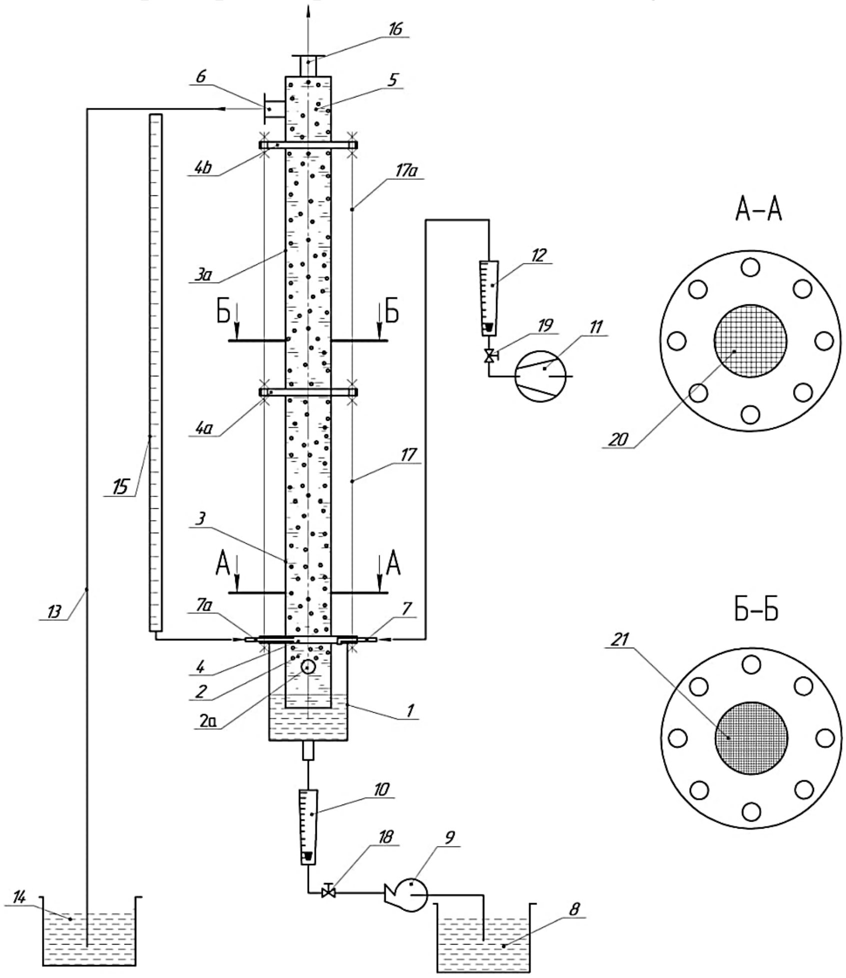



Figure 1. Scheme of bubble absorption apparatus: 1 — gas distribution section, 2 — gas distribution nozzle, 2a — gas supply hole, 3 — bottom section, 3a — top section, 4,4a, 4b — flanges, 5 — separator, 6 — saturated absorbent pipe, 7 — gas transmission channel, 8 — absorbent vessel, 9 — pump, 10 — rotameter, 11 — poison gas compressor, 12 — poison gas rotameter, 13 — saturated absorbent vessel, 14 — absorbent drain pipe, 15 — connected vessel tube, 16 — cleaned gas pipe, 17 — suction studs, 18 — absorbent valve, 19 — gas valve, 20 — large grid, 21 — small grid

The structural structure of the device is as follows. The device consists of collapsible and detachable parts, consisting of sections mounted on top of each other. These sections act as the steps of the device. Hardware sections 3, 3a, made of glass tubes. Glass tubes are pulled using metal studs 17a and 17b in a similar position to the metal flange 4, 4a, 4b. The cross-cut surfaces (torets) of the glass tubes are sealed with flanges 4, 4a, 4b, larvae with two rubber and acid-resistant rubber gaskets. The section is mounted to the center of the lower flange 4 by welding a metal pipe 2, part of which protrudes from the lower part of the flange 4. The hole 2a in it serves to transfer gas to the lower and upper sections 3 and 3a of the apparatus. The lower flange 4 is lined with a large-sized grid 14 to the lower section of the device, and the upper section to the flange 4a is lined with a small-sized grid 15. These grids serve to crush toxic gas bubbles.

On the sides of flange 4, channels 7 and 7a are opened by drilling. Channel 7 serves to transmit toxic gas to the apparatus. Channel 7a is connected to a glass tube 15 in the form of a connecting vessel to determine the level of absorbent liquid in the hardware sections 3 and 3a.

To ensure the full operation of the device sections, the flange 4b is equipped with an absorbent and a gas separator 5, which ensures the separation of gas. The secondary absorbent that absorbs the gas through channel 6 in this pipe is poured into vessel 13 through a special pipe 14. Through channel 16, the purified gas is released into the atmosphere. Pump 9 serves to supply the absorbent from the vessel 8 to the device. The required volume of the supplied absorbent is adjusted by means of a rotameter 10 and a tap 18. Toxic gas is supplied to the device through compressor 11 and the nozzle 19 and rotameter 12. For crushing gas bubbles, the flanges of apparatus 4 and 4a are fitted with 20 large-sized and 21 small-sized grids.

The operation of the experimental equipment is carried out in the following order. The absorbent liquid is transferred from vessel 8 through the gas distribution section 1 to hardware sections 3 and 3a from the bottom of the nozzle 2 by means of a pump 9. The required amount of absorbent fluid flow is provided by an RS-3 brand rotameter 10 and is limited by a valve 18. Along with the absorbent liquid, the cleaned gas is fed to the lower 3 and upper 3a sections of the device through the holes 2a in the nozzle 2 through the compressor 11. A gas cushion is formed to ensure that the toxic gas supplied to the mixing sections of the apparatus through the gas supply channel 7 enters evenly and evenly. The desired value of the gas cushion, the gas flow supplied by the compressor 11, is provided by means of valve 19 using an RS-5 brand rotometer 12. The height of the gas cushion is monitored using scales on a dimensional paper tape attached to a glass tube 1. To determine the value of the amount of volumetric gas in the mixing sections of the device, these sections are connected by a glass tube 15 in the form of a connecting vessel.

Inside the bottom 3 and top 3a bubble pipes, the absorbent fluid moves from bottom to top. Toxic gas bubbles, flanges 4,4a, 20 large square-sized and 21 small-square-sized metal grids mounted on the larvae are gradually crushed and rapidly mixed with the absorbent liquid. As a result, toxic components in the gas are absorbed into the absorbent.

Saturated absorbent liquid and purified gas, moving from bottom to top in the mixing zone, exit to the separator part 5 and the saturated absorbent liquid is poured into vessel 13 using a special pipe 14 through the discharge pipe 6. The purified gas is released into the atmosphere through pipe 16. The ratio of absorbent and toxic gas consumption to the device is determined experimentally depending on the efficiency of the mass transfer process. This in turn depends on the mixing time of the absorbent and toxic gas in the mixing zones. The number of steps of the device is also determined experimentally by the efficiency of the mass transfer process. The value of the gas cushion "h" in the smooth transfer of toxic gas to the mixing zones of the apparatus is determined theoretically and experimentally depending on the resistance coefficients of the grids mounted on the gas supply hole 2a and flanges 4.4a and the internal and external pressures acting on the centres of the gas inlet. The optimal values of the volumetric amounts of gas in the mixing zones are also determined experimentally on the basis of the optimal values of the mass transfer efficiency depending on the velocities of the liquid and gas.

*Results and discussion*

It is important to determine the height of the gas cushion "h" in the equal distribution of purified gas in the contact zones of the absorption apparatus. For this purpose, we analyze the value of the gas cushion height based on theoretical research. The value of the gas cushion height depends on the velocities of the gas exiting the gas supply hole 2a to the contact zones of the apparatus, the hole diameters play a key role and are important in creating a stable gas cushion. The equation for calculating the value of the height of the gas cushion was developed by V.N. Sokolov and Yu.K. Proposed for gas-liquid reactors by Gellis. However, the absorbent apparatus offered by us has lower and upper mixing sections, and each section is equipped with large and small-sized grids for crushing gas bubbles. Figure 2 shows the gas cushion calculation scheme. The height of the gas cushion "h" is the distance from the central axis of hole 2a to the level occupied by the liquid. When designing the apparatus, the diameter of the holes should be chosen in such a way as to create conditions for a hydrodynamic process of equal intensity in several bubble sections located on the hardware stages of the gas cushion [5,6,8].

In order to find the height of the gas cushion "h", if the Bernoulli equation is applied to sections 1–1, II-II, III-III and IV-IV, we consider the total pressures in the sections depending on the pressure Rs in the gas cushion and the pressure Ro inside the bubble pipe (Figure 2).

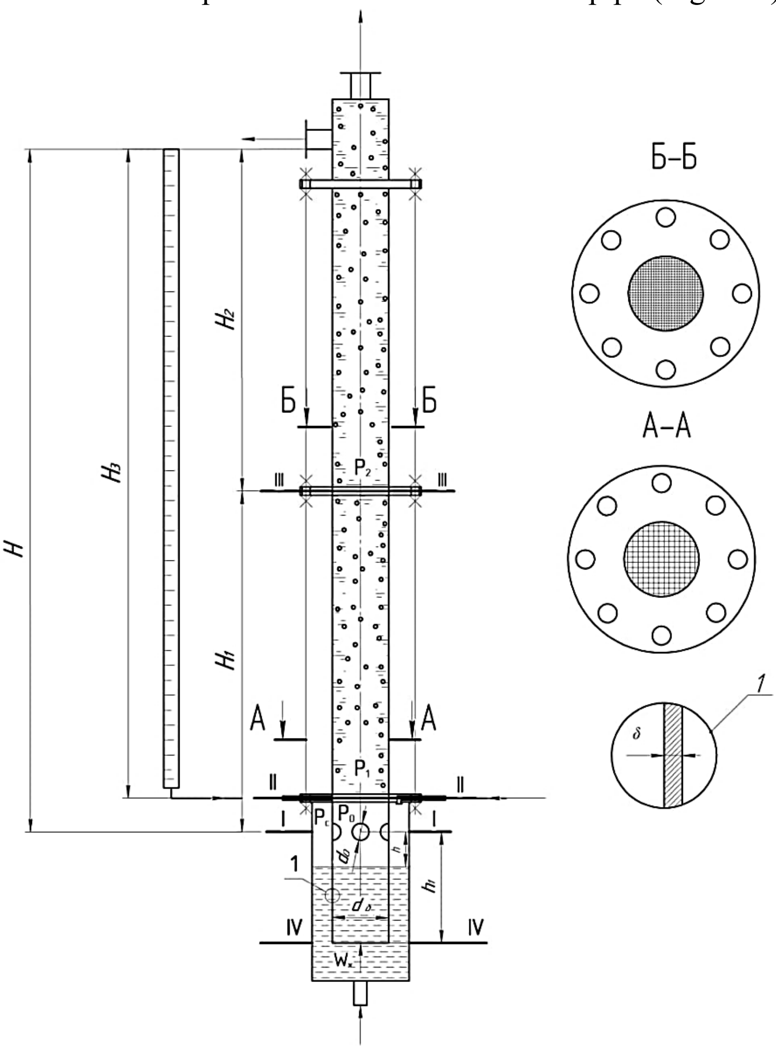



Figure 2 Gas cushion calculation scheme.

We write the pressures in sections I-I (at the center of the hole) and II-II (at the entrance of the liquid to the bubble pipe) as follows.

$$P_c + h\rho_г g + (h_1 - h)\rho_c g = P_o + h_1\rho_c g + \frac{\rho_c \overline{w}_c}{2} + \Delta P_n \tag{1}$$

where $\bar{w}_c = w_c(1-\phi)$ — the relative velocity of the fluid in the section I-I m/sec; $\varphi$-- the amount of gas in the liquid in the section.

$\Delta P_n$ - $h_1$ — -is the pressure drop at altitude, which is found using the following equation.

$$\Delta P_n = \left( (\xi_1 + \xi_2 + \xi_{вх} + \lambda_Б \frac{h_1}{d_Б} \right) \frac{\rho_c w_c^2}{2} \quad (2)$$

where ξ1— is the coefficient of hydraulic resistance of the fluid of section III-III through the large mesh; ξ2- — IV-IV coefficient of hydraulic resistance of the liquid in the section through the fine mesh; XVX is the coefficient of resistance at the inlet of the liquid to the bubble pipe.

The resistance coefficients ξ1 and ξ2 in the apparatus under test are determined as follows [6, 7].

$$\xi_1 \xi_2 = П \cdot \frac{d}{a} \cdot \sum S \quad (3)$$

where П- is the correction factor and is determined experimentally; d is the diameter of the selected grid cable, m; d-grid square hole size, m; The total surface area of the S-grid, m$^2$.

If the pressure in the gas cushion is expressed in terms of Pc and Po, and the pressure loss to overcome the hydraulic resistance of the gas-conducting holes in the bubble pipe is expressed in ΔPг, it looks like this.

$$\Delta P_Г = \xi_0 \frac{\rho_г \cdot w_г^2}{2} + \frac{2\sigma}{R_o} + \Delta P_{CT} \quad (4)$$

Where $\xi$ o is the resistance coefficient of the hole; ΔPст — static pressure of the liquid layer; Ro — is the radius of the gas-permeable hole in the bubble pipe.

Putting equation (4) into equation (5), the equation looks like this if the necessary mathematical operations are performed.

$$P_0 = P_C - \xi_0 \frac{\rho_Г \cdot w_Г^2}{2} \quad (5)$$

By substituting this equation (1) into the equation, the following equation can be formed.

$$h\Delta\rho g = \xi_o \frac{\rho_г \cdot w_г^2}{2} - \left( \xi_1 + \xi_2 + \xi_{вх} + \frac{1}{(1-\phi)^2} + \lambda_Б \frac{h_1}{d_Б} \right) \frac{\rho_c \cdot w_c^2}{2} \quad (6)$$

$\omega_г$ - actual velocity of the gas leaving the hole, m/s; By experimenting on the above equations, the value of ΔPст is determined by determining ΔPг and $\xi$o. The corresponding empirical equations are then determined. The result is a computational equation that is sufficiently reliable in practice. However, with such an approach, some unreasonableness arises when analyzing the mechanism of gas leakage from the hole in the liquid layer [5, 8].

According to Laplace's law, the pressure in a gas bubble, which has a spherical structure with radius Rп, increases the value of the pressure of the liquid surrounding it $\Delta m_{\ddagger} = \frac{2\sigma}{R_n}$ achieved when a hemispherical bubble with a small radius Rп equal to the hole radius R is formed in front of the hole. In addition, at all stages, there is Rp> Ro. Therefore, the ratio in equation (4) $\frac{2\sigma}{R_{..}}$ should be considered only in the case of separate ruptures of the bubbles. For the case under investigation $\xi_0 \frac{\rho_г w_0^2}{2}$, the expression $\frac{2\sigma}{R_0}$ consisting of cannot be taken into account [5, 8].

Laplace's law states that in the structural model of the gas leaving the hole, ΔPст in equation (4) is not taken into account. Studies of a multi-pipe reactor model show that as the number of bubble pipes increases, so does the gas cushion. This can be explained as follows. The pulsating passage of gas through the various pipe openings is due to the high-level vibrations of the gas-liquid mixture in the apparatus.

In multi-pipe bubble apparatus, the average actual velocity of the gas in the hole identifying the gas cushion is higher than the velocity calculated in terms of gas consumption. Studies show that such a difference is observed until the number of bubble pipes is determined. The law of averaging dynamic oscillations for the upper level of the fluid in the apparatus comes into force (Figure 3).

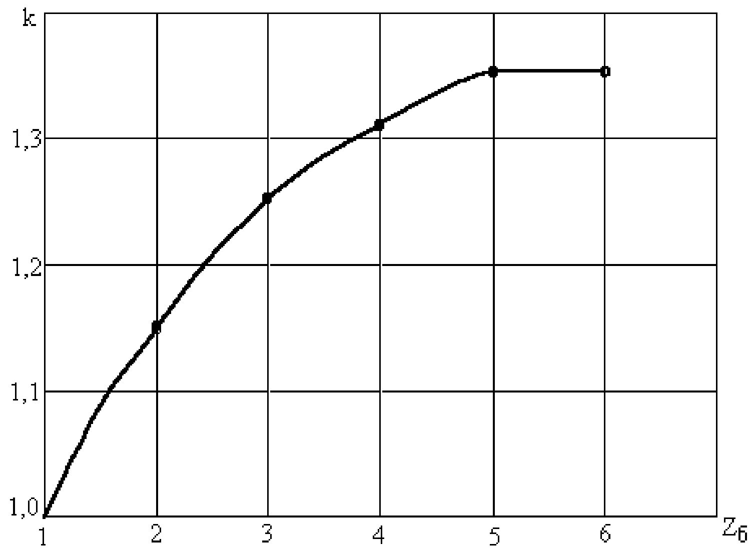



Figure 3. Graph of change of pulsation coefficient

This is the pulsation coefficient from the graph $K = \frac{w_г}{(w_г)\rho}$ with, the relationship between the number of bubble pipes Zб can be seen [5, 8]. From Equation (7), the height of the gas cushion "h" is given by the following mathematical operations.

$$h = \xi_o \frac{[Kw_o]^2 \rho_г}{2g\Delta\rho} - (\xi_1 + \xi_2 + \xi_{вх}) \frac{\rho_c \cdot w_c^2}{2g\Delta\rho} \qquad (7)$$

here $\xi_0$ — is the coefficient of resistance of the hole in the bubble pipe; $w_0$ — is the flow rate of the gas through the hole, m/sec; $\rho_г$ — density of gas in kg/m$^3$; K — pulsation coefficient, $\rho_c$ — density of the liquid, kg/m$^3$; g — free-fall acceleration, (9.8 m/sec$^2$); $\Delta\rho$ — density of the mixture, kg/m$^3$.

Using the given equation (8) it is possible to find the coefficient of resistance $\xi_0$ of the gas supply hole to the mixing sections of the apparatus and the height of the gas cushion "h" if the gas velocity w0 is known [5].

It is recommended by Yu. K. Gellis to calculate the resistance coefficient of the holes by the following equation [5, 8].

$$\xi = 0{,}5 + \left(1 + 0{,}37\frac{\sigma}{\sigma_{сув}}\right)^2 + \tau_0\left(1 - \frac{\sigma}{\sigma_{сув}}\cdot 0{,}37\right) + \lambda_0\frac{\delta}{d_0} \quad (8)$$

Where, $\tau_o = f\left(\frac{\delta}{d_o}\right)$ — coefficient depending on the shape of the hole; $\lambda_0$ — is the coefficient of friction, which is found by the following equation if the gas flow is in laminar mode [5, 8, 10].

$$\lambda_0 = \frac{64}{Re} \quad (10)$$

where Re Reynolds criterion; δ –hole wall thickness (m); do — hole diameter, (m); Several researchers have determined the reliability of Equation (9) depending on the shape of the hole, and have taken experimental values ξ=1,5÷2 for the dry hole. This is perfectly legal for a dry hole $\frac{f_o}{f_{Bx}} \approx 0$ were and the value of τo varies from 0.7 to 0 with respect to [5, 8; 9]. (Figure 4).

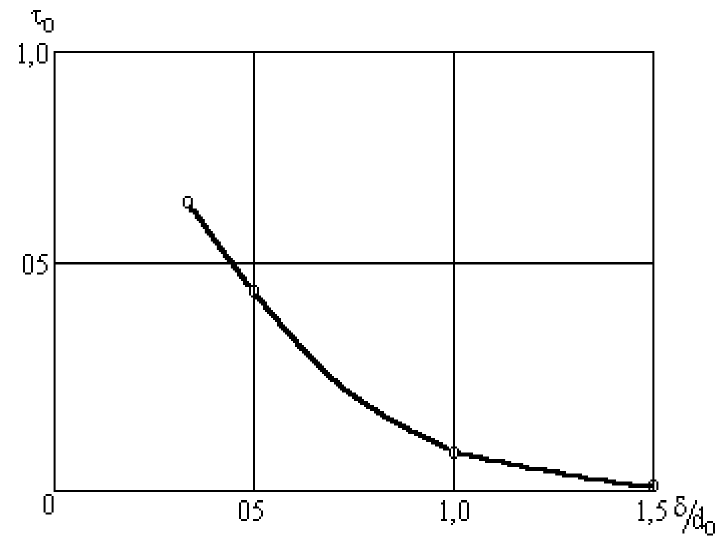
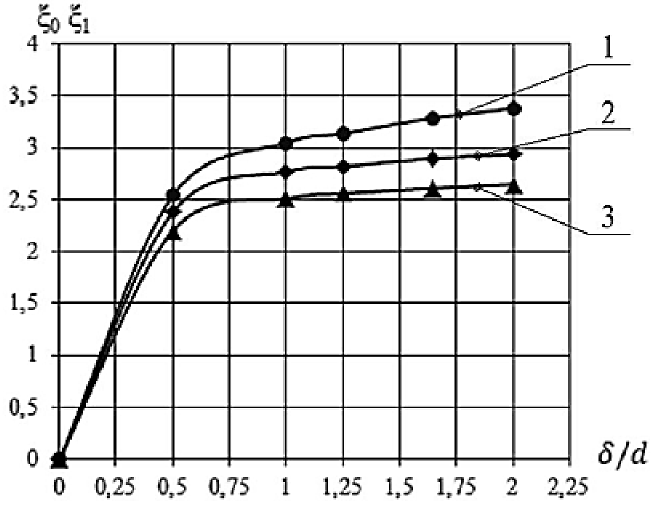



Figure 4. Graph of the relationship between $\frac{\delta}{d_0}$ and $\tau_0$.

Using Equation (9), the resistance coefficients of the gas transmission holes of the apparatus we are examining were determined (Figure 5).




1. σ=0,073 N/m, 2. σ=0,038 N/m, 3.σ=0,0248 N/m

Figure 5. Graph of the relationship between ξ1 ξ0 and δ/d

The total resistance coefficient of the liquid entering the bubble pipe consists of the sum of three expressions:

$$\xi_{Bx} + \frac{1}{(1-\varphi)^2} + \lambda \frac{h_1}{d_6} \tag{11}$$

As a result of the experiments, Gellis determined the coefficient of resistance of the liquid at the entrance to the bubble pipe, depending on the surface tension of the liquid [8]. (Figure 6).

The Idelchik recommendation can also be used when designing a gas distribution device [8]. If $\frac{\delta}{d_0} > 0{,}05$ in that case $h_2 > d_6$ and $h_1 = 4d$ in this case $\xi_{вх} = 0{,}5$ accepting that, $\frac{\lambda_0 h_1}{d_6}$ can also be ignored (Figure 6).

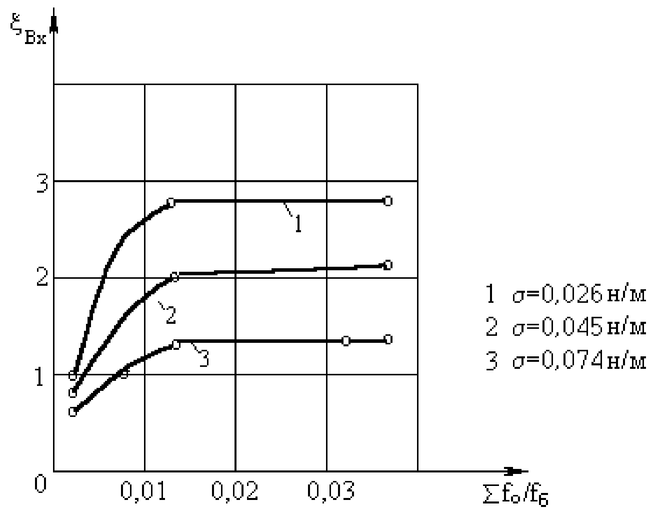



Figure 6. Graph of the relationship between ξвх and Σf0/fб

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*Conclusions*

In the research work, an improved design of a compact, high efficiency bubbling absorption apparatus with high absorption efficiency, which cleans particles and gas mixtures from industrial gases, was proposed. As a result of theoretical research, an equation was proposed to calculate the value of the height of the gas cushion "h", which provides equal distribution of purified gas to the mixing sections of the apparatus and operation in a stable hydrodynamic mode. As a result, it was possible to calculate the gas consumption of the device.

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