Experimental Research on Determining Gas Quantity on A Bubble Absorption Device

Karimov Ikromali Tojimatovich[1*], *Ibrohimov* Kobiljon[1], *Karimov Bakhromali* Tojimatovich[2], *Askarov Xasanjon* Abduqakharovich[3]

[1]Mechanical Engineering Department, Fergana State Technical University, Fergana, 150000, Uzbekistan.
[2]Pedagogical Sciences. Tashkent State Technical University was named after I.A. Karimov, Tashkent, 100000, Uzbekistan
[3]Andijan State Technical Institute, Andijan, Uzbekistan

Abstract. This article presents a method for determining the gas content value in the mixing zone of a newly created bubble absorption device and the results of experimental studies conducted on the experimental apparatus. In the experimental studies, gas content values were determined when liquid and gas flows were supplied through ceramic nozzles of various sizes installed in the mixing zones of the device. Based on the experimental results, the limit values of gas quantity and gas velocity were determined. As a result, an opportunity was created to achieve high efficiency in absorbing gas supplied to the device through these limit values.

Keywords: Absorption, bubbling, gas quantity, gas velocity, nozzle, size, mixing zone, liquid, gas

1 Introduction

Currently, the main principles in creating new designs of bubbling absorption units include simplifying the unit's construction, increasing purification efficiency reducing energy consumption by improving the contact between gas and absorbent, and increasing the focus on environmental protection [1-5].

These principles are crucial for enhancing the efficiency of absorption processes and achieving ecological sustainability. We have developed a new design of a bubbling absorption device that meets the principles mentioned above [6-10].

* Corresponding author: qobiljonibrohimov9898@gmail.com

2 Experimental

2.1. Materials

During the operation of bubbling apparatuses in liquid-gas systems, one of the characteristics of mixing gas with absorbent is the actual amount of gas φ_g formed when the liquid layer is bubbled through with gas, which is determined as follows.

$$\varphi_g = \frac{f_g}{f_{mix}} = \frac{\omega_g}{u_g} \tag{1}$$

In this case, far represents the area occupied by the gas-liquid mixture in the cross-sectional area of the device, measured in m^2; f_g is the area occupied by gas in the cross-sectional area of the device, in m^2; wg is the reduced velocity of the gas, in m/s; u_g is the actual velocity of the gas at the cross-sectional area of the device, in m/s. The volume of liquid in the gas-liquid mixture, v_c, is determined using the average value of the gas quantity φ_g as follows.

$$v_c = v_{mix}(1-\varphi_g) \tag{2}$$

where: v_{mix} - the volume of the gas-liquid mixture, m^3; φ_g - the amount of gas.
The height of the gas-liquid mixture layer H_{ar} and the density ρ_{mix} of the mixture is determined by the following equations.

$$H_{mix} = \frac{h}{\varphi_g} \tag{3}$$

The density of the gas-liquid mixture is determined as follows:

$$\rho_{mix} = \rho_l(1-\varphi_g) + \rho_g\varphi_g \tag{4}$$

where h is the height of the given liquid layer in meters; ρs and ρg are the densities of the liquid and gas in kg/m^3, respectively.
The amount of gas depends on the properties of liquids and gases and their velocities. Therefore, different types of equations are used to calculate gas quantities, depending on the type of bubbling absorption apparatus. For the device we are examining, we use the following equations. Depending on the flow direction of the gas-liquid mixture, additional characteristics arise. Specifically, the ratio between the superficial velocity of the liquid ω_l and its actual velocity can be expressed in terms of the gas quantity as follows.

$$\frac{\omega_l}{u_l} = 1-\varphi \tag{5}$$

Depending on the difference in phase densities, the actual velocities of gas and liquid differ from each other due to the effect of buoyant force. When a gas-liquid mixture rises upwards, the true velocity is determined by the following equation.

$$u_{real} = u_g - u_l = \left(\frac{\omega_g}{\varphi_g}\right) - \left(\frac{\omega_l}{\varphi_g - 1}\right) \tag{6}$$

When the gas-liquid mixture flows downward, the real velocity is determined as follows.

$$u_{real} = u_l - u_g = \left(\frac{\omega_l}{1-\varphi_g}\right) - \left(\frac{\omega_g}{\varphi_g}\right) \tag{7}$$

Based on these conditions, the amount of gas in the mixing zones of the bubble absorber operating in the intensive mode we are investigating can be determined by relating the gas content in the stationary liquid to the liquid velocities in the internal and external mixing zones of the device [2,3].

The gas content is determined as follows when the movement of liquid and gas is in co-current flow:

$$\varphi = (1 - 0.04\omega_l ')\varphi ' \tag{8}$$

When the movement of liquid and gas is in opposite directions

$$\varphi = (1 + 0.04\omega_l '')\varphi ' \tag{9}$$

will be.

Where ω_l' and ω_l'' are the flow velocities of the liquid at the cross-sectional area of the bubbling pipe and the annular channel, measured in cm/s. Equation (8) is applicable for co-current flows of liquids and gases with a velocity of ω_l=0.20 cm/s, while equation (9) is valid for counter-current flows of liquids and gases with a velocity of ω_l=0.10 cm/s. These equations fully correspond to the device we are examining. φ' represents the gas content in the liquid at rest, which is determined by the following equation[2,4,5].

$$\varphi_l = 2.47 \cdot \omega_g{}^{0.97} \tag{10}$$

where ω_g is the gas velocity in the mixing zone, measured in m/s;

In the bubble absorption device we developed, the gas and absorbent flow directions are co-current, and we use formula 8.

With the help of equation (10), it is possible to determine the limiting value of the gas content for a liquid at rest. In bubble mode, the gas content should be $\varphi \leq 03$. At a gas content value of $\varphi > 03$, the system exits bubble mode and transitions to jet mode. In this case, coalescence of the bubbles occurs in the system. As a result, the efficiency of mixing decreases. The value of the gas content depends on the gas velocity, and several researchers have established that the limiting gas value for the bubbling regime is ω_g=0.04·0.1 m/s. The amount of gas in the mixing zones of the device is of great importance in the design of the device, the influence of the device diameter on the amount of gas begins from D=150-200 mm, and the height loses its force from H=600 mm. For the device to operate in normal bubbling mode, the above values must be maintained.

From the above equations (8) it is clear that the gas volume φ also depends on the liquid velocity, and with an increase in the liquid velocity in the internal mixing zone, the value of the gas volume increases. In this case, it also leads to a decrease in the geometric pressure in the mixing zone of the apparatus.

Kutateladze and Stirikovich summarized the results of their experiments to determine the value of the gas volume in bubbling columns and recommended calculating it using the following equation.

$$\varphi_g = C\left(\frac{\rho_g}{\rho_l}\right)^{0.5}\left(\omega_g\sqrt{\frac{\Delta\rho}{\sigma g}}\right)^{0.68} \tag{11}$$

where C=04 is a dimensionless quantity.

Using equation (11), it is possible to determine the boundary values between the gas velocity passing through the cross sections of the mixing zones of the device and the gas volume.

By performing the necessary mathematical operations in equation (11), (12), (13), (14), the gas velocity is found, and the equation becomes, in m/s:

$$\omega_g = \sqrt[4]{\frac{\sigma g}{\Delta\rho}} \cdot (\frac{\varphi_g}{c})^{1,47} \cdot (\frac{\rho_l}{\rho_g})^{0,22} \tag{12}$$

Experimental studies were conducted on the experimental setup of the new device to determine the gas volume value in gas and liquid flow regimes of various values. The experimental device is presented in Fig. 2.

Fig 1. Experimental device of bubble absorber

3 Result and Discussion

The following main parameters were selected during the experimental studies. The diameter of the gas inlet to the mixing zone of the device was d=1; 1.5; 2mm, the gas flow rate was constant from Q_g=0.15÷0.85 m^3/h (in steps of 0.10 m^3/h), the liquid flow rate to the mixing zone was from ω_s=0.051 to 0.171 m/s (in steps of 0.03 m/s), the dimensions of the ceramic nozzles installed in the mixing zone were d=9÷15 mm, (in steps of 3 mm), the volume of the support grid on which the ceramic nozzles were placed was V= 0.000369m^3, and the gas cushion value at constant gas velocities was h=20,40,50,60,80,100 mm [11-15].
In the mixing zone of the absorption device, the liquid and gas flows are co-current, and the value of the gas volume φ decreases with increasing liquid velocity. When designing the

device, the dimensions of these zones must be correctly selected to regulate the liquid velocity in the mixing zones.

When determining the gas volume values, the mixing zones of the device were connected by glass tubes in the form of a connecting vessel (Fig. 2).

The experimental value of the gas volume in the mixing zones of the absorption device is determined by the change in the liquid level as follows.

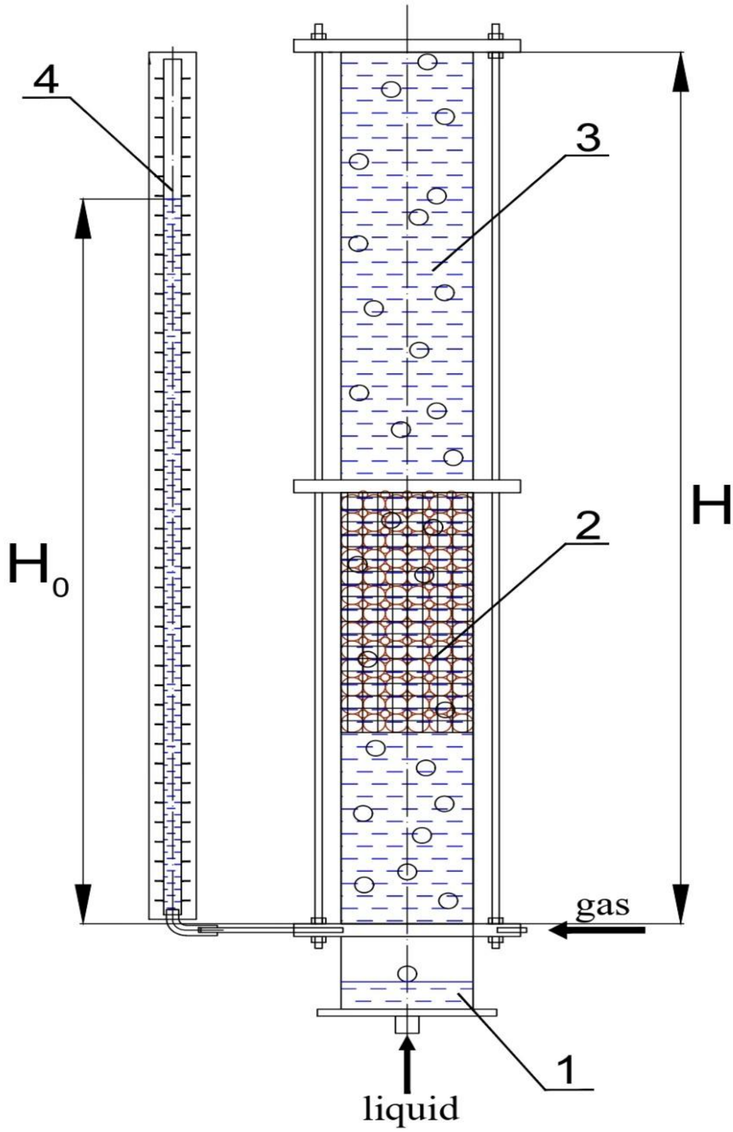


Fig 2. Scheme of experimental determination of the amount of gas in the mixing zones of the device

$$\varphi_0 = \frac{\Delta h_0}{H_0} \tag{13}$$

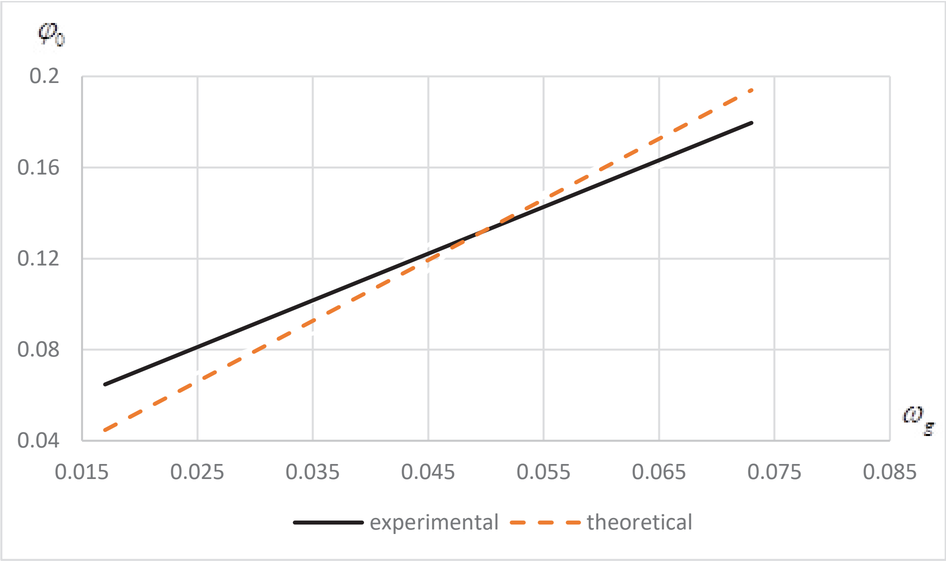
$$\varphi_1 = \frac{\Delta h_1}{H} \tag{14}$$

Here, H is the total height of the mixing zone, H_0 is the height occupied by the liquid in the mixture, and these heights were determined using glass tubes installed in the form of a connecting vessel.

In the experimental determination of the gas amount, gas was supplied to the mixing zone of the apparatus through holes of size d_0=1;1.5; 2 mm formed in the gas distribution nozzle. Initially, a mesh column filled with 9 mm ceramic nozzles was installed in the mixing zone of the apparatus. The gas flow rate was changed from Q_g=0.15; to 0.75 m^3/h in steps of 0.1 m^3/h, and the liquid flow rate supplied to the apparatus was changed from Q_l=0.23;0.55 m^3/h in steps of 0.08 m^3/h. Water was taken as an absorbent. For each of the liquid flow rates Q_l=0.23;0.31;0.39;0.47;0.55 m^3/h, the gas flow rates Q_g=0.15; 0.25; 0.35; 0.45; 0.55; 0.65; 0.75; 0.85 m^3/h were given separately, and the change in the gas flow rate was checked. The experiments were conducted separately for each hole in the mixing zone with dimensions d_0=1; 1.5 and 2 mm. The gas flow rate through the holes in the mixing zone with dimensions d_0=1 mm was Q_g=0.15; 0.25; 0.35; 0.45; 0.55; 0.65; 0.75; 0.85; m^3/hour, the corresponding gas volume values changed to φ=0.062; 0.088; 0.111; 0.14; 0.155; 0.177; at a constant liquid velocity ω_l=0.051m/s. When the gas flow rate Q_g=0.75 m^3/hour was given, it was not possible to determine the gas volume value. The reason was that the length of the gas distribution nozzle was not sufficient. When experiments were conducted with the d_0=1mm hole in the mixing zone closed and the d_0=1.5mm hole opened and the constant liquid velocity ω_l=0.051m/s, the values of φ=0.038; 0.066; 0.1; 0.138; 0.15; 0.166; changed to. When the d_0=1.5mm hole in the mixing zone was closed and the d_0=2mm hole was opened, the φ=0.038; 0.066; 0.1; 0.138; 0.15; 0.166; changed to, corresponding to the above-mentioned gas flow rates. The experiments were repeated 5 times for each gas flow rate with d_0=1;1.5;2 mm holes. The tests revealed that the increase in the gas flow rate supplied to the device had a noticeable effect on the change in the gas volume.

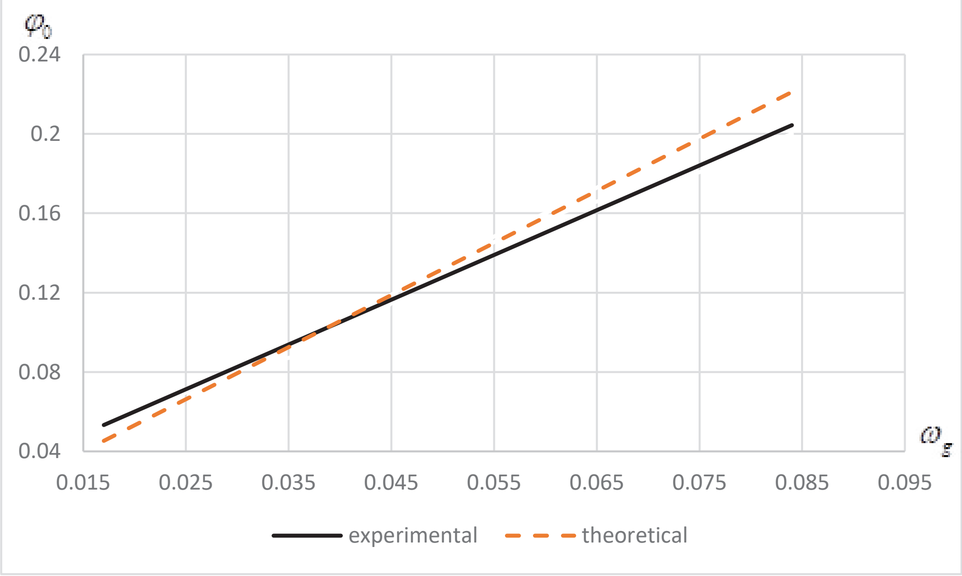
In the conducted experimental studies, the value of the gas content changed significantly when the meeting columns filled with nozzles d_0=12mm and d_0=15mm were installed in a row and experiments were carried out according to the above-mentioned regimes.

The conducted experiments were theoretically verified using equation (8) and a comparative graph was constructed (Fig. 3). The experiments fully confirmed this equation.



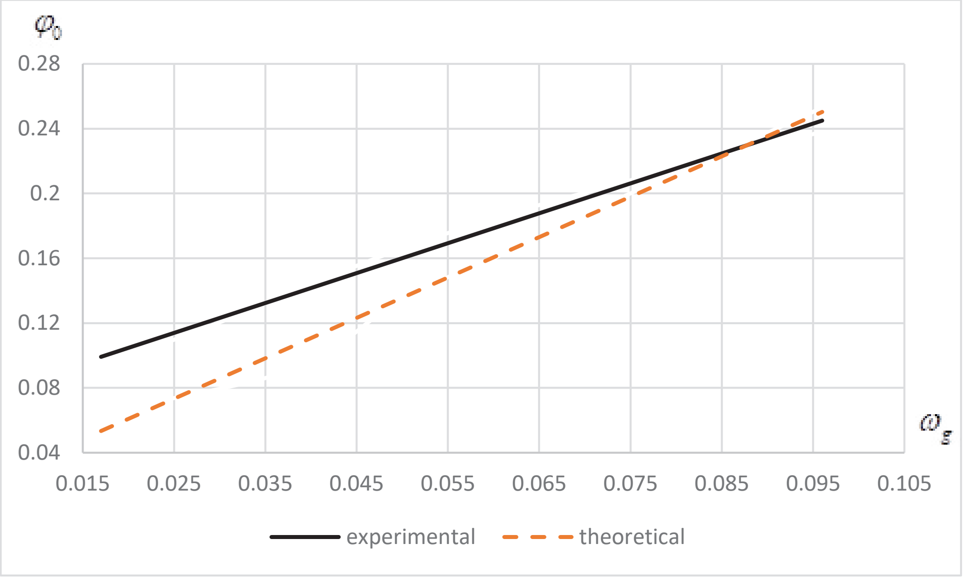
(a) A graph of the change of the total amount of gas depending on the gas velocity ω_s=0.051м/с const.

D_h=1 mm hole with a d=9 mm ceramic nozzle inserted
The forms of the identified regression equations are as follows.
y = 2,051x + 0,0299 R^2 = 0,9917
y = 2,6648x - 0,0006 R^2 = 0,9922



(b) A graph of the change of the total amount of gas depending on the gas velocity ω_s=0.051м/с const.

D_h=1 mm hole with a d=12 mm ceramic nozzle inserted
The forms of the identified regression equations are as follows.
y = 2,2553x + 0,0149 R^2 = 0,9942
y = 2,624x + 0,0007 R^2 = 0,9951



(c) A graph of the change of the total amount of gas depending on the gas velocity ω_s=0.051м/c const.

D_h=1 mm hole with a d=15 mm ceramic nozzle inserted

The forms of the identified regression equations are as follows.

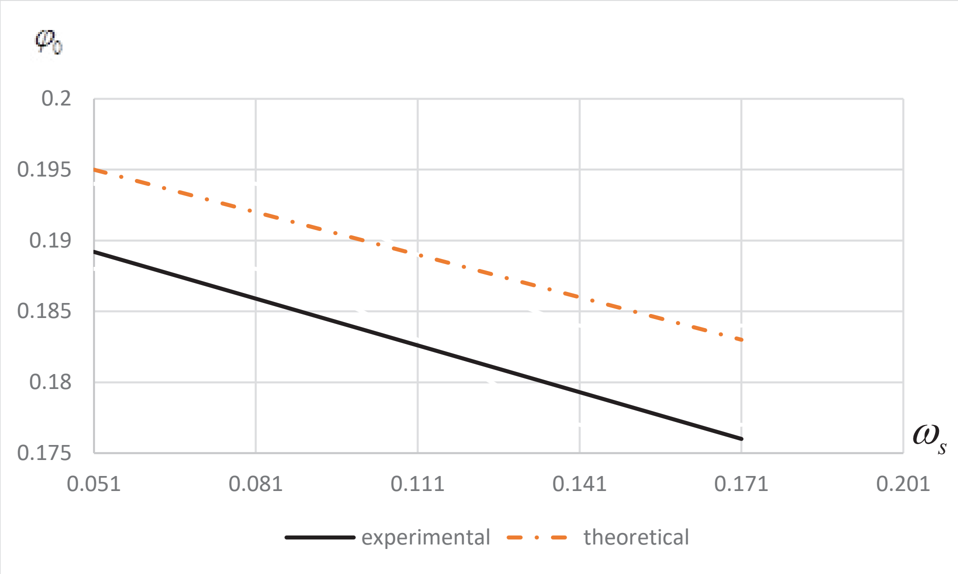
y = 1,8456x + 0,0678 R^2 = 0,9908

y = 2,4924x + 0,0111 R^2 = 0,9871

Fig 3. Graph of the total gas volume change depending on the gas velocity ω_l=0.051m/s const**.**

In the next stage, when we gradually increased the liquid flow rate while keeping the gas velocity constant, the gas volume decreased accordingly. Because as the liquid flow rate increased, the contact time between the gas and the liquid increased, the gas absorption process in the liquid accelerated, and as a result, the gas volume decreased.

As a result of the experiments, the gas volumes φ in the mixing zones of the device were determined depending on the liquid velocity[6]. Using the formula 8, the theoretical values were determined and compared with the experimental values. Experimental studies fully confirmed formula 8. The experimental results were processed using a computer program and regression equations were obtained.



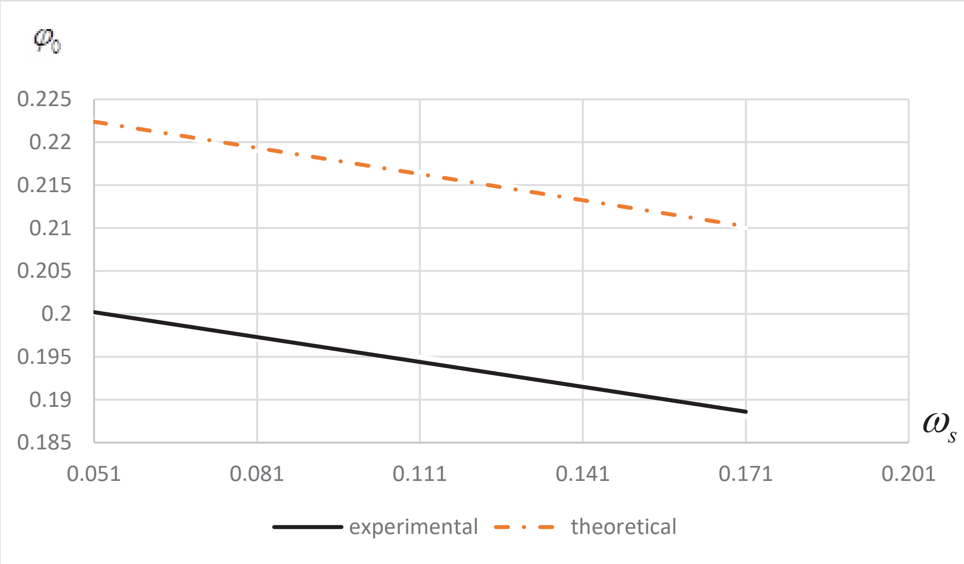
(a) A graph of the change of the total gas amount depending on the liquid velocity ω_g=0.073м/с const.

D_h=1mm D_n=9mm

The forms of the identified regression equations are as follows

y = -0,11x + 0,1948 R^2 = 0,8985

y = -0,1x + 0,2001 R^2 = 0,9



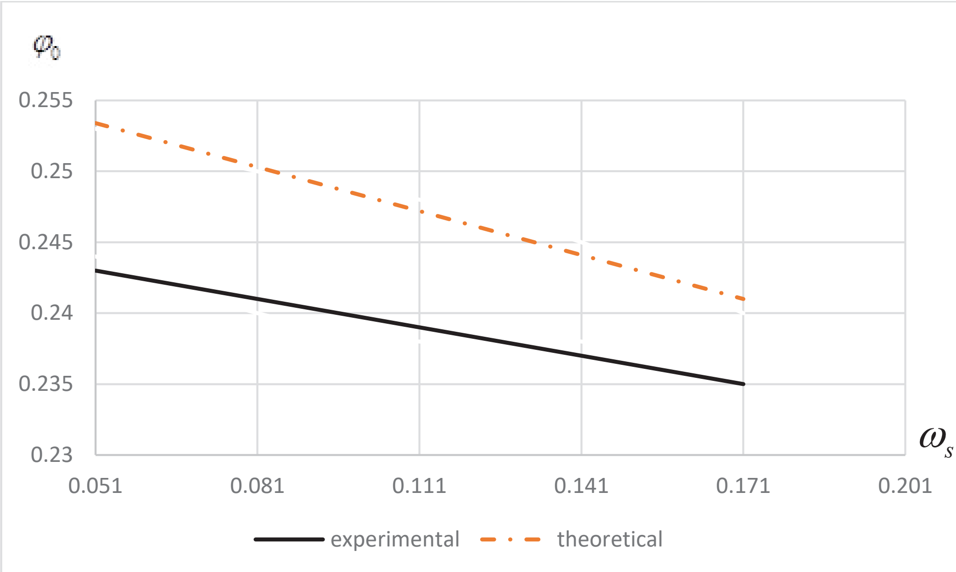
(b) A graph of the change of the total gas amount depending on the liquid velocity ω_g=0.073м/с const.

D_h=1mm D_n=12mm

The forms of the identified regression equations are as follows

y = -0,0967x + 0,2051 R^2 = 0,9871

y = -0,1017x + 0,2276 R^2 = 0,9971



(c) A graph of the change of the total gas amount depending on the liquid velocity ω_g=0.073м/c const.

D_h=1mm D_n=15mm
The forms of the identified regression equations are as follows
y = -0,0667x + 0,2464 R^2 = 0,9091
y = -0,1033x + 0,2587 R^2 = 0,9727

Fig 4. Change in gas quantity as a function of fluid velocity (comparative graph)

4 Conclusion

As a result of an experimental study conducted in an experimental device to determine the value of gas content in the mixing zone of the created bubbling absorption device, the values of gas content were determined in the modes of liquid and gas flows through ceramic nozzles of different sizes installed in the mixing zones. Based on the results of the experiment, the limit values of gas quantity and gas velocity were determined. As a result, an opportunity was created to achieve high cleaning efficiency of the device through these threshold values in the absorption of the gas transmitted to the device.

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