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Research Article

Experimental Studies Conducted to Determine the Gas Content in The Mixing Zones of a Bubble Extractor

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I.T.Karimov
Fergana State Technical University, Uzbekistan

I.M.Mamarizaev
Fergana State Technical University, Uzbekistan

Abstract

In the article, experimental values of the gas content in the inner and outer mixing zones in the newly created design of an intensive bubble extractor in gas and liquid flow modes are determined and compared with theoretical values. The values of gas quantities are important for the bubbling regime, ensuring stable mixing of liquid phases. As a result of the conducted experimental studies, the limit values of gas quantities were determined at constant gas flow rates and at variable fluid velocities. This, in turn, is important for ensuring a stable mode of mass transfer efficiency in the mixing zones of the apparatus.

Keywords

Extractor, mixing zones, gas quantity, hole size, liquid velocity, gas flow rate, internal, external, stage.

Introduction

Liquid extraction is widely used in the chemical, petrochemical, food, pharmaceutical, biotechnological, and hydrometallurgical industries. For researchers, the creation of new designs of high-performance extractors with a simple design and compact layout is one of the urgent tasks of today. In this regard, special attention is paid to the use of compressed gas energy, which is chemically inert to liquids, improving models of droplet grinding and mass transfer based on the physicochemical properties of liquid phases, reducing extractant

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consumption and ensuring stability in the stages of the unit, creating extractors with a new design structure capable of extracting various liquids, high-performance metal and energy-saving by reducing the number of stages. We have developed a new design of a bubbling extractor that meets the above requirements [1].

Object of research.

Figures 1 and 2 below show the experimental setup of the created bubbling extractor and serve as the object of research. Figure 1 shows the diagram of the experimental setup, and Figure 2 shows the general view of the setup [2,3,4].

The proposed bubbling extractor has internal and external mixing zones. The gas content in the inner mixing zone φ_0 and the gas content in the outer mixing zone φ_1 are important in the design of the device, the influence of the device diameter on the gas content begins at D=200 mm, and the height it begins at H=600 mm [2]. For the extractor to operate in normal bubbling mode, the above values must be maintained.

The amount of gas depends on the properties of liquids and gases and their velocities. Therefore, different types of equations are used when calculating the amount of gas, depending on the type of bubble extractor [2]. For the device we are examining, the following equations are suitable. Depending on the direction of the flow of the gas-liquid mixture, additional characteristics arise, i.e., the ratio between the reduced velocity of the liquid w_c and its actual velocity u_c can be expressed by the amount of gas as follows.

$$\frac{\omega_c}{u_c} = 1 - \varphi \quad (1)$$

Depending on the difference in the density of the phases, the actual velocities of the gas and liquid due to the action of the lifting force $u_{хак}$ differ from each other.

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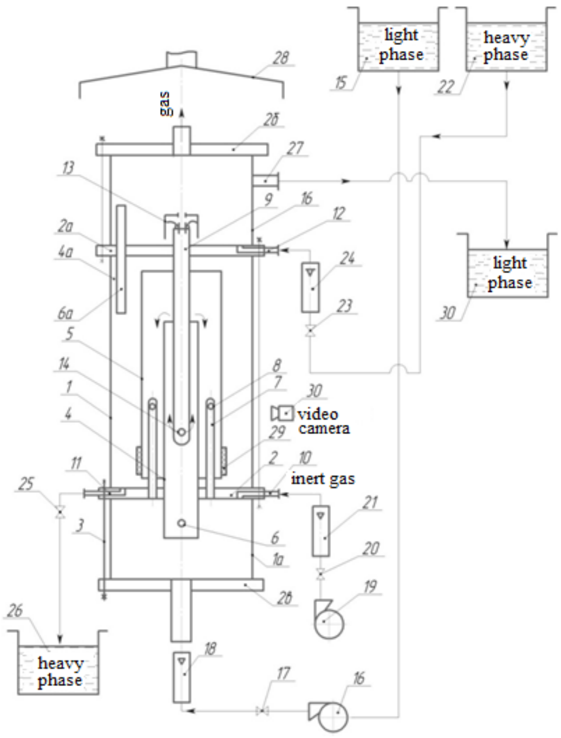

Fig. 1 shows the diagram of the experimental setup

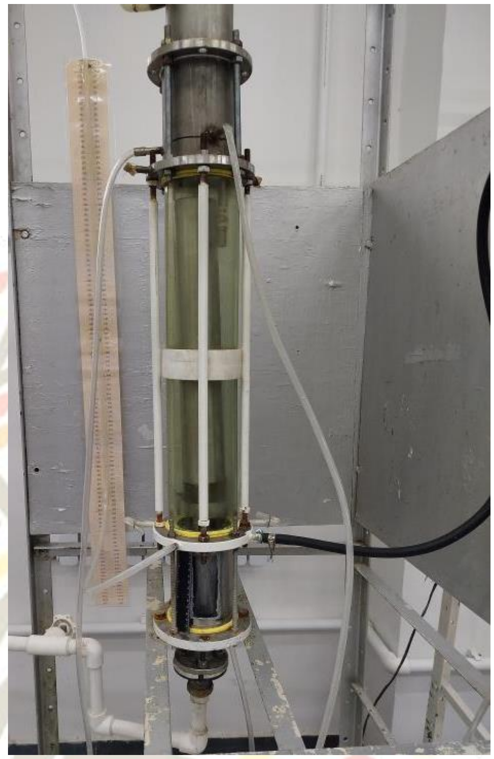

Fig. 2 shows the general view of the setup

1-glass pipe, 2, 2a, 2b, 2c - flanges, 3-tension stud, 4-internal bubbling pipe, 5-external bubbling pipe, 6-gas outlet, 7-gas outlet pipe, 8-gas outlet, 9-heavy fluid pipe, 10-gas inlet channel, 11-heavy fluid outlet channel, 12-heavy fluid inlet channel, 13-cap, 14-heavy fluid outlet, 15-light fluid tank, 16-pump, 17-valve, 18-rotameter, 19-compressor, 20-gas valve, 21-rotameter, 22-heavy fluid tank, 23-cock, 24-rotameter, 25-cock, 26-heavy fluid tank, 27-light fluid outlet channel, 28-sound, 29-filter, 30-video camera.

When a gas-liquid mixture rises upwards, the true velocity is determined by the following equation.

$$u_{\text{хак}} = u_{\Gamma} - u_c = \left(\frac{\omega_{\Gamma}}{\varphi_{\Gamma}}\right) - \left(\frac{\omega_c}{\varphi_{\Gamma} - 1}\right) \qquad (2)$$

When the gas-liquid mixture is directed downwards, the true velocity is determined as follows.

$$u_{\text{хак}} = u_c - u_{\Gamma} = \left(\frac{\omega_c}{1 - \varphi_{\Gamma}}\right) - \left(\frac{\omega_{\Gamma}}{\varphi_{\Gamma}}\right) \qquad (3)$$

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Based on these conditions, it is possible to determine the gas content in the mixing zones of the filter bubble extractor operating in intensive mode, which we are examining, by connecting the gas content of the liquid to the gas content at rest, and by the liquid velocity in the internal and external mixing zones of the device [2,3,4,5].

The amount of gas φ_0 is determined when the movement of liquid and gas is accompanied by a stream as follows:

$$\varphi_0 = \left(1 - 0{,}04 w'_c\right)\varphi' \quad (4)$$

When liquid and gas move in opposite directions will be

$$\varphi_1 = \left(1 + 0{,}04 w_c''\right)\varphi' \quad (5)$$

In this case, w'_c and w''_c are the flow velocities of the liquid at the cross-sectional area of the bubbling pipe and the annular channel, cm/s; (4) Equation is valid for accompanying fluids and gases with a velocity of $w_c = 0.20\ sm/s$, and equation (5) is valid for opposing fluids and gases with a velocity of $w_c = 0.10\ sm/s$. These equations are fully consistent with the device we are examining; φ' is the amount of gas in a liquid at rest, determined by the following equation [2].

$$\varphi_c = 2{,}47 \cdot w_\Gamma^{0{,}97} \quad (6)$$

where w_Γ - gas velocity in the mixing zone, m/s;

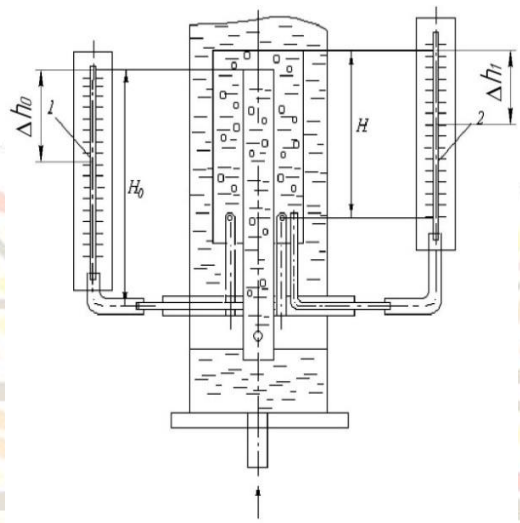
Using equation (6), it is possible to determine the limiting value of the gas content for a liquid at rest. In bubble barbotage mode, the gas content should be $\varphi \le 03$. At a gas content value of $\varphi \ge 03$ the system exits bubble mode and switches to jet mode. In this case, coalescence of the bubbles occurs within the system [2,3,6]. As a result, the efficiency of mixing decreases. The value of the gas quantity depends on the gas velocity, and several researchers have determined that the limiting gas value for the bubbling regime is $w_\Gamma = 0.04 \div 0.1\ m/s$ [4,5,6].

As can be seen from equations (5) and (6), the amount of gas also depends on the fluid velocity, and in the apparatus under investigation, with an increase in the fluid velocity in the inner mixing zone, the amount of gas decreases, and in the outer mixing zone, on the contrary, the amount of gas increases. In this case, the external mixing leads to a decrease in the geometric pressure in the zone. As a result, most of the supplied gas passes into the external mixing zone. Equally intensive hydrodynamic processes are not created in the device. To create an equal-intensity hydrodynamic process in the mixing zones of the device, at a constant gas cushion value [6], the diameters of the mixing zones, i.e., the cross-sectional areas, should be selected so that the values of the gas content in both zones are equal.

Results

Experimental studies were conducted in the following series. When determining the gas content values, the mixing zones of the device were connected by glass tubes in the form of a closed tank (Fig. 3).

The experimental value of the gas content in the mixing zones of the extractor is determined by the change in the liquid level as follows.



1. Glass tube for determining the amount of gas in the internal mixing zone.
2. Glass tube for determining the amount of gas in the external mixing zone

Fig. 3. Diagram of experimental determination of the gas content in the mixing zones of the device

$$\varphi_0 = \frac{\Delta h_0}{H_0} \quad (7)$$

$$\varphi_1 = \frac{\Delta h_1}{H} \quad (8)$$

In the absence of changes in the opening of holes d_0=1mm for supplying gas to the internal bubbling pipe of the device, the distance between the holes for supplying gas to the internal and external mixing zones is H_1=315; 240; 165 mm, respectively, d_1=0.6; 0.8; Experimental studies were conducted with sequential opening of 1.0 mm holes. Each of these holes, supplying gas to the internal and external mixing zones, has 4 holes.

Initially, gas was supplied to the external mixing zone by opening holes with a size of d_1 = 0.6 mm. The total gas flow rate $Q_{Г\,ум}$=0.85 $m^3 / hour$ was given at a constant value. At this gas flow rate, the gas flow rate entering the internal bubbling pipe was Q_0=0.713 $m^3 / hour$, and the gas flow rate entering the external mixing zone was Q_1=0.135 $m^3 / hour$. The flow rate of the liquid supplied to

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the device was transferred to Q_C =0.07÷0.39 $m^3/hour$ with a step of Q_C =0.08.

According to these fluid flow rates, the fluid velocity in the internal mixing zone of the apparatus is from $w_s^{'}$ =0.021 to 0.141 m/s with a velocity step of 0.03 m/s, and in the external mixing zone, fluid is supplied from $w_s^{''}$ =0.014 to 0.082 m/s with a velocity step of 0.017 m/s.

Experimental values of gas quantities φ_0 and φ_1 in the internal and external mixing zones of the apparatus were determined with a change in liquid velocity at constant gas flow rates. At the next stage of the experiments, a hole d_1 =0.8 mm with a height of H_1 =240 mm was opened and the experiments were conducted.

When the total gas flow rate $Q_{Г\ ум}$ = 0.85 $m^3/hour$ is given at a constant value, the gas flow rate entering the internal bubbling pipe Q_0 =0.57 $m^3/hour$, and the gas flow rate entering the external mixing zone Q_1 =0.280 $m^3/hour$ [6]. Experiments were conducted with sequential opening of 1.0 mm holes with a height of N1=165 mm, and with a total gas flow rate $Q_{Г\ ум}$ =0.85 $m^3/hour$, the gas flow rate entering the internal bubbling pipe was Q_0 =0.385 $m^3/hour$, and the gas flow rate entering the external mixing zone was Q_1 =0.465 $m^3/hour$ [6], and the experimental values of the gas quantities were determined. The flow rate and velocity of the liquid supplied to the apparatus were maintained while maintaining the above-mentioned regimes. The theoretical values of the gas content were determined using the formulas (4), (5), (6) and compared with experimental studies. The obtained experimental values were processed based on a computer program and dependence graphs were constructed (Fig. 4, 5).

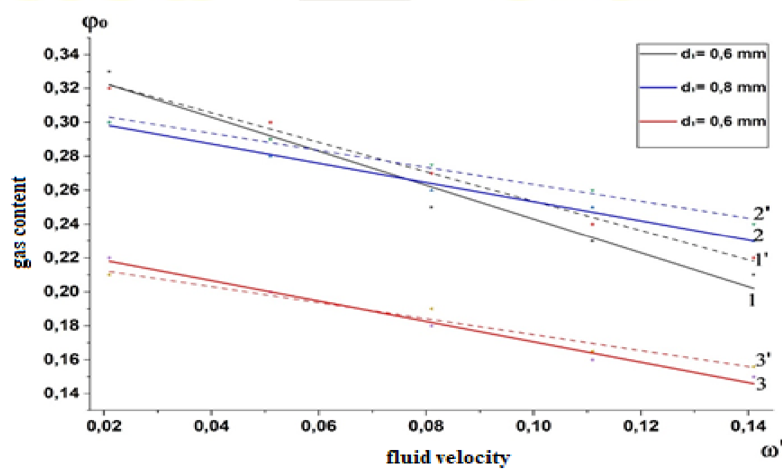

Fig. 4. Graph of the dependence of the gas content value on the change in the liquid velocity in the internal mixing zone of the apparatus. d_0=1mm-const. (Comparative graph)

The obtained regression equations are as follows:

If H_1=315мм, y = -0,8667x + 0,3402 R^2 = 0,9941

If H_1=240мм, y = -0,5667x + 0,3099 R^2 = 0,9897

If H_1=165мм, y = -0,6x + 0,2306 R^2 = 0,9878

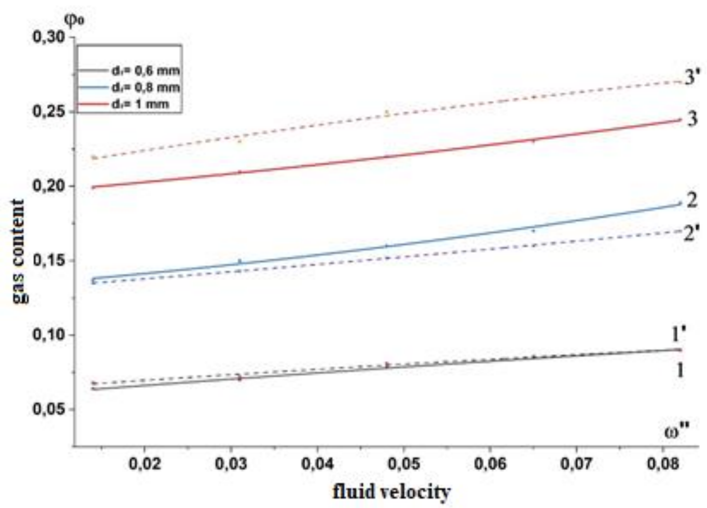

Fig 5. Graph of the dependence of the gas content value on the change in the liquid velocity in the external mixing zone of the apparatus. d_0=1mm-const. (Comparative graph)

The obtained regression equations are as follows:

If H_1=315мм, y = 0,3388x + 0,0631 R^2 = 0,9814

If H_1=240мм, y = 0,7294x + 0,1262 R^2 = 0,9839

If H_1=165мм, y = 0,3941x + 0,0585 R^2 = 0,9949

In the next stage of the experiments, the gas supply openings of the internal bubbling pipe with a size of d_0=1mm were closed, and the opening of the d_0=1.5mm opening remained unchanged, while the gap between the gas supply openings to the internal and external mixing zones was maintained at H_1=315; 240; 165 mm, respectively, d_1=0.6; 0.8; 1.0 mm experimental studies were conducted with sequential opening of holes. The total gas flow rate supplied to the apparatus $Q_{Гум}$ =0.85 m³/hour and the gas flow rates distributed to the inner and outer mixing zones were given at the above values, and the experimental values of the gas quantity were determined. The theoretical values of the gas content were determined using the formulas (4),

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(5), (6) and compared with experimental studies. The obtained experimental results were processed based on a computer program and dependence graphs were constructed (Fig. 6, 7).

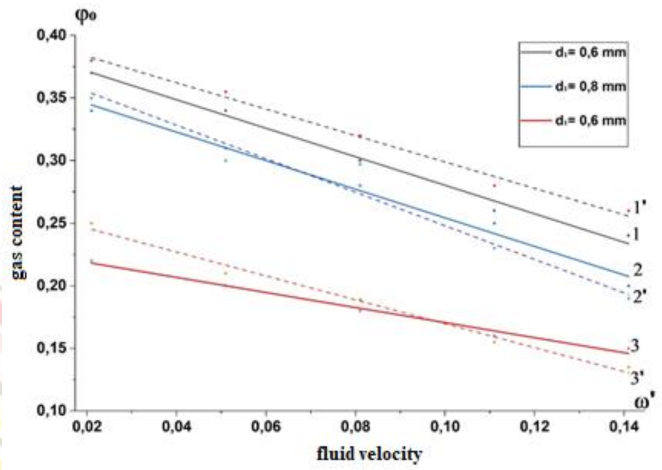

Fig. 6. Graph of the dependence of the gas content value on the change in the liquid velocity in the internal mixing zone of the apparatus. d_0=1.5mm-const. (Comparative graph)

The obtained regression equations are as follows:

If H_1=315мм,	y = -1,1333x + 0,3938	R^2 = 0,9897
If H_1=240мм,	y = -1,1333x + 0,3678	R^2 = 0,9863
If H_1=165мм,	y = -0,6x + 0,2306	R^2 = 0,9878

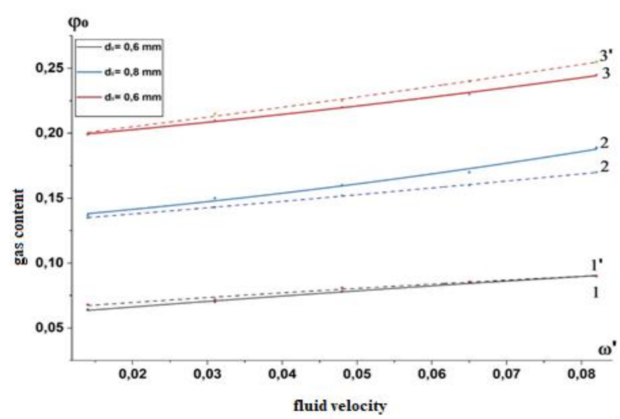

Fig. 7. Graph of the dependence of the gas content value on the change in the liquid velocity in the external mixing zone of the apparatus. d0=1.5 mm-const.

The obtained regression equations are as follows:

If H_1=315мм, $y = 0{,}5118x + 0{,}1274$ $R^2 = 0{,}9985$

If H_1=240мм, $y = 0{,}6588x + 0{,}1892$ $R^2 = 0{,}9933$

If H_1=165мм, $y = 0{,}3941x + 0{,}0585$ $R^2 = 0{,}9949$

Conclusion

The values of gas quantities are important for the bubbling regime, ensuring stable mixing of liquid phases. As a result of the conducted experimental studies, the limit values of gas quantities were determined at constant gas flow rates and at variable fluid velocities. This, in turn, is important for ensuring a stable mode of mass transfer efficiency in the mixing zones of the apparatus.

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