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Research Article

HYDRODYNAMICS OF HEAVY LIQUIDS IN A BUBBLING EXTRACTOR

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Karimov Ikromali Tojimatovich
Doctor Of Technical Sciences, Professor, Fergana Polytechnic Institute, Fergana, Republic Of Uzbekistan

Rakhmanov Abdukhalim Toshpulat Ugli
Assistant, Fergana Polytechnic Institute, Fergana, Republic Of Uzbekistan

Abstract

The article proposes a formula for calculating the flow rate of a heavy liquid supplied to the mixing zones of the apparatus. The experimental setup presents the results and analysis of experimental studies carried out to determine the flow rate of heavy liquid in the mixing zone of the bubbling extractor. The analysis confirmed the accuracy of the theoretical equation proposed for calculating the heavy liquid flow rate. According to the results of the study, it was possible to determine the flow rate of heavy liquid depending on the size and coefficient of resistance of the holes.

Keywords

Heavy phase, flow, velocity, pressure, gas content, gas velocity, drag coefficient, flow rate, density, fluid velocity.

Introduction

All over the world, scientific research is being carried out to create new designs of highly efficient extractors for liquid extraction processes, increase the surface area of contact of liquid phases and accelerate the mixing process. In this regard, the use of the energy of compressed gas, which is chemically inert to liquids, the improvement of models for crushing drops and mass transfer in terms of the physicochemical properties of liquid phases, reducing the consumption of extractant and stability in the stages of the apparatus, reducing the number of stages, high-performance metal and energy-saving, compact, special attention is paid to the creation of a new series of extractors capable of extracting various liquids.

Object of study

Following the above requirements, we have developed a new design of a bubbling extractor using inert gases [1]. The light liquid is supplied from the bottom of the apparatus to several contact mixing elements located on the steps of this multistage bubbling extractor, depending on the performance of the apparatus [1,2].

The heavy liquid is supplied from the top of the apparatus through holes drilled in special pipes. The rate at which this liquid flows out of the hole depends on the size of the hole, and the physicochemical properties of the liquid, i.e. the difference in density of the liquids, surface tension, and amount of gas content. It is recommended to choose the diameter of the pipe that discharges the heavy liquid into the mixing zone of the apparatus in the range dt = (3÷5) mm, depending on the diameter of the hole drilled in it.

The velocity of a heavy liquid flowing through a pipe also depends on φ the amount of gas content generated from the gas and liquid velocities.

Approximating the maximum amount of gas content in the mixing zones of the apparatus to the maximum value in the given limit $\varphi \to 0.3$, it is possible to achieve the maximum decrease in the geometric pressure in the inner bubble tube [3,4,5,6,7,8].

This, in turn, accelerates the flow of the heavy fluid. As a result, the performance of the device is improved. Let's analyze it theoretically (Fig.1).

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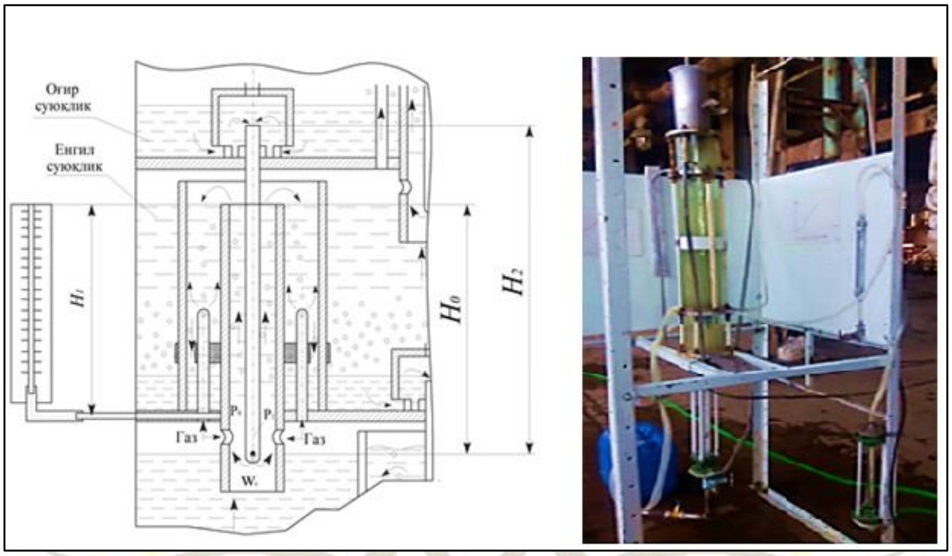

Figure 1. Calculation scheme and experimental setup

The total pressure in the centre of the drain holes is [4,7]

$$P_{об} = p_0 + p_1 + \Delta p_{ж}, Па \quad (1)$$

where P_0– is the pressure of the light liquid in the inner bubble tube entering the centre of the heavy liquid drain hole, which is determined by the following formula.

$$P_0 = \rho_{см} \cdot g(1-\varphi_o)H_0, Па \quad (2)$$

where ρ_{ap} - the density of mixtures of light and heavy liquids, which is determined as follows.

$\rho_{ap}= \rho_o a + \rho_c (1-a)$, кг / м^3 ; (3)

where φ_0 – the amount of gas content in the inner mixing zone, H_0 is the height of the mixing zone, m; a - the proportion of heavy and light liquids in the mixture,%;

P_1 - the static pressure of the heavy liquid in the bubble pipe falling towards the centre of the hole, defined as follows.

$$P_1 = \rho_m g H_2, Па \quad (4)$$

Where H_2 - the height of the heavy liquid branch pipe to the centre of the hole, m; ρm is the density of the heavy liquid, kg/m^3.

$\Delta P_ж$ – Pressure loss due to the outflow of heavy liquid from the hole of the drain pipe, which is determined as follows.

$$\Delta P_{ж} = \xi_0 \frac{\omega_o^2 \cdot \rho_m}{2}, Па \quad (5)$$

where ξ_0 - the coefficient of resistance of the heavy liquid flowing out of the hole, ωo is the velocity of the heavy liquid flowing out of the hole, m/s.

Now we substitute equations 2, 4, and 5 into equation 1.

$$p_{см} \cdot g(1-\varphi_0)H_0 + \rho_m \cdot g \cdot H_2 + \xi_0 \frac{\omega_0 \rho_m}{2} \quad (6)$$

From expression 6 we find the speed of the outflow of a heavy liquid.

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$$w_c = \sqrt{\frac{2g(\rho_m \cdot H_2) - \rho_{cm} \cdot (1-\varphi_0) \cdot H_0}{\xi_0 \cdot \rho_m}} \quad (7)$$

Depending on this speed, one can find the flow rate of a heavy liquid flowing through a single hole.

$$Q = \pi R^2 \omega_o \cdot 3600, м^3 / соат; \quad (8)$$

With the effective implementation of mass transfer processes in the apparatus, the ratio of light and heavy liquids should be correct from the point of view of inversion [9]. It is very important to take this ratio into account when designing equipment. Depending on this, the number of holes in the heavy liquid drain is determined.

As a result of the above theoretical studies, an equation was proposed for determining the flow rate of a heavy liquid into the internal mixing zone of the apparatus.

As a result, we will be able to find the volume of the heavy liquid supplied to the apparatus. Depending on this value, conditions were created for the correct selection of the ratio of light and heavy liquids, i.e. conditions for the correct choice of inversion.

RESULTS

At the first stage of the experiment, δ/d = 0,275; 0,475; 0,675; to the size of the hole opened in the heavy liquid drain pipe; 1 Depending on and selection of liquids with three different values of surface tension, the drag coefficients of the holes were determined. The ratio of the hole wall thickness to the hole diameter δ/d and the surface tension of the liquids were plotted graphically. (Figure 3).

The next task was to test the proposed equation 7 by determining the flow rate of the experimental device in the internal mixing zone depending on the change in the gas content φ and the density of the heavy liquid ρo, the density of the mixture ρar.

Water was chosen as a light liquid, and a mixture of carbon tetrachloride with benzene was chosen as a heavy liquid. The densities of a mixture of light and heavy liquids were determined by equation (9). To better distinguish between heavy and light liquids in experimental processes, the heavy liquid was stained with a powder called Dithizone.

The size of the hole for draining the heavy liquid was chosen d = 2 and 1 mm. The densities of a mixture of light and heavy liquids were determined by the following formula [9].

$$\rho_{ap} = \rho_0 \cdot a + \rho_c (1-a), кг / м^3 \quad (9)$$

where: ρ_{ap} - mixture density, kg/m3; ρ0 is the density of the heavy liquid, kg/m^3;
a - the percentage of liquid density, %;
In the experiments, the proportion of heavy liquids was 33%, and the proportion of light liquids was 67%. As a result, the densities of the mixture were determined.

1. ρ_{ap} = 1200 · 0,33 + 1000 (1 - 0,33) = 1066, кг / м^3;
2. ρ_{ap} = 1100 · 0,33 + 1000 (1 - 0,33) = 1033, кг / м^3;

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Initially, a hole with a diameter of 2 mm was drilled into the internal mixing zone of the apparatus in the heavy liquid drain pipe, and the heavy liquid was supplied. The velocity of the liquid mixture supplied to the mixing zone of the apparatus was transferred unchanged at the value w0 = 0,07 m/s. The gas velocities at constant liquid velocities varied by wг =0.051, 0,086, 0,012 m/s, and the experimental values of the gas content in the internal mixing zones of the apparatus were determined. To determine this value, the internal mixing zone of the apparatus was connected to a glass tube in the form of a communicating vessel, and the change in the height of the liquid mixture level H1 was recorded (Fig. 1).

a-hole 2mm **b-hole 1mm**

Figure 2. Determination of the heavy liquid flow rate in the sedimentation zone.

According to these gas velocities, the experimental values of the amount of gas content changed up to φ = 0.1, 0.2, 0.3. Based on the established regimes, the flow rate of the heavy liquid entering the mixing zone of the apparatus was experimentally determined. To do this, depending on time and layer height h, the volume of heavy liquid formed as a result of settling in the apparatus zone was determined (Fig. 2-a and b), and the time set in the experiment was 0.25 hours. The sequence of experiments was carried out separately for each of the holes with dimensions d = 2 and 1 mm, with gas content values φ = 0.1, 0.2 0.3.

The theoretical value of the amount of gas content was determined by the following equation [3,4].

$$\varphi_0 = \left(1 - 0{,}04 w'_c\right)\varphi' \quad (10)$$

where w'_c - the reduced fluid velocity in the mixing zone, m/s;

φ' - the amount of gas content in the liquid state at rest, defined as follows.

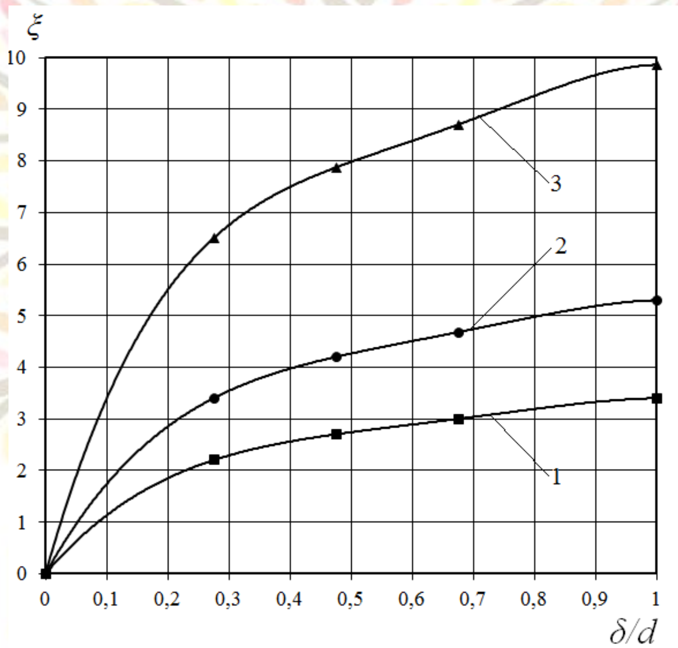
$$\varphi' = 2{,}47 \cdot \omega_{\text{г}}^{0{,}97} \quad (11)$$

where: $\omega_{\text{г}}$ – the reduced gas velocity in the mixing zone, m/s;

Using Equation 7, the theoretical heavy fluid flow rates were determined. The flow rate of the heavy liquid was determined by equation 8. Theoretical and experimental values were compared and analyzed. The analysis confirmed the correctness of the proposed theoretical equation for calculating the heavy liquid flow rate. The largest difference between the theoretical and experimental values was ±7%. Graphs of the change in the heavy liquid flow rate depending on the change in the volume of gas content are plotted (Fig. 4 and 5). An empirical formula is proposed for determining the hydraulic resistance of holes based on the results of experimental studies.

$$\xi = \frac{0,59}{\sigma_t} \cdot \frac{\delta}{d} \quad (12)$$

where σ - the surface tension of the heavy liquid, N/m; δ - hole wall thickness, m; hole diameter, m.



1.σ = 0,073 n/m, *2.σ* = 0,046 n/m, *3.σ* = 0,0245 n/m.

Figure 3. Graph of the change in the drag coefficient depending on the change in wall thickness and hole diameter.

The form of the resulting regression equations is as follows:

$y = -4,419x^2 + 7,594x + 0,1297$ $R^2 = 0,974$

$y = -6,8454x^2 + 11,806x + 0,1952$ $R^2 = 0,9757$

$y = -13,019x^2 + 22,183x + 0,4017$ $R^2 = 0,9704$

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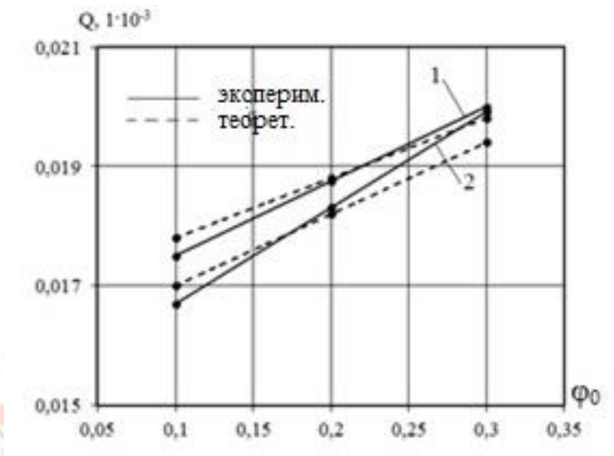

Figure 4. Q = ƒ (φ) Graph of the change in heavy liquid consumption depending on the change in gas volume (comparative graph).

Hole resistance coefficient *ξ = 2,7*; fluid velocity w_c = 0,07 m/s, (const).

1,2 - heavy liquid density ρ_0= 1200 kg/m³, mixture density ρ_{ap} = 1066 kg/m³;

3,4 - heavy liquid density ρ_0= 1100 kg/m³, mixture density ρ_{ap} = 1033 kg/m³;

The form of the obtained regression equations is as follows

1.y = 0,0125x+0,0163 R^2 = 1 (13)

2.y = 0,012x+0,0158 R^2 = 1 (14)

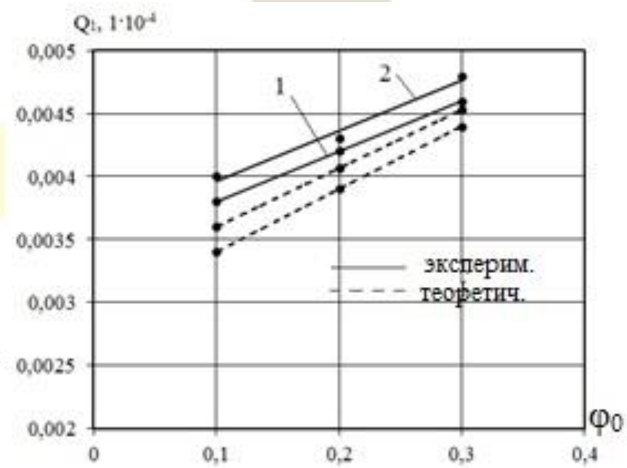

Figure 5. Q = ƒ (φ) Graph of the change in heavy liquid consumption depending on the change in gas volume (comparative graph).

Hole resistance coefficient ξ = 3,7; fluid velocity w_c = 0,07 m/s, (const).

1,2 - heavy liquid density ρ_0 = 1200 kg/m³, mixture density ρ_{ap} = 1066 kg/m³;

3,4 - heavy liquid density ρ_0 = 1100 kg/m^3, mixture density ρ_{ap} = 1033 kg/m^3;

The form of the obtained regression equations is as follows

$$1. y = 0{,}004x + 0{,}0034$$

$$R^2 = 0{,}9881 \quad (15)$$

$$2. y = 0{,}004x + 0{,}0036$$

$$R^2 = 0{,}9776 \quad (16)$$

Conclusion

As a result of the theoretical studies carried out above, a formula was recommended for calculating the flow rate of a heavy liquid supplied to the mixing zones of the experimental apparatus. To test this formula, experiments were carried out and analyzed on the experimental setup of a bubbling extractor to determine the rate of outflow of a heavy liquid into the mixing zones. The analysis confirmed the correctness of the proposed theoretical equation for calculating the heavy liquid flow rate. Based on the results of the study, it was possible to determine the flow rate of heavy liquid depending on the size and number of holes and to choose the right ratio of liquid phases.

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