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Volume-Surface Diameters of Drops in Barbotaj Extractor

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ANNOTATION

A formula for calculating the volumetric surface diameter of droplets, which is important in the calculation of mass transfer processes depending on the physicochemical properties of liquids, is proposed and the theoretical and experimental values are compared. The calculations performed fully confirmed the proposed formula. As a result of the research, it was possible to determine the volumetric surface diameter of the dispersed phase droplets and the interfacial specific surfaces, which is one of the main factors determining the efficiency of the proposed bubble extractor.

Keywords: gas velocity, liquid velocity, mixing zone, droplet diameter, distribution, proportion, volumetric surface diameter, mixing time, surface tension, viscosity, density.

Introduction:

In pneumatic mixing of non-additive liquids, a multi-dispersed system of crushed droplets is formed, which differs from other mixing methods. This multi-dispersed system contains droplets of different sizes, which form interfacial contact surfaces depending on their size. These droplets are distributed over the entire volume of the gross phase. The value of the droplet size affects, firstly, the speed of the mass transfer process at the boundary of the phase separation during the extraction process, and secondly, the deposition rate of the droplets in the deposition zones of each stage of the apparatus.

In a multi-dispersed system of droplets, there are difficulties in theoretically substantiating the process of massaging. Therefore, as a result of several studies conducted to simplify the calculation, the calculation was changed from a multi-dispersion system to a calculation using a single-dispersed particle size. This makes it possible to determine the mass coefficient relative to a single drop [1].

Research methods:

The theory based on the transition from a multi-dispersed system to a single-dispersion system for calculating the coefficient of mass displacement from a drop to a single-dispersion system was proposed by Gal-Or.

Depending on the diameter of the drop, the specific interfacial contact surfaces are determined as follows [2,3,4];

$$F_{ud} = \frac{6 \cdot V \cdot \varphi}{d_{x.y}}; \qquad \varphi = V_d / (V_y + V_d) \qquad (1)$$

where V– the volume of the mixing zone, m^3, ph is the volume fraction of the dispersed phase in the total phase; V_y and V_d– gross and dispersed phase consumption, m^3 / s; $d_{x.y}$– average volume-surface diameter of a drop, m;

The following equation was obtained to calculate the specific surface area of the droplet formed in periodically operating bubble columns [5.15].

$$F_s = 152\varphi^{0,72} \cdot (w_g/\sigma^{0,6}) \cdot (\tau/\gamma_d)^{\frac{1}{3}} \cdot \exp\,(3{,}5\Delta\rho/\rho_y) \qquad (2)$$

Whereγ_d– the kinematic viscosity of the dispersed phase;

Through experimental studies, Metkin recommended the determination of the specific interfacial contact surface of the droplets distributed in the mixing zone of a multi-stage tubular extractor as follows [11].

$$F_s = 0{,}8\left[\frac{\tau^{0,33} \cdot w_g^{0,5} \cdot w_s^{1,7} \cdot l^{0,33} \cdot \gamma_y^{0,67} \cdot \rho_y^{1,1}}{\gamma_d \cdot \sigma^{1,1} \cdot d_p^{0,9}}\right] \times \exp\left[\frac{3{,}9(\rho_y - \rho_d)}{\rho_d}\right] \times [V_d/(V_d + V_y)]^{0,72} \qquad (3)$$

where l– the length of the pipe, m; d_p-pipe diameter, m;

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Equation (3) obtained from studies in a tubular circular mixing extractor can be used in ideal mixing extractors close to these apparatus [14]. The inability to strictly apply this equation was studied by Professor B.A. Alimatov [6,7,8,9] because the liquids extracted in the mixing zones of the multi-stage bubble extractor are in direct flow contact [6,7,8,9].

The average volume-surface diameter of a drop can be determined on the basis of the following equation [10,11,12];

$$d_{x.y} = d_{max}/(1 + a \cdot e^{0,25\beta\cdot\beta}) \qquad (4)$$

where d_{max}– the maximum diameter of the drop in the emulsion, m; a and β - do not change.

[13] according to recommendations β = 0.725, and "a" can be found from the following equation:

$$a = (d_{max} - d_{50})/d_{50} \qquad (5)$$

where d_{50}– the diameter of the droplets corresponding to a relative volume of 50–50%.

In turn:

$$\frac{d_{max}}{d_{50}} = [d_{50}(d_{90} + d_{10}) - 2 \cdot d_{90} \cdot d_{10}]/(d_{50}^2 - d_{90} \cdot d_{10} \qquad (6)$$

where d_{90} and d_{10}, the diameter of the drops corresponding to 90% and 10%, m.

As a result of experimental studies, the proportions and distribution of droplets by size were studied and the volumetric surface diameter of droplets was determined by the following empirical formula: recommended.

$$d_{x.y} = 6{,}7 \cdot 10^{-6}(\sigma^{0{,}35} \cdot \varphi^{0{,}8})/(w_g^{0{,}2} \cdot t_{av}^{0{,}45} \cdot \mu_y^{1{,}1}) \qquad (7)$$

The design structure of the bubble extractor studied by B.A. Alimatov is based on mixing the liquid phases only in the bubble tube. The bubble extractor we are testing has an additional mixing zone [2] where the liquid phases are additionally mixed in the inner bubble pipe as well as in the outer ring channel. The advantage of this extractor is that it works in intensive mode due to the large mixing time. This, in turn, requires research on the dispersion and size distribution of droplets in the mixing zones of the apparatus.

Therefore, the experimental device for the new design of the bubble extractor was studied to study the proportion and distribution of dispersed phase droplets scattered from the mixing zones of the apparatus. [14,15].

Research results:

Experimental research was carried out on the experimental device of the bubble extractor installed in the SA and SKR shops of JSC "Fargonaazot". During the extraction washing of butyl acetate and ethyl acetate liquids with water in the experimental device, the movement and size of water droplets were filmed and photographed using a video camera. However, because water and butyl acetate and ethyl acetate liquids were the same color, it was difficult to determine the size of water droplets using photographs. Therefore, model liquids were used. A mixture of carbon tetrachloride + benzene was obtained as a heavy liquid. The density of the mixture was formed at ρ_d = 1120 kg/m3. Density was determined using a hydrometer under laboratory conditions. The physicochemical properties of industrial and model fluids are given in Table 1.

The experiments were performed in the following order. In the first stage of the experiment, nitrogen gas, which is inert to liquids, was supplied to the internal and external mixing zones of the apparatus through the gas supply holes. The size of the gas supply hole to the internal mixing zone is d_0 = 1.5mm, and the size of the gas supply hole to the external mixing zone is d_1 = 1mm. The total phase was transferred to the apparatus at a constant value, with a flow rate of Q_s = 0.23 m3 / h. At this fluid flow rate, the liquid velocity in the internal mixing zone was wsi = 0.051m / s, and in the external mixing zone w_s^i = 0.026m / s. Gas was delivered to the mixing zones at constant liquid velocities at Q_g = 0.55; 0.65; 0.75 m3 / h. In accordance with these gas consumption, the gas velocities in the internal mixing zone were changed to w_g^t = 0.03; 0.06; 0.09 m / s, and in the external mixing zone to w_g^t = 0.08; 0.0803; 0.805. Mixing time was t_{av}=22 s. The value of the gas cushion in the gas distribution element of the device was h = 15; 20; 37 mm in accordance with the gas consumption. The ratio of light to heavy liquids supplied to the apparatus was chosen as a constant value of 3/1 for each experiment. , 8 mm wire was installed in the external mixing zone. Five photographs were taken to determine the droplet size at each gas velocity. In the second phase of the experiment, the total phase consumption Q_s = 0.31 m^3/h was changed to a constant value. The fluid velocities in the internal and external mixing zones were w_s^i = 0.11m / s and w_s^t = 0.035m / s. The values of gas consumption in the mixing zones at these constant liquid velocities were repeated in the first phase of the experiments. Gas Q_g = 0.55; 0.65; 0.75 m^3 / h. In accordance with these gas consumption, the gas velocities in the internal mixing zone w_g^1 = 0.03; 0.06; In the external mixing zone at 0.09 m / s, w_g^t = 0.08; 0.0803; Changed to values of 0.805. Mixing time was t_{av} = 14 s.

For each stage of the experiments, 400 ÷ 600 droplet sizes were determined from the photographs taken, and percentage values were found at intervals. Physicochemical properties of liquids are given in Table 1.

Table 1 Physicochemical properties of liquids

Liquids	Continuous phase		Dispersed phase		σ	φ
	ρ_s	μ_s	ρ_d	μ_d		
	kg / m^3	$\cdot 10^{-3}$ Pa·s	kg / m^3	$\cdot 10^{-3}$ Pa·s	N / m	-
Butyl acetate-water	880	0.685	1000	1.00	0.0248	0.25
Ethyl acetate-water	888	0.423	1000	1.00	0.024	0.25
Water-carbon tetrachloride + benzene	1000	1.00	1120	0.72	0.073	0.25

The next task was to derive an equation that calculates the average volume-surface diameter of the droplets used to calculate the mass transfer processes in the proposed bubble extractor based on the results obtained.

Based on the experimental results, the average volume-surface diameter of the droplets is 4,5,6 - we determine by equations [3.14].

$$\frac{d_{max}}{d_{50}} = [d_{50}(d_{90} + d_{10}) - 2 \cdot d_{90} \cdot d_{10}]/(d_{50}^2 - d_{90} \cdot d_{10})$$

where d_{90} and d_{10} are the diameter of the droplets corresponding to 90% and 10%, respectively.

For line 1 in Figure 4:

d_{90} = 400 mkm, d_{50} = 330 mkm, d_{10} = 240 mkm.

We determine these values by putting in equation (6):d_{max}

$$d_{max} = \frac{\left[\frac{330(400 + 240) - 2 \cdot 400}{300^2 - 400 \cdot 240}\right]}{330} = 491\ mkm$$

We define the distribution parameter.

$$a = \frac{d_{max} - d_{50}}{d_{50}} = \frac{491 - 330}{330} = 0{,}48$$

In that case dh.yu. is equal to:

$$d_{x.y} = \frac{d_{max}}{1 + a \cdot e^{0{,}25\beta \cdot \beta}} = \frac{491}{1 + 0{,}48^{0{,}25 \cdot 0{,}725 \cdot 0{,}725}} = 317\ mkm.$$

The calculation of the experimental results is given in Table 2.

Table 2

Parameters	Dropsizesbymodes					
	1	2	3	4	5	6
d $_{90}$, mkm	400	450	575	635	690	784
d $_{50}$, mkm	330	380	490	575	600	685
d $_{10}$, mkm	240	300	410	480	510	580
d $_{max}$, mkm	491	600	735	702	840	1175
a	0.48	0.59	0.68	0.22	0.4	0.49
$d_{h.yu}$, mkm (taj)	317	362	413	561	576	603
$d_{h.yu}$, mkm (naz)	357	375	396	486	523	545
$d_{h.yu}$ error%	10	2	4	13.3	9.2	9.6
F_{sol} (taj), m^2	4.16	3.6	3.2	2.35	2.2	2.09
F_{sol} (naz), m^2	3.7	3.52	3.3	2.71	2.29	2.4

Theoretical research on the application of the proposed formula for calculating the volumetric surface diameter of the droplets in the bubble extractor [13], developed by Professor B.A. Alimatov, to the bubble extractor we are testing. In the apparatus under test, the gas is distributed to the internal and external mixing zones. The liquids are in the internal mixing zone w_g^i mixed with gas speed, flows into the external mixing zone and is further mixed at this gas rate again in this zone. As a result, the mixing and standing times of the liquid phases in these zones are extended and the size of the heavy phase droplets is reduced. The conducted tariffs also confirm this process. Therefore, the arithmetic mean of the gas velocities in the internal and external mixing zones and the constant multiplier were included in formula 7. w_g^t

The formula is as follows.

$d_{x.y} = 3{,}3 \cdot 10^{-5}(\sigma^{0{,}35} \cdot \varphi^{0{,}8})/((w_g^i + w_g^t)^{0{,}2}/2 \cdot t_{av}^{0{,}45} \cdot \mu_y^{1{,}1})$ (8)

Using this formula, the volumetric surface diameters of the droplets were determined.

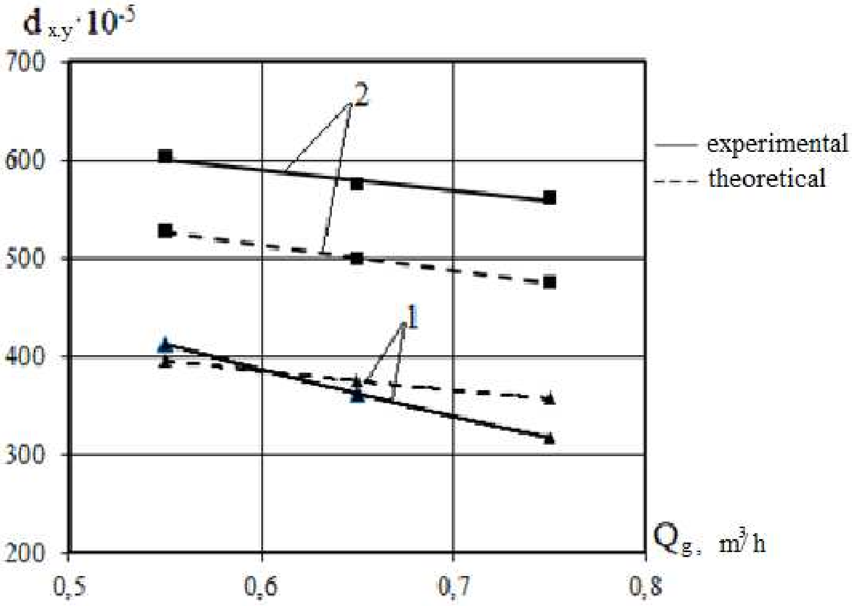
For column 1 (Table 2).

$w_g^i = 0{,}09\frac{m}{s}$, $w_g^t = 0{,}08\frac{m}{s}$, $\sigma = 0.073n / m$, $t_{av} = 22sek$, $\mu_y = 0.001Pa \cdot s$,

$\varphi = 0.25$.

$d_{x.y} = 3{,}3 \cdot 10^{-5}(0{,}073^{0{,}35} \cdot 0{,}25^{0{,}8})/((0{,}09 + 0{,}08)^{0{,}2}/2 \cdot 22^{0{,}45} \cdot 0{,}001^{1{,}1})$ = 3.3 · 10-5 (0.132) / (0.00122) = 357 mkm

The volumetric surface diameters of the droplets were also determined for the remaining columns. The calculation results are presented in Table 2. It can be seen from the table that the error rate between the volumetric surface diameter of the droplets calculated using the proposed formula and the experimental values is 2 ÷ 13.5%. A graph was constructed to compare the experimental and theoretical values of the volumetric surface diameters of the droplets (Figure 5).



1. t_{av} = 22s; 2. t_{av} = 14s

Figure 5. Graph of change in volumetric surface diameter of droplets depending on gas consumption
(comparative graph)

The following empirical formulas were obtained for the experimental results using the least squares method.

on the t_{av} = 22c;

y = 300x2 - 870x + 800.75R² = 1 (9)

on the t_{av} = 14c;

y = 300x2 - 870x + 800.75R² = 1 (10)

Using the above formula 1, the values of the specific interfacial contact surfaces were determined experimentally and theoretically determined and the volumetric surface diameters given in Table 2 were determined and a comparative graph was constructed depending on $d_{x.y}$.

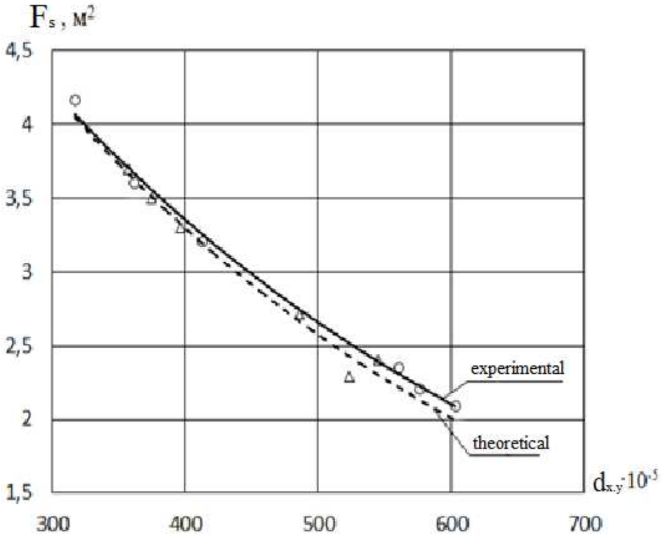


Figure 6. Graph of change of the interfacial specific surface depending on the volumetric surface diameter of the drop (comparative graph)

The following empirical formulas were obtained for the experimental results using the least squares method.

$y = 0.0018x2 - 2.4665x + 1067.7 \quad R^2 = 0.9994$ (11)

Conclusion:

In the experimental device of the bubble extractor, the process of scattering a heavy liquid into droplets by mixing the liquid phases using an inert gas was studied. Depending on the mixing time at constant values of the total phase velocity, at different values of the gas velocity, the dispersion and size distribution of the droplets were determined experimentally. Processed using a computer, regression equations were obtained. Based on the results of experimental studies, the volumetric surface diameters of the droplets were determined. A formula for calculating the volumetric surface diameter of droplets, which is important in the calculation of mass transfer processes depending on the physicochemical properties of liquids, was proposed and the theoretical and experimental values were compared. The calculations carried out fully confirmed the proposed formula.

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