Energy consumption of small-since mixers in emulsification processes

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Abstract. There is given a common method of calculation of power consumptions for emulsification at systems liquid-liquid in low volume mixing devices (rotary pulsating apparatuses and rotor-disc mixers) in this Article. Named mixing devices shown a high efficiency at processing of liquid-liquid systems and are widely used at chemical processes. It is shown that at determination of energy consumptions it is need to take in account energy dissipation processes, caused by viscous friction forces, which affect a significant influence at high gradients of speeds turbulent motion. It is obtained the ratio, which connects an angular velocity of rotor rotation of mixing device and a characteristic size of dispersed phase particles of a mixing device. There are given an experimental equations of consumed power of rotor-disc mixers on rotor rotations number and characteristic sizes of dispersed particles for the system water and diesel fuel. Also it is known that in decrease of dispersed particles size and in increase of volume consumption of the processed mixture, the consumed power is increase, and it due to the fact by increase energy consumption for creation of interphase surface.

1. Introduction
The aim of mixing of mutually insoluble liquids in low volume mixing devices (rotor pulsating devices and others (1-4)) is a getting of emulsions with given size of drops, for example, for emulsion polymerization, of liquid extraction processes and also of chemical reactions in systems liquid-liquid

For emulsification processes are wide used rotor-pulsating devices (RPD) and rotor-disc mixers (RDM). In rotor-pulsation devices the process medium moves in radial direction (from the center to periphery) passing through slots in the rotor and stator, which overlap with a specific frequency, having generating pulsations of speed and pressures of the liquid [1]. In the slots of cylindrical form between rotating cylinders of rotor and fixed cylinders of the starter takes place a require energy influence. At the rotor-disc mixers the process mixture moves in axial direction through the holes in work discs, and mixing carries out thanks to a high hydro-dynamic influence of rotating and fixed discs [2].

2. Experimental part
Calculation methods development When designing of constructions of low-volume mixing devices, intended for named processes, the main aim is determination of power for getting of emulsion with given size of dispersed particles, which determine a value of interphase surface. In this work given an algorithm of power consumptions determination in common form, which can be used for calculation of specific mixing devices, by giving a constructive, technologic parameters and properties of process liquids. A power consumption is determined by energy, which is required to divide of emulsion drops in the turbulent flow and dissipation of
energy due to viscous friction processes. In common the power which need to carrying out of named processes will determine by the formula

\[ P = \frac{1}{2} J \omega^2 Q + \int \tau_{ik} \frac{\partial v_i}{\partial x_k} dV + \frac{\delta \varphi}{d_k} Q \]  

(1)

where \( J \) - liquid inertia moment in the mixing device (kg/m²); \( V \) - working volume (m³); volumetric consumption of the process mixture; \( \omega \) – an angular velocity of mixing device rotor rotation; \( d_k \) - averaged size of dispersed particles (m); \( \sigma \) - coefficient of interphase tension (N/m); \( \tau_{ik} \) - components of stress tensor [5].

Considering the axial symmetry of mixing devices, we will use a cylindrical coordinate system, the axis \( Z \) of which is the same with axis of the shaft \( x_k=\{r,\theta,z\} \), where \( r \) - radial coordinate; \( \theta \) – azimuthal angle.

In this case all components of the velocity \( V_i=\{V_r,V_\theta,V_z\} \), and integration carries out over all volume, occupied by the liquid in the device, and summation carries out by repetitive index. Considering that an angular velocity of rotation of the liquid in mixing device significantly exceeds axial velocity of motion \( V_z \) and radial pulsations of the velocity in the right pat of the equation (1), can be as follow:

for rotor-pulsation device [1]

\[ \int \mu \left( \frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r} \right)^2 r dr d\theta dz \]  

(2)

for rotor-disc mixers [2]

\[ \int \mu \left( \frac{\partial v_\theta}{\partial z} \right)^2 r dr d\theta dz \]  

(3)

where \( \mu \) – turbulent coefficient of dynamic viscosity of the mixture.

An integration by the radial coordinate is carried out on transverse dimensions of the apparatus, and by axis \( Z \) - on height of the device. The profile of azimuthal velocity of the liquid will be determined by the angular velocity of the shaft rotation of the mixing device and its construction. For example, the integral (3) for rotor-disc mixer will be as follow:

\[ N = \sum \pi \mu 0.25 \rho^{0.75} \delta^{0.25} \frac{0.75}{R_0^4 - R_e^4} \]  

(4)

where \( \omega \) – angular velocity of rotor rotation
\( \mu, \rho \) – dynamic viscosity coefficient and density of the processed mixture;
\( \delta \) – the amount of clearance between the disks;
\( R_0 \) – radius of discs;
\( R_e \) – radius of the shaft;

A summation is carried out by number of the gaps between rotating and fixed discs.

Considering, that to create in turbulent flow of dispersed particles, which diameter \( d_k \) need an intensity of turbulence pulsations, scale of which not more than size of drops with a energy density [3]

\[ \rho \frac{V^2}{2} \approx \frac{4 \sigma}{d_k} \]  

(5)

It can be estimated a linear velocity of processed mixture and a radial velocity of the rotor of the mixing device

\[ V_p = \omega R_p \]  

(6)

where \( R_p \) – a characteristic radial size of a mixing device.

At turbulent mode of process mixture motion, a speed of turbulent pulsations connected with speed \( V_p \) by the ratio [5]

\[ \frac{V_p}{V_d} \approx \left( \frac{R_p}{d_k} \right)^{\frac{1}{3}} \]  

(7)
In accordance with the equation (6) we can estimate an angular velocity of mixing device shaft rotation.

$$\omega \cong \frac{2^{3/2}}{R^3} \left( \frac{\sigma}{\rho} \right)^{1/2} \frac{1}{d_k^{3/4}}$$

In accordance with the last equation an angular velocity of the mixing device is increase by increase of interphase tension and decrease of size of dispersed phase particles. For example, at \( RP \approx 0.1 \) m; \( \sigma \approx 0.07 \) N / m; \( \rho \approx 103 \) kg / m3; \( d_k \approx 0.1 \) mm, angular velocity \( \omega \approx 120 \) rad / s, which corresponds to a shaft rotation frequency of 1150 rpm. Thus, the above ratios allow us to determine the power of the mixing device depending on the design parameters, the size of the dispersed particles of the emulsion and the parameters of the processed mixture.

3. Results and discussion

In the figures 1-3 given an experimental curves of relation of averaged sizes of dispersed particles on number of rotations of the mixing device, consumed power on rotations number and size of dispersed particles for rotor-disc mixer.

A rotor-disc mixer is a device, which consist of cylindrical body, (operate volume 0.8 dm3), in volume of which hardly fixed still discs, and between them take place a rotating disc with a similar function, fixed of rotating rotor, and gap between fixed and rotating discs ~2 mm, diameters of discs 120 mm. On the lower surface of the upper fixed, on the upper surface of the lower fixed and on both surfaces of the movable disk are additional elements in the form of teeth of rectangular section, oriented from the center to the periphery. The components of process mixture served to the device through the input pipe, located in the upper part of the device, components having going across operative area of the device are exposed to intensive influence by the work organs, and after this the ready mixture removes through a discharge port to the bottom of the device. As components of the mixture was used water (\( \rho = 998 \) kg / m3, dynamic viscosity 1004 μPa · s, kinematic viscosity 1.006 · 10⁻⁶ m² / s, surface tension 0.07 N / m (at 293K) and diesel fuel (\( \rho = 860 \) kg / m3, dynamic viscosity 560 μPa · s, kinematic viscosity 0.62 · 10⁻⁶ m² / s (at 293 K) [4].

![Figure 1. Relation of averaged diameter of dispersed particles on volume consumption of the medium at different velocity of rotor rotation.](image-url)
Figure 2. Relation of consumed power on volume consumption of the medium at different velocity of rotor rotation.

Figure 3. Relation of consumed power on averaged diameter of dispersed particles on volume consumption of the medium at different velocity of rotor rotation.

As it shown from the given equations, there is a quality conformity of given ratios and the experimental curves. So, for example, it is shown from the figure 1, that the averaged size of dispersed particles is inversely proportional to radial velocity of rotor rotation and is proportional to quantity of volume consumption of process mixture. Such relation of dispersed particles sizes is explained by decrease of process time of mixture and could be found in by the formula (1) which displays that at given power \( P \), a characteristic size of dispersed particles is proportional to size of volumetric consumption. As it shown from the figure 2 the power of rotor-disc mixer, which is required to create of emulsion with averaged size of dispersed particles at range of 5 to 25 mkm, is increase by increase of rotations number \(-n0.37\). In the relations, given in the figure 3 is shown, that by decreasing of dispersed particles size and by increasing of volumetric consumption of process mixture, the consumed power is increase[6-8].
4. Conclusions
The relations for determining the power consumption of low-volume mixing devices are found, which adequately describe the power dependence on the design parameters of mixing devices, the properties of the processed mixture and the size of dispersed particles. These ratios can be used to determine the power consumption at designing of small-sized mixing devices for emulsification processes in specific technological processes.

References
[1] Shulaev N S, Nikolaev E A and Ivanov S P 2009 Low-volume rotary-disk mixers (Moscow: Chemistry) p 186
[2] Laponov S V, Shulaev N S, Ivanov S P and Ibragimov I G 2018 Carbonization of a soda solution in rotary disc reactors Buterov Communications 53(3) 118-23
[3] Laponov S V, Shulaev NS, Ibragimov IG and Ivanov SP 2016 Features of emulsification in rotary disk mixers Oil and gas business 14(4) 126-9
[4] Braginsky LN, Begachev VI and Barabash VM 1984 Mixing in liquid medias: Physical principles and an engineer calculation methods (Leningrad: Chemistry) p 336
[5] Landau L D and Lifshits E M Hydrodynamics (Moscow: Nauka) p 736
[6] Bogdanov VV, Khristoforov EI and Klotsung BA A Effective low-volume mixers 1989 (Leningrad: Chemistry) p 224
[7] Balabudkin MA Rotary pulsation apparatus in the pharmaceutical industry 1983 (Moscow: Medicine) p 160
[8] Promtov MA Pulse devices of rotary type: Theory and Practice 2001 (Moscow: Mechanical Engineering) p 260