

Modeling emulsification processes in rotary-disk mixers

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Abstract. This article presents the experimental studies results of emulsification processes in liquid-liquid systems in rotary-disk mixers, allowing regulating the distribution of dispersed particles by changing the process conditions and the ratio of the dispersed phase. It is shown that with the increase of mixer's revolutions per minute (RPM), both the size of dispersed particles and the deviation of dispersed particles sizes from the average decrease. The increase of the dispersed particles part results in the increase of particles average sizes at the current energy consumption. Discovered relationships can be used in the design of industrial equipment and laboratory research.

1. Introduction

The processes of emulsification are among the most common in the industry. The productivity and quality depend lot on the efficiency of this process. Among mixing devices, there are a large number of small rotary-disk mixers, which allow one to create emulsions with a given degree of dispersion at a relatively low energy consumption. Complexity and variety of hydrodynamic effects in mixers do not allow one to create the analytic models of emulsification processes, which depend on environment properties and constructive parameters of devices [1-3]. Therefore, empiric proportions and experimental results are used during design of industrial devices. In the presented work, the results of experimental studies of emulsification processes in the liquid-liquid (water - diesel) system in a rotary-disk mixers with different ratios of water/diesel fuel and modes of mixing are presented. The dependence of the dispersed phase particles size distribution on the processing mode was determined [4].

2. Rotary disc mixer description

The rotary disc mixer (figure1) consists of input pipe branches 1, 2 and output pipe branch 3, cylindrical framework 4, where perforated discs are permanently fixed 5, arranged alternately with the similar design as perforated disk 6, mounted on rotating rotor 7. The rotor is set in motion by the motor (not shown in the figure). Perforated discs contain tools (paddles, cogs, blades and etc.), which creates pulsations of the processed mixture [5].

Under the action of mass forces, generated during rotation of the rotor, the treated heterogeneous medium is moved from the input (loading) of the pipe to the outlet (discharge) nozzle. When moving through the disks channels, the treated mixture is subjected to intensive mechanical stress, which causes the emulsification process. The required capacity of the mechanical impact is determined by the speed of rotor rotation, arising in connection with this high turbulent movement of processed



medium in the gaps between the rotating and stationary disks and a high frequency ripple with frequency f , generated by the interacting flows, generated by the prongs upon rotation of the movable disc [6]:

$$f = \frac{\omega}{2\pi} \cdot Z_1 \cdot Z_2, \quad (1)$$

where ω - the angle rate of the rotor, revolving relative to the starter; Z_1, Z_2 – the number of prongs on the revolving and fixed discs, respectively.

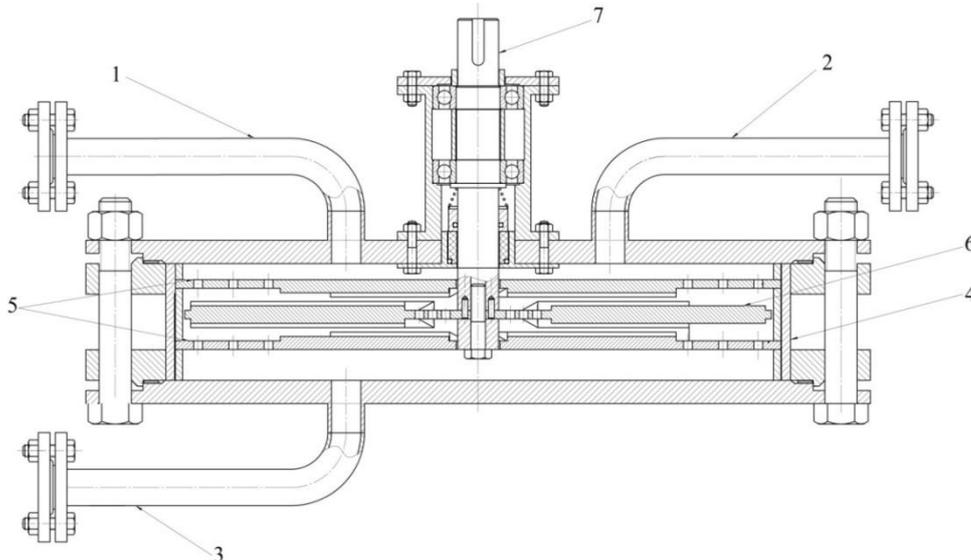


Figure 1. The rotary-disc mixer: 1,2-input pipe branch; 3-output pipe branch; 4- framework; 5- fixed perforated discs; 6-movable perforated discs; 7-rotor

3. Description of the laboratory device

The experimental device (figure 2) consists of a small volume rotary-disc mixer of through type 1, the shaft of which is driven by non-synchronous electric motor 2, tanks 3,4 for the initial components of the mixture, drain reservoir 5 for collecting the finished emulsion, frequency converter 6. The frequency converter is used to change the number of revolutions of the motor and to measure the power. Additional sets of sensors are used for a more detailed study of the operation of the rotary disk mixer: level gauges, flow meters, pressure sensors for each working zone of the apparatus, the tachometer, temperature sensors, etc.

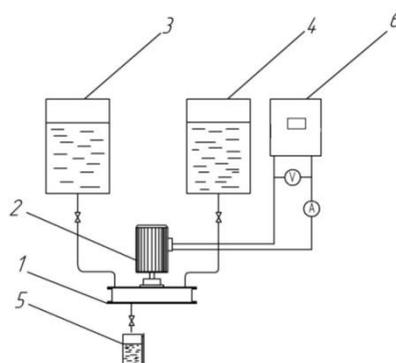


Figure 2. The scheme of the laboratory device: 1- rotary-disc mixer; 2- engine; 3,4-tanks for the initial mixture components; 5- tank for collecting emulsion; 6-frequency convertor.

4. Results and Discussion

In the mass exchange research in the liquid-liquid dispersed systems, a key parameter in determining the flow of the substance through the phase interface is the mass transfer coefficient, which over the solid and dispersed phases is determined by the equations:

$$k = \frac{q}{F_{sp}(C_d - C)}; \quad (2)$$

$$k_d = \frac{q}{F_{sp}(C_d - C_{sd})}, \quad (3)$$

where k , k_d - is the mass transfer coefficient over the solid and dispersed phases; C , C_d , C_{sd} , - concentrations of transitional substance and the equilibrium concentration in the solid and dispersed phases; F_{sp} - specific phase interface (m^2/m^3).

$$F_{sp} = 6\varphi \int_0^{D_{max}} f(D)/D dD, \quad (4)$$

where φ – the volume fraction of the dispersed phase;

$f(D)$ – the distribution function of dispersed particles over sizes, which was determined experimentally.

For these experiments, the water ($\rho=998 \text{ kg/m}^3$, dynamical viscosity - $1004 \text{ }\mu\text{Pa}\cdot\text{s}$, kinematic viscosity - $1,006\cdot 10^{-6} \text{ m}^2/\text{s}$, surface tension - $0,07 \text{ N/m}$ (at 293 K)) and the diesel fuel ($\rho=860 \text{ kg/m}^3$, dynamical viscosity - $560 \text{ }\mu\text{Pa}\cdot\text{s}$, kinematic viscosity - $0,62\cdot 10^{-6} \text{ m}^2/\text{s}$, N/m (at 293 K)) were used as components of the treated mixture

The experiments were conducted as follows: the frequency of the rotor rotation was set; components of the mixture in a given ratio were supplied to the input connections; a valve outlet port establishes the flow of the treated mixture; the power consumption was measured, the photometric method was studied by the fractional composition of the obtained emulsion (figure 3).

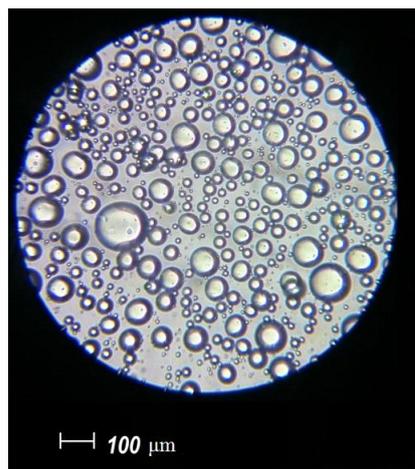


Figure 3. The photo of the emulsion probe

Figure 4 shows the dependence of the power consumption on the rotor rotation speed of the RDM in various proportions of the mixture components - water-diesel fuel. As is seen from the graphs, with the increase of the volume fraction of the diesel fuel, the power consumption increases too. This is because with the increase of the volume fraction of the dispersed phase, the concentration of dispersed

particles increases, and, therefore, the energy required for the formation of dispersed particles, which is proportional to the interfacial surface and interfacial tension, increases. Fig. 5 shows the distribution of the dispersed particle by size at different RDM rotor speeds. As is seen from the figure, with the increasing speed of the rotor rotation, and therefore, with the increasing dissipation of heat energy, the size of dispersed particles is reduced in accordance with the ratio:

$$d \sim \sigma^{0.6} \left(\frac{N}{\rho V} \right)^{-0.4}, \quad (5)$$

where σ – the coefficient of the interface tension;

ρ – mixture density;

V – working capacity of the device;

N – dissipated power.

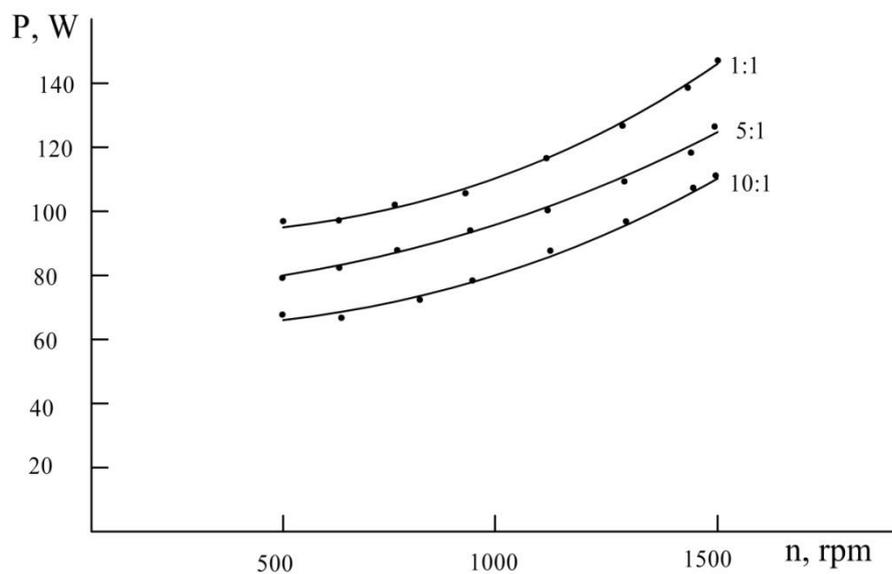


Figure 4. The dependence of mixing power on the rotor rotation rate for various ratios of water and diesel fuel.

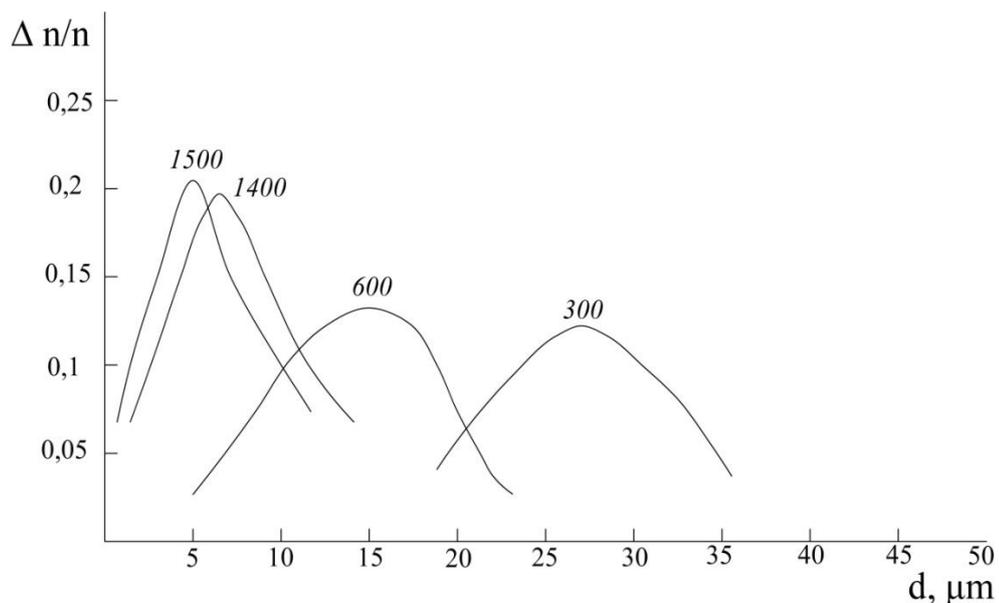


Figure 5. The dependence of particles distribution over the sizes on rotations number.

The dependence of the dispersed particles size, on which the maximum of particle distribution depends, on the rate of rotor rotation is given in figure 6.

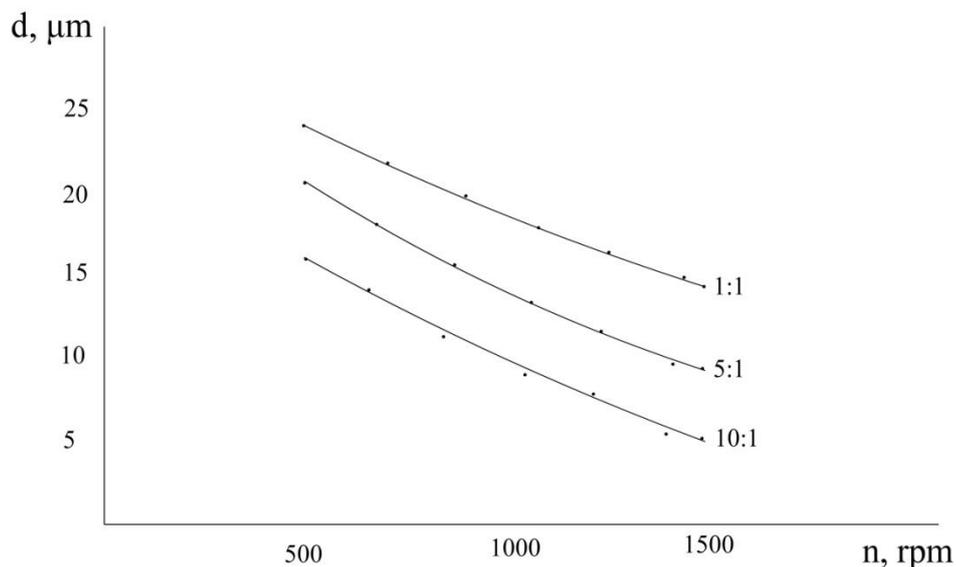


Figure 6. The dependence of the average size of dispersed phase average drops on the number of revolutions.

As is seen from the dependencies, with the increase of the volume fraction of the disperse phase, the average particle size increases as the concentration and frequency of dispersed particles collision, resulting in coalescence, increase. With the relatively small volume fraction of the dispersed phase, the size of dispersed particles decreases, which is inversely proportional to the rate of RDM rotor rotation.

5. Conclusion

From these studies, it follows that the rotary-disk mixers can be successfully used as laboratory equipment for the creation of emulsions in the liquid-liquid system with a given size of dispersed particles and in an industrial environment as low-capacity rotary mixers.

References

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