Two-stage rotary crushing mixer

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Abstract: This article provides an overview of the design of a two-stage rotary crushing mixer and describes the principle of operation. It has been experimentally proven that the use of a two-stage rotary crushing mixer, in comparison with a single-stage apparatus, leads to a significant increase in the quality of the mixture and productivity. It was found that to create an emulsion with a certain size of dispersed particles, a two-stage apparatus consumes less power, this is explained by the fact that in a single-stage apparatus, to achieve the specified size of dispersed particles, the processing time of the mixture increases, and therefore energy consumption increases. In addition, the specific power consumption of the two-stage apparatus is less than the sum of the capacities of the two single-stage apparatus, which indicates a higher energy efficiency of the proposed design of RCM. Expressions (formulas) are given for determining the dissipated energy and power required for carrying out the mixing process, taking into account the design parameters of the apparatus, the properties of the media. It is shown that the power consumption for mixing is determined by the energy required for crushing emulsion droplets in a turbulent flow and energy dissipation due to viscous friction processes.

Rotary Crushing Mixers (RCM) are used to create fine suspensions and emulsions. High efficiency and intensity of emulsification and mixing is the main requirement when choosing an apparatus at the stage of production design. Quality of a mixture conditioned by sizes of dispersed particles depends on many factors, for example: construction of mixer (execution of working parts), properties of supplied components, processing time of media and rotor speed. Change of rotor rotation speed and processing time of the emulsion in the device allows to adjust sizes of dispersed particles and distribution of these particles in given range [1,2]. To achieve the required quality of the mixture and increase productivity, it is necessary to use other highly efficient designs of working parts [3].

To increase productivity or improve the quality of the mixture, several mixing devices are often installed, connected in parallel or in series. When two mixers of the same design are connected in series, the processing time of the medium is doubled, which will lead to a decrease in the average particle size of the dispersed phase, provided that the volumetric flow rate remains unchanged.

Use of two mixers related with increase of capital and operating costs. In addition, the system of supply and removal of components and mixture will become more complicated, the reliability of the unit as a whole will decrease, and energy consumption will increase. To avoid such problems, two-stage rotary crushing mixer are used. One of these devices is a two-stage rotary crushing mixer. (figure 1).

The device consists of inlet tubes 1,2, outlet tube 3, cylindrical body 4 in which installed fixed discs 5,6,7 between which located movable discs 8,9 installed on rotating rotor 10. On surface of the discs located radically oriented, teeth 11 which serve to create additional highly turbulent flows. All discs have
perforations, the sum of the areas of which is commensurate with the area of the free cross-section of the inlet and outlet pipes.

Figure 1. Two-stage rotary crushing mixer. 1,2 - inlet nozzles; 3 - outlet nozzle; 4 - cylindrical body; 5,6,7 - fixed discs; 8,9 - movable discs; 10 - rotor; 11 - teeth.

The operating principle of the device as follows: components of processed media are supplied to the device through nozzles 1 and 2, passing through perforations in fixed disc 5, proceeds to working area of the first stage, which consist of fixed discs 5, 6 and movable disc 8. Then coarse emulsion passes through perforations in fixed disc 6 and proceeds to working area of the second stage, which consist of fixed discs 6,7 and movable disc 9. Then the finished processed mixture is removed via discharge nozzle 3.

The use of a two-stage rotary crushing mixer has the following advantages in comparison with the use of two identical devices: the use of one electric motor, a relatively low metal consumption, during the reconstruction of the existing production there is no need to replace the supply and discharge pipelines. As practice shows, the use of a two-stage RCM, in comparison with single-stage devices, makes it possible to minimize the specific energy consumption for mixing and improve the quality of the mixture by increasing the processing time. In addition, the use of the second stage has no significant effect on the reliability and durability of the apparatus [4,5].

The particle size of the dispersed phase is related to the dissipation energy by the following expression:

\[
d_k = 3.5 \left( \frac{a}{\rho} \right)^{0.6} \left( \frac{N}{\rho V} \right)^{-0.4},
\]  

(1)
where \( N \) is the dissipated power,
\( \sigma \) - coefficient of interfacial tension,
\( \rho \) - is the density of the mixture,
\( V \) - is the volume of liquid in the apparatus.

This expression, which describes the mechanism of drops crushing at turbulent flow, is a common and is used for analysis of dispersion phenomena in devices with various methods of mixing.

Taking into account constructive parameters of rotor-disc type mixers, a dispersible power could be estimated on the following formula:

\[
\sum_{i=1}^{n} \pi \mu (0.25 \omega^{0.75} \rho^{0.75} \delta_{i}^{0.75} \left( R_{di}^{4} - R_{d}^{4} \right)),
\]

where \( \omega \) is the angular speed of the rotor rotation,
\( \mu \) - coefficient of dynamic viscosity of the mixture,
\( R_{d} \) - is the radius of the rotor discs,
\( R_{v} \) - the radius of the rotor shaft,
\( \delta_{i} \) - is the gap between the stationary discs movable by it.

The summation is performed over all the gaps between the movable and fixed discs.

The power consumption for mixing is determined by the energy required for crushing emulsion droplets in a turbulent flow and energy dissipation due to viscous friction processes. In general, the power required for the mixing process is determined by the formula

\[
P = \frac{J \omega^{2} Q}{2V} + N + \frac{6 \phi \sigma}{d_{k}} Q,
\]

where \( J \) is the moment of inertia of the volume of the processed mixture between the gaps,
\( \phi \) - is the volume fraction of the dispersed phase,
\( Q \) - is the volumetric flow rate.

During the experiments, water was used as mixture components (\( \rho = 998 \text{ kg/m}^{3} \)) dynamic viscosity 1004 \( \mu \text{Pa s} \), kinematic viscosity 1.006 \( \times 10^{-6} \text{ m}^{2}/\text{s} \), surface tension 0.07 N/m (at 293K) and diesel fuel (\( \rho = 860 \text{ kg/m}^{3} \), dynamic viscosity 560 \( \mu \text{Pa s} \), kinematic viscosity 0.62 \( \times 10^{-6} \text{ m}^{2}/\text{s} \) (at 293K). The volume of the experimental RCM model is 0.8 dm\(^3\), the gap between the discs is 2 mm, the diameter of the discs is 140 mm. During the experiments, in one device body, the working parts were alternately installed, making up one and two stages.

Figure 1 shows the comparative dependences of the power consumption of a single-stage and two-stage RCM. As can be seen from the above dependences, the power consumption of the two-stage apparatus is less than the sum of the capacities of the two single-stage apparatus, which indicates a higher energy efficiency of the proposed design RCM.

Figure 2 shows the dependence of the power consumption for preparing an emulsion with a given particle size of the dispersed phase. As can be seen from the given dependencies, a two-stage device uses less power to create an emulsion with specific size of dispersed particles. This dependence is explained by the fact that in a single-stage apparatus, to achieve the specified size of dispersed particles, the processing time of the mixture increases, and therefore energy consumption increases. [5,6,7].
Figure 2. Dependence of consumed power on rotor rotation number at various volumetric consumptions Q and volumetric ratio of components water/diesel fuel 9/1. 1, 2 - a single stage Rotary Crushing Mixer. 1’, 2’ - two stages Rotary Crushing Mixer 1 – Q=0.2 m³/h; 2 – Q = 0.05 m³/h.

Figure 3 Dependence of consumed power on average size of dispersed particles at various volume consumptions Q and volumetric relation of components water/diesel fuel 9/1. 1, 2 - a single stage Rotary Crushing Mixer 1’, 2’ - two stages Rotary Crushing Mixer 1 – Q=0.2 m³/h; 2 – Q = 0.05 m³/h.

Thus, the studies carried out have demonstrated a higher efficiency of two-stage rotary-disc mixers in comparison with single-stage apparatus, which makes their implementation more promising in specific technological processes.
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