Development of a design of the mixer for an intensification of chemical and technological processes in the industry

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Abstract. From all variety of instrument registration of processes of hashing for an intensification of chemical and technological processes in the industry small-volume rotor mixers and dispersers with disk actions even more often find application. In this article the design of the small-volume mixer for receiving heterogeneous mixes is described. Constructive design of the device allows to carry out efficiently processing of homogeneous and heterogeneous mixtures.

1. Introduction

In chemical and adjacent industries various designs of agitators are applied to receiving heterogeneous mixes – emulsions (in systems liquid-liquid) and suspensions (fine solid matters – liquid).

Perfecting available and development of brand-new designs of agitators is directed to improvement of quality indicators of process of hashing.

Hashing can be considered as a way of an intensification of chemical and technological processes of distribution of the dissolved substances, the weighed particles and warmth and also dispersion of drops and bubbles in liquid by its reduction in the forced movement.

On the physical mechanism processes which course accelerates when hashing can be subdivided into three main groups. Processes of transfer of the dissolved substances, the weighed particles and warmth on the distances not too small in comparison with the device sizes are the first of them. These processes play the main role at mixture of mutually soluble liquids, suspending, alignment of temperature. Their result is characterized by degree of uniformity of fields of concentration and temperatures or time of achievement of the set degree of uniformity and completely is defined by macrolarge-scale characteristics of a stream of liquid in the device [1-4].

Processes of crushing of drops and bubbles belong to the second group. The sizes of drops and bubbles are small in comparison with the device sizes therefore the end result of hashing - diameter of the formed drops and bubbles or their surface — depends on macrocharacteristics of a stream a little. It is determined mainly by intensity of microlarge-scale turbulence or size of shift efforts and small elements of volume, the sopostakvimykh by the sizes with particles of a disperse phase. It is also necessary to carry to this group cases when alignment of concentration of the reacting substances at the macrolevel is not enough for normal course of chemical reactions and an essential role is played by the speed of a supply or removal of substances at the macrolevel, up to distances at which forces of intermolecular interaction are shown. Though transfer speed in elements of volume of so small scales (micromixture phenomena) is defined first of all by physical and chemical properties of the
environment and the diffusing substances, has an impact on it and microlarge-scale structure of a stream.

The third group the phenomena warm and a mass exchange on limits of the section form liquid - the case of the device, liquid - internal devices, liquid - the weighed particles, drops, bubbles. The main influence on the speed of transfer of warmth or substance at the same time render characteristics of an interface which depend on conditions of a current of the mixed environment in close proximity to an interphase surface.

In all considered cases the intensification of technological processes is result of a current of liquid in the device, however requirements to characteristics of a stream and a design of the device can be various depending on features of the intensified phenomena and scale, characteristic of them.

Even more often, in practice by the solution of such task as the intensification of chemical and technological processes, becomes use of small-volume rotor mixers and dispergators, a design prototype for which were various options of execution of disk mixers.

The analysis of the existing designs of devices and devices with disk working bodies, allows to define their main design faults:

- low productivity because of the low capacity of separate elements of the device;
- inefficient impact on the processed environment from working bodies of the device;
- impossibility of expeditious change of parameters of processing of the environment (for example, change of a gap between disks);
- the increased consumption of power on overcoming hydrodynamic resistance because of presence of speakers of parts over disks (for example, the turbulizing blades);
- a narrow scope (for example, only for systems liquid-liquid or liquid - a solid body);
- complexity of a design of the device (in particular, execution of disks).

In the presented work the design of the mixer which use allows to solve a wide range of tasks of processing of substances in the liquid environment is described: to carry out processes of crushing, emulsification and effective mixture of heterogeneous mixes and allows to minimize above-mentioned shortcomings [5-11].

2. Results

In figure 1 the developed mixer is shown.

![Figure 1. Scheme of two-level RDM (a) and option of execution of its disk (b):](image)

1 – a loading branch pipe, 2 - an unloading branch pipe, 3 - the fixed cylindrical housing, 4 - the punched disks, 5 – a control apparatus.
Construction of RDM with a single-span shaft consists of a boot and unloading branch pipe, the motionless cylindrical case in volume of which the perforated disks located in turn with the perforated disks, similar on construction, fixed on the rotating rotor are rigidly recorded. And openings of perforated disks can be executed in different execution (round, rectangular, trapezoidal, etc.) and to be guided under a different corner in the direction from the center to the periphery. In the drawing of 1 opening are oriented at an angle 45 °. Couple consisting of one mobile and one motionless disk make a working step of the device.

The mixer can be executed with a possibility of regulation of a gap between the mobile and motionless punched disks by means of the control device or by means of the distancing rings.

The mixer works as follows.

Under the influence of mass forces or artificially created excessive pressure the processed mix moves from a loading branch pipe to an unloading branch pipe. At the movement through the punched disks the processed mix is exposed to intensive mechanical and hydrodynamic influence with carrying out process of dispersion and hashing.

The intensity of mechanical influence is reached by rather high rotation frequency of a rotor and the high-eddy of the processed environment arising in this regard in gaps between the rotating and fixed punched disks and due to the compulsory overlapping of channels of a current of the processed environment with emergence of the considerable values of a gradient of speed and pressure. Openings in a rotor and a casing, creating an axial stream, continuously focus environment volume elements perpendicular to the direction of shift influence and also split up streams for small volumes, promoting the significant increase in an interfacial area and the uniform distribution of elements of volume of the processed mix in the device. Besides, as material is processed in a small gap, in it there are big speeds of shift that allows to reach high intensity of deformation influence.

The significant amount of works is devoted to a research of regularities of flow of fluid in rotor devices [1-3].

The general approach is that for the description of regularities of flow of fluid in RDM it is necessary to have the ratios defining a velocity distribution in a gap between device disks.

In figure 2 the scheme of flow of fluid in a gap between two punched disks RDM is shown. Let's consider a case of flow of fluid in the device when one disk rotates, and the second isn't mobile. We have a stationary current of thick, incompressible liquid between permeable disks. For the solution of a task it is convenient to present flow of fluid in a cylindrical frame of \( r, \theta, z \), and axis \( z \) coincides with a shaft axis.

![Figure 2. The scheme of flow of fluid in a gap between two disks RDM: 1 – the fixed disk, 2 – the rotating disk.](image-url)
Power expenses fullesty corresponds to the quantitative characteristics of the carried-out process and define changes of properties of the processed environment that is confirmed in numerous works, the describing methods and ways of power rating for rotor mixers. For the small-volume device – RDM there is no universal equation connecting design data of the device and property of the processed mix with a metabolic cost now.

The power of $N$ (W) dissipated in all volume of the liquid processed in the device can be calculated on a formula

$$N = \int \tau_i \frac{\partial \chi_i}{\partial \chi_i} \, dV,$$

where $\chi_i = \{r, \theta, z\}$;

$v_i = \{v_r, v_\theta, v_z\}$;

$\tau_i$ - stress tensor components, for a cylindrical frame.

Within the restrictions specified earlier expression (1) will take a form:

$$N = \iiint \mu (\frac{\partial V_{\theta}}{\partial z})^2 rdr \cdot d\theta \cdot dz,$$

Let's designate through $B = \frac{1}{e^{\alpha h} - 1}$, then expression (2) registers in a look:

$$N = 2\pi \mu \int B^2 \alpha_r^2 e^{2\alpha_r \omega} r^2 rdr dz.$$

Considering that $0 < z \leq h, R_b < r \leq R_D$, an integration of expression (3) leads to the following ratio:

$$N = \pi b^2 a_1 \frac{\omega^2}{4} (R_D^4 - R_b^4) e^{2\alpha_h}.$$

Considering expressions for $B$ and $\alpha_1$, the ratio (4) will take a form:

$$N = \pi \frac{v_c \rho}{(1 - e^{-Re_c})} \frac{\omega^2}{4} (R_D^4 - R_b^4),$$

where $\rho$ – density of the processed environment, kg/m$^3$,

$Re_c = \frac{v_c \rho h}{\mu}$ - axial Reynolds criterion.

Finally, for the power dissipated in thick liquid we have:

$$N = \frac{\pi \mu Re_c}{4h} \frac{\omega^2 (R_D^4 - R_b^4)}{(1 - e^{-Re_c})},$$

Expression (6) considers the power dissipated at one step of RDM (one relative frame and one fixed disk), for multistage devices expression (6) will register in a look:
where

\[ \text{Re}_{ci} = \frac{\nu_i \rho h_i}{\mu}, \]

where

\[ i \quad \text{- number of steps (gaps) between the fixed and rotating disks, } 1 \leq i \leq k; \]
\[ n_i \quad \text{- number of openings of } i \text{ of a disk;} \]
\[ S_{oti} \quad \text{- area of an opening of } i \text{ of a disk, } m^2 \]
\[ h_i \quad \text{- gap size between disks } i \text{ of a step, } m \]

Except the power dissipated in the device, it is necessary to consider also the power spent for transportation of the processed environment via the device. Power of transportation of the processed environment will be defined by one step of the device by a ratio:

\[ N_T = \left( \frac{G}{\rho n S_{oti}} \right)^3 \frac{\pi \rho (R_D^2 - R_B^2)}{2} + \frac{\omega^2 G}{2n} \sum_{j=1}^{n} r_j^2, \]

where \( r_j \quad \text{- distance from the center of a shaft to center } j \text{ of an opening of a disk } (1 \leq j \leq n) \).

For multistage devices expression (8) will register in a look:

\[ N_T = \left( \frac{G}{\rho n S_{oti}} \right)^3 \frac{\pi \rho (R_D^2 - R_B^2)}{2} + \sum_{i=1}^{k} \left( \frac{\omega^2 G}{2n} \sum_{j=1}^{n} r_j^2 \right), \]

The total power spent for processing of mix in the device is addition of the dissipated power and the power spent for transportation of mix via the device:

\[ N_T = N + N_T, \]

For multistage devices we have:

\[ N_T = \sum_{i=1}^{k} \left( \frac{\pi \mu \text{Re}_z}{4h_i} \frac{\omega^2 (R_D^4 - R_B^4)}{(1 - e^{-\text{Re}_z})} \right) + \sum_{i=1}^{k} \left( \frac{G}{\rho n S_{oti}} \right)^3 \frac{\pi \rho (R_D^2 - R_B^2)}{2} + \sum_{i=1}^{k} \left( \frac{\omega^2 G}{2n} \sum_{j=1}^{n} r_j^2 \right). \]

3. Conclusion

Apparently from the last ratio, power is proportional to a rotor rotation frequency square \( \omega \) and depends on design data of the device \( (R_D, R_B, h, n, S_{oti}, i) \) and also on properties of the processed mix \( (\mu, \rho) \) and an expense of \( G \) which eventually influence determination of overall performance of the device.

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