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Mixing intensification

L.R. Gaynullina, V.P. Tutubalina

Kazan State Power Engineering University, 51 Krasnoselskaya St, Kazan 420066, Russia

gainullina7819@mail.ru

Abstract. Intensification of different system mixing process, particularly in non-isothermal conditions, is a critical task for many industries, where local overheating prevention, chemical reaction acceleration or heat and mass transfer coefficient increase are required. In this regard, an experimental study of the mixing process was carried out using the transformer oil as an example. Temperature equalization time in the fluid and the mixer power consumption were used as indicators of the process efficiency. The influence of the mixer type, presence of bafflers in a vessel, and the mixer speed on the fluid mixing intensity revealed the optimal design and process parameters of the mixing units.

Introduction

In the industries such as power engineering and chemical industry, many technologies are associated with the mixing process. For different systems, especially in non-isothermal conditions, there is a matter of the mixing intensity increase that is one of the most important ways to increase the process efficiency.

The mixing process intensification enables the most qualitative chemical reaction with its acceleration, reduces the probability of local overheating of the reaction mass, increases the heat and mass transfer coefficient, etc. [1, 2]

Relation between the mixing process and hydrodynamic factors necessitates the study of hydrodynamic features of mixing, which in turn depend on the unit design, mixer profile and process parameters. One of these parameters is the fluid flow condition [3]. In laminar flow, the velocities at each point of the flow have a constant value and direction. In turbulent flow, the deformation structure of the flow is characterized by a velocity pulsation at each point of the flow, i.e. velocity variation in time at each point. Turbulent pulsations are defined not only by the velocity, but also by the turbulence scale, i.e. the mixing path length. The larger the pulsation rate, the larger the motion scale [4-6].

In general, the turbulence is formed at the fluid flow boundaries due to the interaction of the mixer with the mixed fluid and the interaction of moving flows with fixed parts of the unit, including its walls. Thus, local differences in the mixed medium structure and turbulence decay depend on the location of the turbulence sources, which in turn should be taken into account when choosing the mixer type.

The mixing efficiency is characterized by the achieved degree of homogeneity of the mixed fluid. The amount of power consumed per unit volume can be taken as a measure of the mixing intensity [7].

Experimental procedure

Experimental study of the mixing process was carried out using the transformer oil.

Different types of mixers were tested during the study: 3-blade propeller, open turbine mixer, 2-blade mixer with blades at an angle of 45° to the horizon, 2-, 3-, 4-, 6- and 8-radial-blade mixers. Mixer diameter is 75, 100, 125 and 150 mm. During the test, a thermal pulse with a power of 2.5 kJ/s was fed to a stationary fluid in the units using a heater. After 30 seconds, the heater was switched off and the mechanical mixer was rotated. The temperatures at the lower and upper points of the mixed transformer oil was measured at a given mixer speed. Temperature equalization in the upper and lower points of the mixed fluid was regarded as the end of the mixing process. The temperature equalization time, the mixer speed, the power consumed by the mixer, the thermal pulse power, the thermal pulse duration were measured during the tests.

The first series of tests was carried out to study the mixing efficiency under thermal pulse conditions, which was determined by the temperature equalization time and the consumed process power. The fluids under study were mixed using different types of mixers in a smooth-wall vessel and in a unit with four baffles. The mixer speed was n = 100 rpm. The results are presented in Tables 1 and 2.

Table 1. Comparative efficiency of mixers when mixing the transformer oil in a smooth-wall vessel (n = 100 rpm, D = 200 mm)

No.	Mixer type (dimensions, mm)	N, W	τ, sec	Nτ, J	Comparative efficiency with respect to	
					τ	Nτ
1	3-blade propeller d = 75	$1.09 \cdot 10^{-3}$	11.2	$7.31 \cdot 10^{-1}$	1.87	0.18
2	3-blade propeller d = 100	$1.14 \cdot 10^{-2}$	6.0	4.10	1.0	1.0
3	3-blade propeller d = 150	$0.76 \cdot 10^{-1}$	2.4	11.08	0.40	2.70
4	Open turbine d = 75	$5.45 \cdot 10^{-3}$	8.8	2.20	1.47	0.54
5	Open turbine d = 100	$5.63 \cdot 10^{-2}$	4.4	14.81	0.74	3.62
6	Open turbine d = 150	$3.81 \cdot 10^{-1}$	1.6	36.59	0.27	8.92
7	2-blade mixer d = 100, h = 40	$4.14 \cdot 10^{-2}$	9.0	22.37	1.50	5.46
8	2-blade mixer with blades at 45° d = 100, h = 20	$3.10 \cdot 10^{-2}$	10.0	18.54	1.67	4.53
9	4-blade mixer d = 100, h = 20	$5.76 \cdot 10^{-2}$	7.5	25.51	1.25	6.23
10	6-blade mixer d = 100, h = 20	$6.0 \cdot 10^{-2}$	7.0	25.11	1.17	6.17

Table 2. Comparative efficiency of mixers when mixing the transformer oil with 4 baffles (n = 100 rpm, D = 200 mm)

No.	Mixer type (dimensions, mm)	N, W	τ, sec	Nτ, J	Comparative efficiency with respect to	
					τ	Nτ
1	2	3	4	5	6	7
1	3-blade propeller, d = 75	$3.78 \cdot 10^{-3}$	10.2	2.35	2.12	0.35
2	3-blade propeller, d = 100	$2.29 \cdot 10^{-2}$	4.8	6.67	1.0	1.0
3	3-blade propeller, d = 150	$1.29 \cdot 10^{-1}$	2.0	15.50	0.42	2.34
4	Open turbine, d = 75	$18.98 \cdot 10^{-3}$	8.2	9.32	1.71	1.41

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Continuation of table 2

1	2	3	4	5	6	7
5	Open turbine, *d* = 100	$11.31 \cdot 10^{-2}$	3.4	23.15	0.71	3.51
6	Open turbine, *d* = 150	$6.43 \cdot 10^{-1}$	1.4	56.11	0.29	8.45
7	2-blade mixer, *d* = 100, *h* = 40	$13.73 \cdot 10^{-2}$	8.0	65.82	1.67	9.89
8	2-blade mixer with blades at 45°, *d* = 100, *h* = 20	$4.12 \cdot 10^{-2}$	9.3	22.95	1.94	3.45
9	4-blade mixer, *d* = 100, *h* = 20	$7.65 \cdot 10^{-2}$	6.0	27.57	1.25	5.85
10	6-blade mixer, *d* = 100, *h* = 20	$5.10 \cdot 10^{-2}$	4.1	13.24	0.85	1.98

Obtained test data (Table 1 and 2) revealed the effect of two basic factors on the mixer performance: temperature equalization time (τ) and energy (*N*τ) consumed on fluid mixing. Each of these factors taken separately can not be used to evaluate the mixer work. Together, the latter ones allow a quite complete assessment of the mixing efficiency of each mixer.

Tables 1 and 2 show that the open turbine with a diameter d = 150 mm is the most advantageous to obtain the minimum temperature equalization time in the turbulent region. However, this mixer consumes 9 times more power than a 3-blade propeller with d = 100 mm. Therefore, when comparing the mixer efficiency per unit the parameters of a 3-blade propeller with d = 100 mm were taken.

The results presented in Tables 1 and 2 show that the most effective mixers are a 3-blade propeller and an open turbine mixer. 4- and 6-radial-blade mixers with relatively good mixing quality consume more power. 2-radial-blade mixers provide insufficient mixing quality. 2-blade mixer with blades at an angle of 45° gives poor mixing quality. Baffles also reduce the temperature equalization time by 9-40 %, depending on the mixer type.

The following series of tests was carried out to study the mixer speed effect on the temperature equalization time, when mixing the transformer oil in the unit with 4 baffles (Fig.1) and in a smooth-wall unit (Fig.2).

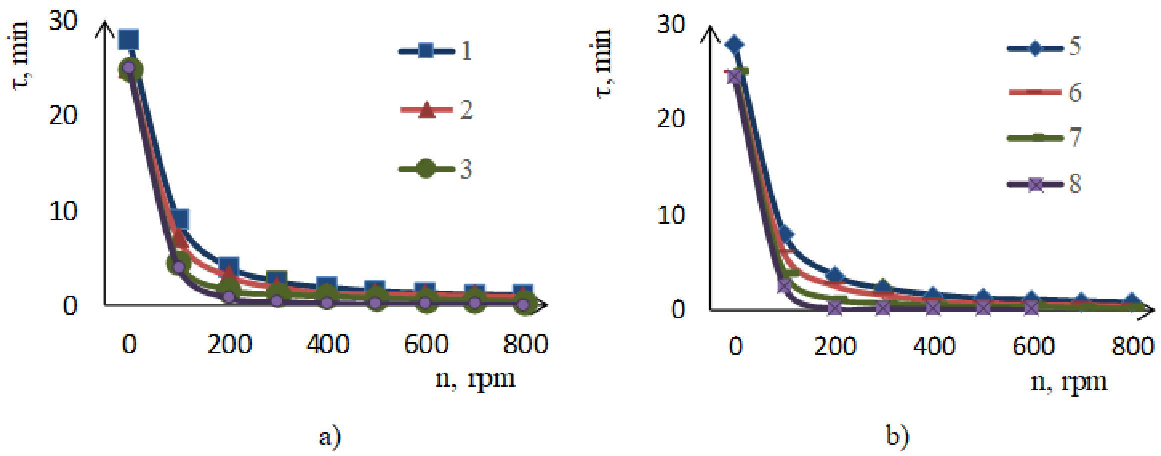

Fig. 1.* Dependence of the temperature equalization time on the mixer speed during transformer oil mixing in the unit with 4 baffles 1 – 3-blade propeller, *d* = 75 mm; 2 – 3-blade propeller, *d* = 100 mm; 3 – 3-blade propeller, *d* = 150 mm; 4 – 4-blade mixer, *d* = 100 mm; 5 – open turbine, *d* = 75 mm; 6 – open turbine, *d* = 100 mm; 7 – open turbine, *d* = 150 mm; 8 – 6-blade mixer, *d* = 100 mm, *h* = 20 mm.

*in all subsequent figures, the mixer types have same indication, unless otherwise stated

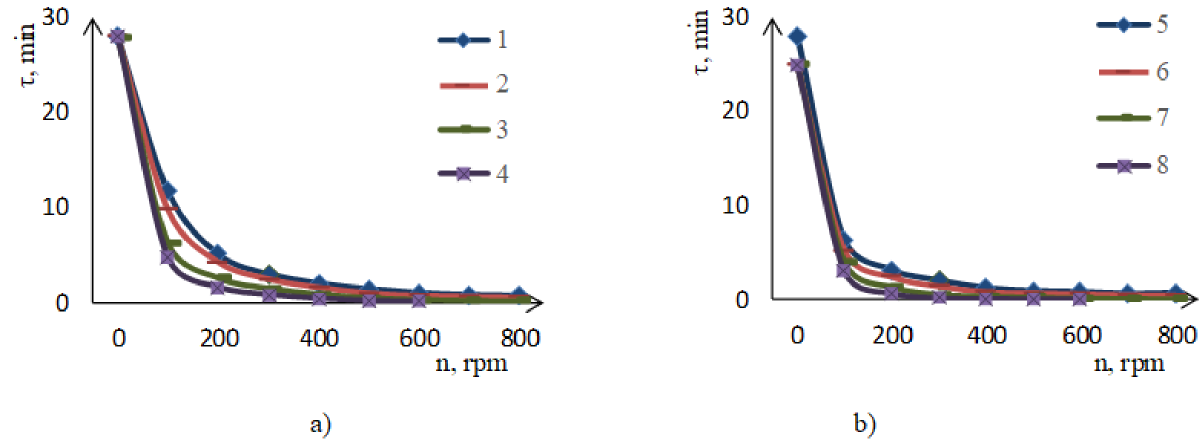

Fig. 2. Dependence of the temperature equalization time on the mixer speed during transformer oil mixing in a smooth-wall unit

In accordance with the test data shown in Figures 1 and 2, the temperature equalization time decreases with the increase in the mixer speed, by one pattern for all types of mixers both in the smooth-wall unit and in the baffled unit. The speed increase above 300 rpm does not affect the mixing process and, therefore, is impractical, since it causes an increase in power consumption. The results of experimental studies presented in Figures 1 and 2 confirm the efficiency of a 3-blade propeller and an open turbine mixer.

Conclusions

Tests determining the effect of the mixer types in smooth-wall and baffled vessels and the mixer speed on the temperature equalization time were carried out in order to increase the mixing efficiency and, as a result, accelerate the processes in transformer oil.

Studies have shown that the most effective mixers used in the tests were a 3-blade propeller with d = 150 mm and an open turbine mixer with d = 150 mm. With the best mixing quality, the time required for the temperature equalizing at the upper and lower points of vessels and the power were minimal. The optimal speed, at which the mixing efficiency increases, is 300 rpm. Further speed increase does not affect the process.

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