A POWER CALCULATION METHOD FOR SELF-SUCKING MIXERS

Sergey Shabratsky
Department of processes and equipment, chemical and petrochemical industries
Sumy State University
2 Rimskiy-Korsakov str., Sumy, Ukraine, 40007
sh-sv@online.ua

Vitaliy Storogenko
Department of processes and equipment, chemical and petrochemical industries
Sumy State University
2 Rimskiy-Korsakov str., Sumy, Ukraine, 40007

Abstract

Most recently, in tank vessels designed for gas-liquid reactions, self-sucking mixers have been used as mixing devices. Great interest is the issue of mixing power determination of mixers designed for processes in gas-liquid systems, which can be an essential component in designing reaction vessels using effective mixing devices of self-sucking type for both liquid and gaseous phases. The efficiency of a mixing device is determined by evaluating the intensity of circulation of the mixed reaction mass, gas content and the ratio between the power consumption to create a gas-liquid medium and the total power consumption for mixing. In spite of a considerable number of publications on the determination of mixing power nowadays, there are no simple methods in existence for determination of mixing power of self-sucking mixers in vessels for gas-liquid reactions. For this reason, the mixing power calculation of self-sucking mixers for gas-liquid processes is an important part in the design of reaction vessels.

Keywords: mixing, self-sucking mixers, power, gas-liquid, reaction vessel, mass transfer, speed of mixer, criterion of power, sulfonation reactions.

DOI: 10.21303/2461-4262.2016.00077

1. Introduction

Reaction vessels with mixing devices are often used in the chemical and petrochemical industry [1, 2] for gas-liquid mass transfer processes in which the mixing has a decisive influence on the process. During the rotation of the mixer in the tank, flows with different speeds and directions are generated, which cause turbulent and circulation currents the intensity of which depends on the constructive features of the mixing device, rotation speed and properties of the mixed fluid. Mixed vessels employed in the industries for aeration and mixing liquids, use standard open or closed turbine and propeller mixers, for which the mixing power N is calculated by a formula obtained from an analysis of variables dimensions for geometrically similar systems [1].

$$N = k_N \rho n^3 d_M^5, \text{ Wt}, \quad (1)$$

where k_N – criterion of power, ρ – density of the stirred medium, kg/m^3, n – rotational speed, s^{-1}, d_M – the diameter of the mixer, m.

The efficiency of a mixing device is determined by evaluating the intensity of circulation of the mixed reaction mass, gas content and the ratio between the power consumption to create a gas-liquid medium and the total power consumption for mixing. The structure of the gas-liquid mixture in the vessel depends on the intensity of mixing, conditions of the gas introduction into the reaction zone and the consumption thereof. The injection of reagent gas into the vessel and the formation of a gas-liquid mixture lead to a decrease in the power required for mixing as a result of a lower density of the mixed medium in the blade rotation area [2, 3].

2. Materials and Methods

Most recently, in tank vessels designed for gas-liquid reactions, self-sucking mixers have been used as mixing devices, which, according to the authors [4–7], are more efficient due to the fact that the carrying out of these processes in proposed reactors does not require any extra capacity in addition to reagent gas feeding lines or an extra stage for exhaust gas purification which would make the process scheme more complicated. This is especially noticeable when using reaction vessels with self-sucking mixers for carrying out sulfonation reactions of aromatic hydrocarbons with sulfur trioxide-air mixtures [4, 5] or in chlorination of hydrocarbons with gaseous chlorine [6, 7], the quality of which reactions affects the yield of the end product.

The new self-sucking mixing devices [8–10] is proposed, in addition to their main function – absorption and distribution of gas reagent – must perform a rational distribution of the energy introduced into the reaction zone in accordance with the specific processes and provide an initial contact of reagents under positive displacement conditions. Such conditions can be created by means of self-sucking mixers by placing within a hollow rotor of ejection membrane which allows both the gas and fluid reagents be sucked simultaneously. Also, the great interest is the issue of mixing power determination of mixers designed for processes in gas-liquid systems, which can be an essential component in designing reaction vessels using effective mixing devices of self-sucking type for both liquid and gaseous phases. For this reason, the mixing power calculation of self-sucking mixers for gas-liquid processes is an important part in the design of reaction vessels.

3. Experimental Procedures

In spite of a considerable number of publications on the determination of mixing power of mixing devices for the use in gas-liquid reaction vessels, nowadays, there are no simple methods in existence for determination of mixing power of self-sucking mixers in vessels for gas-liquid reactions. Therefore, in order to determine the impact of constructive features of self-sucking mixers on a test stand (**Fig. 1** and photo) in a reaction vessel there were conducted laboratory tests with the use of a special coupling (**Fig. 1**) to show the dependence of the mixing power of self-sucking mixers on rotation speed and gas content of the mixed fluid.

To determine power consumption for mixing in a reactor with self-sucking mixers, a spring dynamometer (**Fig. 1**) was used, which consisted of a housing made up of two semi-couplings connected by a spiral spring.

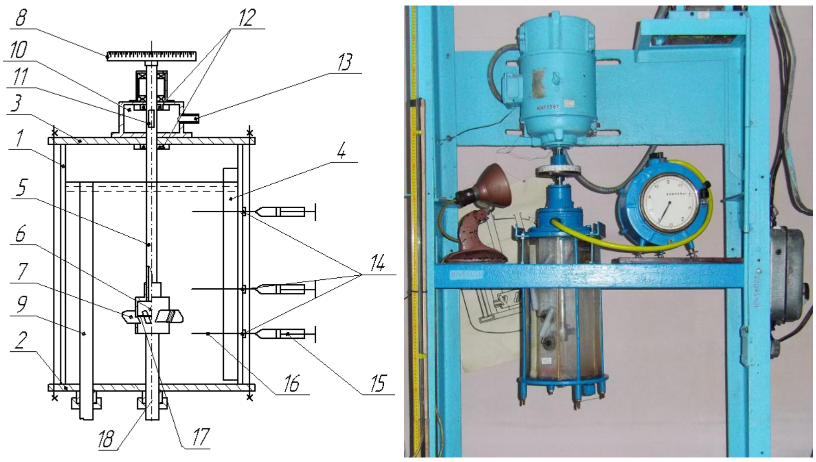


Fig. 1. Test stand and photo of the reactor for studying the mixing power of self-sucking mixers: 1 – vertical cylindrical shell; 2 bottom; 3 cover; 4 baffler; 5 hollow shaft; 6 centrifugal ejection self-sucking mixer; 7 hollow blades; 8 power measurement device; 9 overflow pipe; 10 divider box; 11 hollow shaft inlet; 12 rubber cuffs; 13 nozzle; 14 sampler; 15 syringe; 16 – capillary tube; 17 – ejection membrane; 18 – fluid feed pipe

The construction of the device is shown in **Fig. 2.** It essentially represents a special coupling that connects the electric motor shaft 1 with the end 2 of the mixer shaft. The upper part of the dynamometer casing consists of a horizontal flat ring 4 with a cavity in the form of groove 5 wherein a rope for calibration of spiral spring 3 is located, and bushing 6 which under calibration conditions is loosely fitted on the shaft 1 of the electric drive. In the course of experiments, the coupling 6 was rigidly connected to the shaft 1 using fasteners 11. The lower part of the dynamometer casing is a flat ring 7 with a bushing 8, that, by means of fasteners 12, is rigidly connected to the end 2 of the mixer shaft. The rotational speed of the electric motor is passed on to the mixer shaft by means of a flat steel spring 3, one end of which is attached to the upper half of the coupling, and the second – to the lower half.

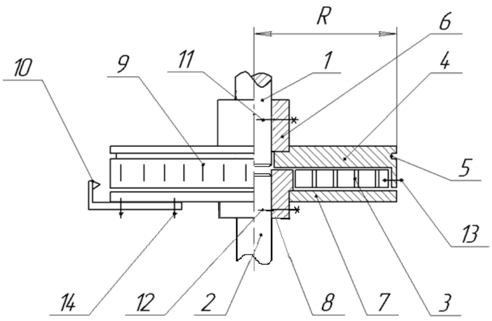


Fig. 2. Device for measuring mixing power of the mixing device: 1 – motor shaft; 2 end of the mixer shaft; 3 spiral spring; 4 upper flat ring; 5 groove; 6 upper bushing; 7 lower flat ring; 8 lower bushing; 9 angle graduation marks; 10 arrow indicator; 11, 12, 13, 14 – fasteners

Depending on the resistance faced by the frontal surface of the blade of self-sucking mixers, the flat spiral spring 3 is twisted at a certain angle, the value of which is read on the outer surface of the upper flat ring 4. The outer surface of the cylindrical part of ring 4 has a graduated scale on it ranging from 0^o to 360^o. For registering the angle of twist, on the lower ring 7 that rotates together with the shaft and the mixer, there is an arrow indicator 14 fixed with fastening elements 14.

The calibration of the dynamometer flat spring consists in balancing the twisting moment of the spring by the action of a given weight. When the shaft 2 of the mixer is locked and the bushing 6 freely rotates on the motor shaft 1, the moment twisting the spiral spring is equal to:

$$M_{кр} = F \cdot R, \text{ N·m}, \tag{2}$$

where F is the force acting on the rope; R is the force lever at the inner diameter of the groove.

Thus, to each value of force F, there corresponds a specific twisting moment value $M_{кр}$, which will determine the twisting angle α of the spring. Consequently, the twisting angle α of the spring which is controlled by the arrow indicator is defined by the relationship

$$M_{кр} = f(\alpha). \tag{3}$$

During the experiments on self-sucking mixers, by means of the optical device, the rotational speed of the mixer and the deflection angle of the arrow indicator were measured and the twisting moment value was determined on a calibration graph (**Fig. 3**). After that, the power consumption for mixing was determined by the formula:

$$N = M_{кр} 2\pi n, \ \text{Wt}, \tag{4}$$

where $M_{кр}$ is the twisting moment, N·m.

4. Results

Experiments to determine the power for mixing a homogeneous liquid were carried out in reaction vessels with a diameter of 0,25–0,4 m fitted with three baffles having a width equal to 0.1 of the vessel diameter and using self-sucking centrifugal-ejection mixers with a diameter of 0,063–0,18 m, with flat hollow blades and different immersion depths of the mixer. First tests were conducted using laboratory scale models of self-sucking mixers, with the hollow shaft plugged with a rubber stopper, thus preventing the centrifugal-ejection mixer from the possibility to suck air in. Thereby, it was possible to carry out preliminary tests to determine the influence of the blade width and the mixer diameter on the mixing power in a homogeneous liquid medium.

During rotation, the resistance of the liquid stirred is taken by the frontal part of the blade, the amount of which is passed on to the shaft and balanced by the twisting of the flat spring at a certain angle. During the test using an electronic stroboscope, the rotational speed of the shaft and the position of the arrow indicator and the angle of its relative turn were registered. At a constant rotational speed of the self-sucking mixer, repeated measurements of the turn angle were conducted by which the amount of power consumption for mixing a homogeneous liquid was determined. An analysis of the data obtained indicates that the mixing power is influenced by parameters such as rotational speed and immersion depth as well as the width and tilt angle of the blade **Fig. 3**.

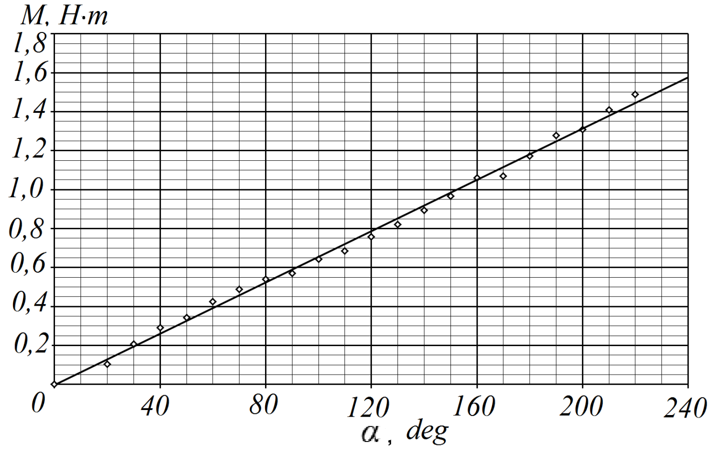
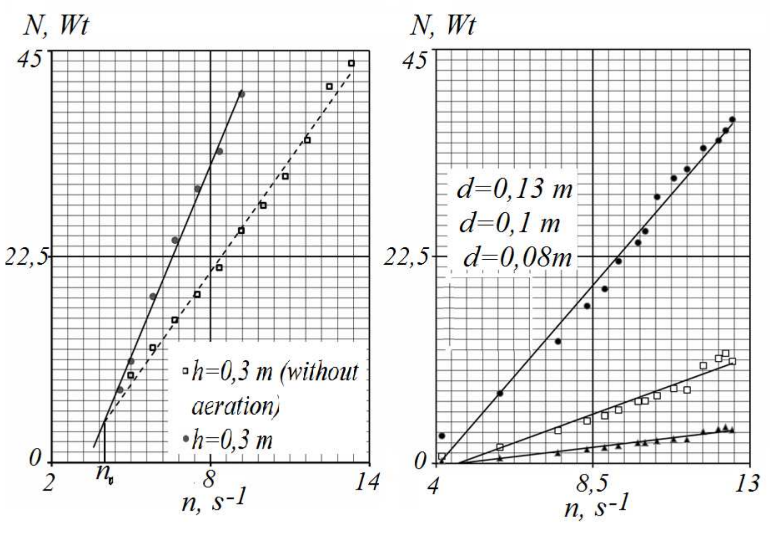


Fig. 3. Calibration graph of the mixing power measurement device

Then, without altering the basic parameters of the vessel or the mixer, the rubber stopper was removed from the hollow mixer shaft, the reactor was filled with water to a height corresponding to the height of liquid in the previous case, the motor was started and the rotational speed of the mixer was increased.

During the rotation of a self-sucking mixer, through the action of radial flow and the flooding of the hollow blade by the fluid stirred, there is formed a vacuum in the cavity of the shaft and the mixer, which promotes the sucking of the air and the dispersion of it into the stirred medium. This happens when the mixer speed exceeds the initial speed at which some air bubbles appear in the stirred medium. A further increase in the mixer rotational speed leads to a growth of the volume of sucked air and an intensification of the stirred medium in the vessel. As a result of intensive mixing of the air bubbles with the fluid in the reactor, the average density of the mixed fluid is reduced, which leads to a reduction of power consumption for mixing compared with the power consumption when a homogeneous fluid is mixed. **Fig. 4, *a*** shows the comparison of the power consumption of a self-sucking mixer with a diameter of 0,13 m at a constant immersion depth when a homogeneous fluid and a gas-liquid mixture are stirred. The solid line represents the power dependence when a homogeneous fluid is mixed while the dashed line reflects the impact of gas content on the mixing power. The meeting point of the two lines corresponds to the initial rotation speed of self-sucking mixer n_0. **Fig. 4, *b*** shows the power dependence of self-sucking mixers with a diameter of 0.08, 0.10, 0,13 m on rotational speed for self-sucking of air.



a *b*

Fig. 4. Dependence of the power of self-sucking mixer on rotation speed and the presence of gas content in the stirred volume in the reaction vessel: *a* – rotation frequency and gas content; *b* – mixer diameter

5. Discussion

An analysis of the results obtained from laboratory tests showed that the power for mixing a gas-liquid mixture by self-sucking mixers is reduced in relation to the quantity of the sucked gas and the average gas content, which is confirmed by the commonly used factor of N_g/N ratio **Fig. 5**.

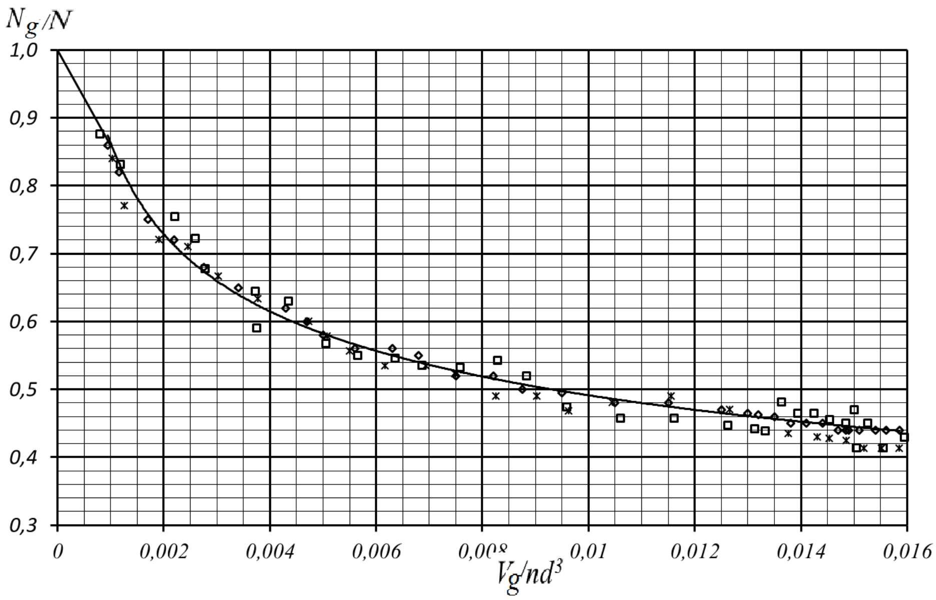


Fig. 5. Dependence N_g/N of the pumping power $\frac{V_g}{n \cdot d_M^3}$ of self-sucking mixers

Processing of the obtained experimental data allowed the authors to deduce the dependence for determining the power consumption of self-sucking mixers on volume capacity in terms of gas.

$$\frac{N_g}{N} = 0{,}32 \cdot \left(\frac{V_g}{nd^3} \right)^{-0{,}08}. \quad (5)$$

6. Conclusions

A comparison of the above studied self-sucking mixers with turbine self-sucking stirrers makes it possible to reproduce the start of a gas-liquid reaction in displacement mode, followed by an intense mixing with the main reaction mass while conducting rapid exothermic reactions under gentle conditions which makes it possible to improve the quality of the end product. The tests were carried out with purpose of determining the power of self-sucking mixers of a similar type that can be useful in calculations of reactors for sulfonation reactions and chlorination of hydrocarbons with gas reagents.

References

[1] Strenk, F. (1975). Stirring machines with agitators. Leningrad: Chemistry, 384.

[2] Braginsky, L. N., Begachev, V. I., Barabash, V. M. (1984). Mixing in liquid media: Physical foundations and engineering methods of calculation. Leningrad: Chemistry, 336.

[3] Sokolov, V. N., Domanski, I. V. (1976). Gas-liquid reactors. Leningrad: Mechanical engineering, 216.

[4] Golubev, A. R., Markov, V. A., Ershov, A. I. (1987). Apparatus for mixing liquid and gas. AS № 1318271 (USSR), 23.

[5] Storozenko, V. Y., Barvin, V. I., Shabratsky, V. I. (1980). A method for producing alkyl aryl or acidic sulfates and device for its implementation. AS № 771089 (USSR), 38.

[6] Shabratsky, V. I. (2008). Experience of introduction of reactors with active hydrodynamic regime. Poltava, 105–107.

[7] Shabratsky, V. I. (1983). Application of capacitive type reactors with suction stirrer chlorination passive organic compounds. Chemreactor. Shymkent, 253–258.

[8] Belkin, D. I. (1998). Chlorination passive hydrocarbons. Dnepropetrovsk, 41–44.

[9] Shabratskyi, V. I., Bielkin, D. I., Barvin, V. I., Shabratsky, S. V. (10.06.2011). Device for mixing fluids. Patent of Ukraine № 60097. Bull. № 11. Available at: http://uapatents.com/6-60097-pristrijj-dlya-peremishuvannya-ridin.html

[10] Shabratsky, S. V., Storozhenko, V. Ya., Bielkin, D. I., Shabratskyi, V. I., Barvin, V. I. (10.01.2013). Device for mixing fluids. Patent of Ukraine № 76528. Bull. № 1. Available at: http://uapatents.com/7-76528-pristrijj-dlya-peremishuvannya-ridin.html

[11] Bielkin, D. I., Storozhenko, V. Ya., Shabratskyi, V. I., Barvin, V. I., Shabratsky, S. V. (10.07.2012). Device for mixing. Patent of Ukraine № 71183. Bull. № 13. Available at: http://uapatents.com/6-71183-pristrijj-dlya-peremishuvannya.html