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GEOMETRIC DISTURBANCES IN MECHANICALLY AGITATED TANKS IN LAMINAR FLOW REGIME

Efraín Mesino- Martínez
Basic Sciences and Engineering Area, Universidad Autónoma de Nayarit Ciudad de la Cultura Amado Nervo México.

Raúl Delgado-Delgado
Basic Sciences and Engineering Area, Universidad Autónoma de Nayarit Ciudad de la Cultura Amado Nervo México.

Miguel Angel Espinoza-Rodríguez
Basic Sciences and Engineering Area, Universidad Autónoma de Nayarit Ciudad de la Cultura Amado Nervo México.

Antonio Hidalgo-Millán
Basic Sciences and Engineering Area, Universidad Autónoma de Nayarit Ciudad de la Cultura Amado Nervo México.

Abstract: In this study, an alternative is presented to improve the mixing performance in a mechanically agitated container in a laminar regime, with two fluids with different rheological behavior. It is proposed to introduce a disturbance system to the flow generated by the impeller. The study is carried out using two different eccentricities as an alternative to improve the laminar mixing operation. Different scenarios were analyzed and two types of agitators were used, a Rushton turbine and a PBT turbine. Using two fluids, Fluid 1 (USP grade pure glycerin, with a dynamic viscosity of 0.9 Pa s) and Fluid 2 (Carbopol 0.05%, CMC 0.8% and polyacrylamide 0.025%). The flow patterns in the tank were visualized using the Colorimetry technique. Mixing times, homogeneity levels and power consumption were studied. As a result, it was shown that the method proposed in this work has a significant improvement in mixing efficiency at low Reynolds numbers in Newtonian fluids. This method can provide a new innovation in agitated systems.

INTRODUCTION

Various alternatives have been proposed to achieve a higher degree of homogeneity, reduce mixing time and achieve low energy consumption in the mixing process. Among which can be found: the use of eccentric agitators, operating simultaneously and independently, demonstrating that the segregated regions are easily destroyed, using asymmetric agitator conditions combined with dynamic disturbances. With two off-center impellers, a strong influence of the geometry conditions on the mixing times was observed, achieving a better homogenization [1], the introduction of objects in a tank agitated by an impeller. Concluding by means of experimental results that the segregated regions of the mixture above and below the impeller can be eliminated, with which the mixing time can be significantly reduced, especially in the case of introducing larger objects. The comparison of this method of spatial mixing with the dependent temporal time, showed that the method has an advantage at low Reynolds numbers [2], applying a change of speed in the impeller periodically in the mixing process, they found that the Segregated zones can be quickly destroyed by imposing a speed change on the impeller, because some well-mixed fluid fractions escape from inside the well-mixed zones, causing unmixed fluid to enter and improving the level of homogeneity inside the impeller. Stirred tank. In turn, the islands formed during mixing can be eliminated with these hydrodynamic speed changes [3], using a new impeller arrangement, based on the use of Rushton turbines, with which experimental studies were carried out with the agitator off-center, finding that this proposed impeller eliminated the segregated zones inside the tank in a laminar regime, reduced the mixing time and reached higher levels of homogeneity in the stirred tank. This study demonstrated that mixing can be improved by using geometric perturbations based on impeller designs that generate higher pressure differentials within the mixing tank [4], varying the agitator rotation speed and direction of rotation. They concluded that the mixing time can be reduced considerably, due to the great instability produced by the change in speed of the impeller. In turn, the induction of chaotic mixing produced by the change in rotation of the agitator generates a rapid increase in the level of homogeneity, obtaining a significant improvement in the mixing process [5].

Other proposed alternatives demonstrated in a computer simulated system that the mixing could be improved if the flow is continuously disturbed, avoiding the formation of segregated regions near the impeller [6]. These results were later confirmed using concentric

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cylinders rotating in both directions for short times [7, 8, 9, 10].

These strategies to improve the mixing process have been the main expectation to carry out this study with geometric disturbances in the mixing process, thus proposing a new alternative that consists of introducing a disturbance system whose main objective is to obtain a higher level of homogeneity. and quality of the final product in the agitated tank, in a shorter mixing time and thus reducing energy consumption.

METHODOLOGY

MIXING SYSTEM

The experimental system used during this work is shown in Figure 1, and is composed of a transparent cylindrical polycarbonate tank with an internal diameter (T) equal to 165 mm and a height of 210 mm, a fluid height (H) equal to to the inside diameter of the tank (T = H). A square jacket containing the same fluid subject to study was used, whose main objective is to avoid significant changes in the refractive index and reduce the optical distortion generated by the curvature of the tank.

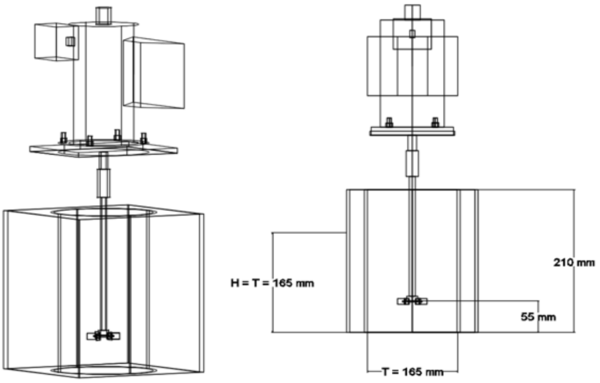

Figure 1. Experimental setup and dimensions of the mixing system.

BASIS FOR GEOMETRIC DISTURBANCE DESIGN

The proposed disturbance system consists of a copper tube with an internal diameter of 16 mm and a length of 200 mm, which was cut crosswise to a height of 173 mm, with a height of immersion in the fluid of 153 mm, thus having a contact area of 76.4 cm2, the measurements were based on the measurements of the agitation tank, said disturbance was placed at an angle of 45° with respect to its horizontal (figure 3.5). This perturbation system was used in two different eccentricities ($\dot{x}$ = 0.25 and $\dot{x}$ = 0.33); $\dot{x} = x/T$, where x = is the distance from the center of the tank to the center of the disturbance (55 mm) and T is the radius of the mixing tank (165 mm).

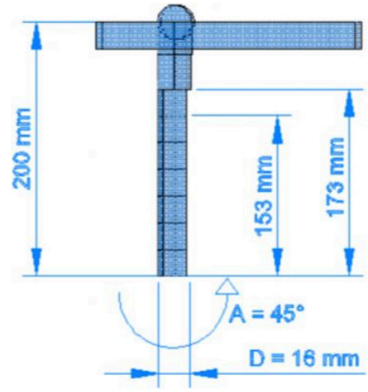

Figure 2. Dimensions and physical diagram of the disturbance system.

DISPLAY METHOD

To investigate the mixing pattern and mixing time, the colorimetry method was used. In it, an acid-base reaction is carried out, which generates color changes in the study fluid by changing its pH. In each of the experiments, photos were taken at constant time intervals, to subsequently analyze the images in order to objectively establish the mixing time. In all the scenarios studied, the operating conditions were the same (60, 120 and 180 rpm), the taking of images was always carried out in the change from blue to yellow hue, because the change in hue is better observed visually.

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MEASUREMENT OF HOMOGENEITY IN THE STIRRED TANK

Once the images were acquired, the following adjustments were applied (Brightness 60%, Contrast 50%, Intensity 50% and Saturation 5%) with Adobe Photoshop CS6® software, to homogenize the intensity of their pixel variations and improve quality from the same. These adjustments are made to obtain a better visualization of the images, each of these were analyzed in detail, due to the dependence between the observer's criteria and his ability to establish the degree of progress of the mixture.

MEASUREMENT OF TORQUE AND ENERGY CONSUMPTION

Torque was measured with a FUTEK® brand torque wrench. The power consumption was determined by measuring the torque with the help of the torque meter placed on the agitator shaft. Three measurements were made and subsequently the data was extracted using the SENSIT Test and Measurement® software, and averaged to obtain the final torque value for each scenario.

The power consumption was determined from the torque value, the power consumed is calculated according to the equation (1).

$$P = 2\pi N\tau \quad (1)$$

Where:

N - Impeller speed *(rev/s)*

τ - couple *(N·m)*

Dividing this value of power consumed by the total volume of fluid in the tank (V), the specific power is obtained, as shown in the equation (2).

$$P = \frac{2\pi N\tau}{V} \quad (2)$$

To calculate the energy consumption for each impeller studied, it was calculated using the equation (3):

$$E = \int_0^t 2\pi N\tau \, dt \quad (3)$$

RESULTS

The results are presented in figures 3, 4, 5 and 6 in terms of the evolution of homogeneity in the mixing process for all the scenarios studied as a function of time. Table 1 describes the configurations used.

Name	Description
Configuration 1	No disturbance at 60 rpm
Configuration 2	No disturbance at 120 rpm
Configuration 3	No disturbance at 180 rpm
Configuration 4	With disturbance at an eccentricity of $\dot{x} = 0.25$ at 60 rpm
Configuration 5	With disturbance at an eccentricity of $\dot{x} = 0.25$ at 120 rpm
Configuration 6	With disturbance at an eccentricity of $\dot{x} = 0.25$ at 180 rpm
Configuration 7	With disturbance at an eccentricity of $\dot{x} = 0.33$ at 60 rpm
Configuration 8	With disturbance at an eccentricity of $\dot{x} = 0.33$ at 120 rpm
Configuration 9	With disturbance at an eccentricity of $\dot{x} = 0.33$ at 120 rpm

Table 1. Description of the configurations used.

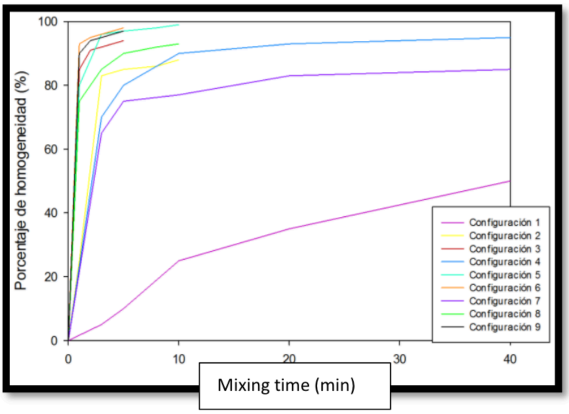

Figure 3. Evolution of homogeneity in the mixing process of fluid 1, with a Rushton turbine at the different configurations studied.

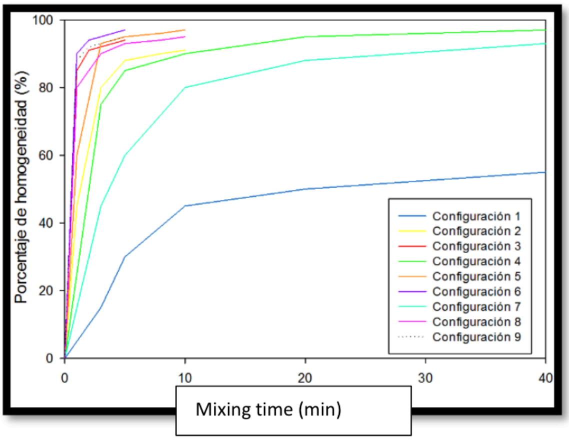

Figure 4. Evolution of homogeneity in the mixing process of fluid 1, with PBT turbine at the different configurations studied.

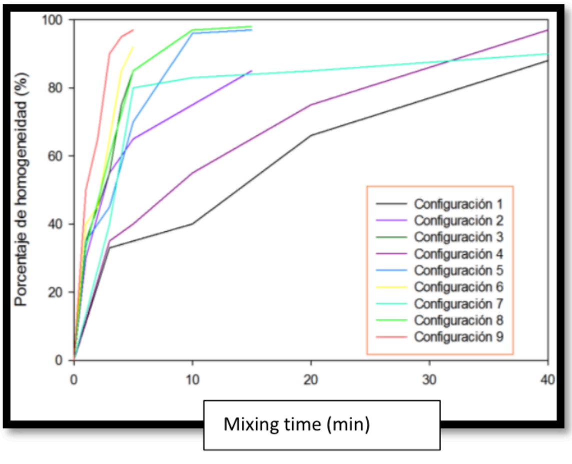

Figure 5. Evolution of homogeneity in the mixing process of fluid 2, with a Rushton turbine at the different configurations studied.

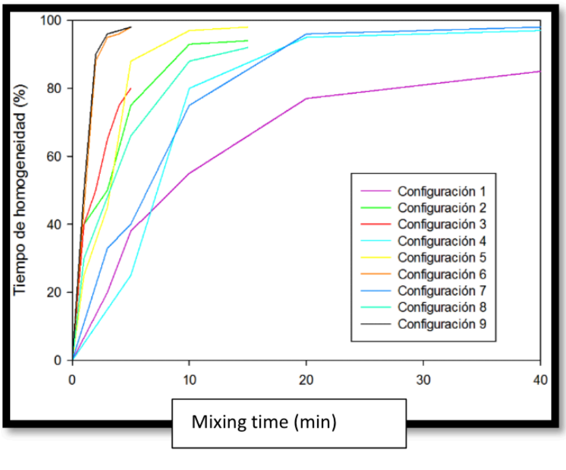

Figure 6. Evolution of homogeneity in the mixing process of fluid 2, with a PBT turbine at the different configurations studied.

From these figures, relevant information can be obtained with the scenarios studied. Among the most important data provided are:

a) By introducing the designed disturbance into a tank mechanically agitated by an impeller, a higher level of homogeneity is achieved in the agitated tank, significantly reducing the mixing time, which agrees with previous studies [2].

b) In the case of the proposed geometric disturbance with an eccentricity of $\dot{x} = 0.25$ at different speeds and with a different agitator, the homogeneity level increases to levels not reached by the other configurations in the same mixing time.

c) This proposed disturbance reaches in both positions, at the three speeds, with the two types of agitators and the two study fluids, the minimum level established as desirable (90%).

Table 2 summarizes the most efficient configurations for each of the studied scenarios, mainly due to the lower energy consumption at 90% homogeneity.

According to this table, for fluid 1, the Rushton turbine is the most suitable for the mixing process at the three different speeds, using the disturbance at an eccentricity of $\dot{x} = 0.25$ for agitation speeds less than 120 rpm and with $\dot{x} = 0.33$ at a speed of 180 rpm. For the case of fluid 2 at three speeds, the use of a PBT turbine is more appropriate, having greater efficiency by introducing the disturbance with an eccentricity of $\dot{x} = 0.25$ and 0.33 at speeds of 60 and 180 respectively, at 120 rpm it is more proper mixing process without any disturbance.

Fluid	Agitator	Speed (rpm)	Disturbance	Time (s)	Torque 10^{-3} (N-m)	Power 10^{-3} (W)	Specific Power (W/m^3)	Energy consumption (KJ/m^3)
1	RUSHTON	60	$\dot{x} = 0.25$	600	2.696	16.941	4.8020	2.8812
1	RUSHTON	120	$\dot{x} = 0.25$	120	0.035	0.445	0.1261	0.0151
1	RUSHTON	180	$\dot{x} = 0.33$	60	2.333	43.980	12.4660	0.7480
2	PBT	60	$\dot{x} = 0.25$	1200	0.372	2.340	0.6633	0.7960
2	PBT	120	Sin	600	0.248	3.117	0.8835	0.5301
2	PBT	180	$\dot{x} = 0.33$	120	1.935	36.476	10.3391	1.2407

Table 2. More efficient arrangements in the mixing process.

CONCLUSIONS

The proposed system is capable of disturbing the flow patterns generated by the impellers studied at the three speeds, having a greater circulation of the fluid, thus reducing the isolated zones within the stirred tank, especially when locating the disturbance at an eccentricity of $\dot{x} = 0.25$ using Newtonian fluids.

The disturbance proposed in this work eliminated the segregated zones inside the tank in a laminar regime, reduced the mixing time and reached higher levels of homogeneity, with lower energy consumption for the batch mixing process.

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