Mixing Flow Characteristics in cylindrical tank

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Abstract. The characterization of the flow from mixing tanks equipped with different impeller models is used for optimizing mixing of working fluids. In this paper is presented a study on flow characteristic of two types of impeller immersed in a tank at different depths and with different rotational speed. Using PIV technique flow distributions for several mixing configurations are obtained. The experiment can be used to determine the still zones in the mixing tank and for the optimization of the mixing parameters.

1. Introduction

Mixing technologies have a major influence on the economic efficiency of process industries. According to several studies, their cost is about half the value of products obtained in this way [1]. Mixing processes play a significant role in proper functioning of processes in many manufacturing industries (chemical, food, pharmaceutical, etc.). Manufacturing processes involving chemical reactions (oxidation of hydrocarbons, e.g.) or biochemical processes such as aerobic or anaerobic digestion, wastewater treatment etc., requires intimate contact between the different components of the mixture.

Mixing is a complex process whose efficiency depends mainly on the flow pattern generated by the rotor. Obtaining a homogeneous concentration in a reactor with a given volume is done by choosing the hydraulic homogenization equipment, judicious choice of the shape and geometric dimensions of the reactor [2]. Mixing requirements vary depending on the problem to be solved. Choosing a suitable rotor for a certain type of mixture is determined primarily by the flow patterns and speed profiles that it is able to generate [3].

Regarding the experimental study of mixing processes, it is difficult to carry out, both due to the problems encountered in developing experimental models that approximate as accurately as possible the industrial installations, and due to the lack of adequate methods for measuring multiphase mixtures.

The improvement of PIV laser techniques in recent decades has made it possible to use them to characterize multiphase flows on an increasingly large scale [4]. Being non-intrusive techniques, they are used in fields where the dynamics of phenomena must be characterized with good accuracy (medicine, aeronautics, natural sciences, etc.).

This work presents the study of fluid flow in two configurations of a mixing experimental setup, extensively described in [5]. Using the PIV technique, the mean velocity fields induced by two types of rotors are obtained, to study the velocities distribution in the liquid volume, focusing on the rotation area of the impeller. The maximum and mean velocities for each studied configuration are presented.
2. Experimental setup and procedure

2.1. Experimental set up

The set up (figure 1) consist in a cylindrical tank (1) with Ø300 mm diameter, filed with tap water up to 330 mm height, in which are immersed two types of impellers (2), driven by a variable speed DC electric motor, provided with a digital speed and torque indicator. A PIV equipment (3), (figure 3) is used for flow characterization. To synchronize the image capture by PIV (CCD camera and Light sheet generator) with a certain position of impeller blade an optical sensor is used (4).

![Figure 1. Experimental set up](image)

The tested mixers are: an impeller with four pitched blades (45° pitch angle) (impeller 1) and an impeller with two flat blades (impeller 2), both with a hub diameter of 20 mm and blade size of 40 mm length and 20 mm width (figure 2.a, figure 2.b).

![Figure 2. Studied impellers](image)

The PIV equipment is schematically presented in figure 3. A laser light source – DualPower TR15-000, which is pulsed Nd:YAG laser of 200 mJ with wavelength of 527 nm and pulse duration of ~150 ns is used. The images are captured with a monochrome CCD camera, FlowSenseEO_4M-32, with resolution of 2072×2072 pixels. The laser source and CCD camera are placed perpendicular to the measurement plane (figure 3). A BNC 575 synchronizes the laser and camera with the optical sensor.

The camera is used in double frame mode with exposure time for frame 1 at 15 µs. The time interval between two laser beams was set between 2000µs to 4000 µs accordingly with operation regime, capturing 200 images at each measurement run.
As tracers, S-HGS particles - silver coated hollow glass spheres of 10 μm in diameter and density of 1.4 g/cm$^3$, are used (figure 3, grey dots from the cylindrical tank).

2.2. Procedure

The working fluid used was tap water under normal pressure and temperature. The two impellers were mounted at a distance of $H_1=120$ mm and $H_2=215$ mm, respectively from the bottom of the tank. The measurements were performed for five rotation speed: 60, 120, 180, 240 and 300 rpm.

To characterize flow in rotor area the measurements were triggered using an optical sensor so that the rotor blade is captured in the same position. By appropriately changing the trigger delay, the rotor blade is captured at following angular position: 0, 10, 20 and 90° (figure 4, a and b).
Dynamic Studio software from Dantec Dynamics was used for configuration, data acquisition, and post-processing. Captured raw images were pre-processed to remove the areas outside of the interest domain as shaded part, free water surface, button and edges of the cylindrical tank (figure 5). Many analysis modules were applied to transform the double frame images in a set of velocity vector fields, from these Average Correlation analysis show more relevant results. In order to remove all the errors resulting from reflections a Range Validation was applied [6].

![Figure 5. Image masking, from left to right: original image, mask, masked image](image)

### 3. Results and discussions

Below are presented in table 1, the points where the raw images were capture.

| Impeller 1 | Height | Rotation speed n (rpm) | Angle (°) |
|-----------|--------|------------------------|-----------|
|           |        |                        | 0 | 10 | 20 | 90 |
| H₁        | 60     | x                      | x | x | x | x |
|           | 120    | x                      | x | x | x |   |
|           | 180    | x                      | x | x | x |   |
|           | 240    | x                      | x | x | x |   |
|           | 300    | x                      | x | x | x |   |
| Impeller 2 | H₁    |                        | 60 | x | x | x | x |
|           | 120    | x                      | x | x | x |   |
|           | 180    | x                      | x | x | x |   |
|           | 240    | x                      | x | x | x |   |
|           | 300    | x                      | x | x | x |   |

**Table 1. Analyised operation points**
In figure 6 is presented one of the studied configurations: impeller with 2 flat blade, mounted a distance of $H_1=120$ mm from the bottom of the tank. The images were captured at $0^\circ$, $10^\circ$, $20^\circ$ and $90^\circ$, at a rotation speed $n = 240$ rpm. The velocity field shows that the fluid is mixed in all the volume of the tank. In the proximity of the blade a vortex evolution is captured at different angular positions.

![Velocity field](image)

**Figure 6.** Velocity field for Impeller 2 at 240 rpm, $H_1$ and at different angular positions.

In figure 7 are shown mean velocity fields for Impeller 1, captured at $0^\circ$ position and at different rotations speed. As it can be seen, there are two still zones in right side of the images and a vortex located under the impeller.
Figure 7. Velocity field for four pitched blade impeller (Impeller 1) at same angular position (0°), H₁ and different rotation speed.
Figure 8. Velocity field for four pitched blade impeller (Impeller 1) at same angular position (0°), \( \text{H}_2 \) and different rotation speed.
In figure 8 impeller functioning in the same conditions as figure 7, except for the distance from the tank bottom, which is $H_2 = 215$ mm is presented. It can be seen a single still area in the right side of the image.

Analysing the velocity fields obtained by image processing, it is observed that the impeller 2 drives the entire mass of liquid regardless of the rotation speed. The mean velocity fields vary between 1.5 mm/s for a rotation speed of 60 rpm and angle 0 and 7.1 mm/s at a rotation speed of 300 rpm and angle 20°. The lowest variation of mean velocity is for the rotation speed of 60 rpm (0.1 mm/s), which means that for this configuration we have the best hydraulic homogenization.

With respect to the pitch blade impeller, it has a blade inclination of 45° and a lower drag coefficient, having a lower liquid movement capacity. This fact is highlighted in figures 7 and 8 by the existence of stagnation areas in the liquid volume. In these zones, the mixing velocities tend toward zero, which shows that this type of impeller is less efficient in this configuration.

4. Conclusions
In this work it was studied dynamic flow in a cylindrical tank in which the fluid is driven by two types of impeller. It has been observed that the impeller with 2 flat blades drives the entire of liquid volume having the lowest variation of mean velocity. The pitch blade type impeller, having a hydrodynamic geometry due to the inclination of the blades, respectively a lower drag coefficient, has a lower capacity highlighted by still zones in the liquid volume. With increasing rotation speed, the fluid is entrained in these area but with significantly lower velocities than the first impeller.

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