EXPERIMENTAL SETUP TO STUDY BIPHASIC MIXTURES

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Abstract: In this paper is presented an experimental setup for the study of biphasic mixtures, adapted for measurements with PIV technique, suitable for the rotor induced flow study in a cylindrical tank used in industrial processes. The design of the setup considers specific aspects of laboratory experimental activities, allowing the visualization of hydrodynamic phenomena from within and being suitable for measurements with modern PIV techniques. Also, the setup is able to replicate as many types of flow. Finally, are presented streamlines and velocity fields induced by the rotor in the mixing tank.

Keywords: Mixing tank, PIV, biphasic mixture

1. Introduction

Over the centuries, researchers have studied the flow of fluids in different ways, this being still an important research field. Flow Visualization is a branch of experimental hydrodynamics that provides important information about flow phenomena. Visualization methods were the first experimental techniques used to understand the phenomena of fluid dynamics. By visualizing the flows, the qualitative aspects of the phenomena are highlighted, with quantitative conclusions being obtained only after some experiments performed with very high accuracy. Experimental viewing techniques are applied for many purposes: to get a first image of the flow of a fluid around a scalar model of a real object, without any calculations, as a source of inspiration for the development of new fluid flow theories, or to verify a new theory or a new model.

However, the flow characterization involves the use of intrusive probes or captors that cause instability in the flow, so that reproduction of phenomena does not remain faithful. Thus, in many situations the fluid flow is disturbed by the experimental technique.

In the most situations encountered in practice in the engineering field, the flows are turbulent. In these conditions, the characteristic parameters are strongly influenced by the presence of vortexes, and solving motion equations for them remains an open problem even with the use of the latest generation solvers. The Particle Image Velocimetry (PIV) measurement technique for turbulent flow characterization provides a reliable solution for validation of CFD data.

The of laser technology in the second half of the 20th century has resulted in increased use of non-intrusive measurement methods. With the introduction of gas lasers, Laser Doppler Velocimetry (LDV), developed by American researchers [1], is one of the most important advances in determining characteristic parameters of the flows. Regarding the LDV technique, significant progress has been made in signal processing techniques and in the optical components used. Also, the LDV method has been expanded to become Doppler Phase Technique, a technique that, in addition of velocity, measures particle or bubble size.

If two decades ago, the main instruments for measuring fluid velocity in a fluid were the Pitot tube and the hot wire anemometer, the main option today is the optical instrumentation. Particle Image Velocimetry (PIV) or Laser Doppler Velocimetry (LDV), are being used on a wider scale. Due to the development of the CCD and CMOS captors and the diminishing of their size, the measuring techniques (Particle Image Velocimetry, Tomography, Particle Tracking Velocimetry, Holography, etc.) have become very common in the field of Fluid Mechanics. PIV measurement techniques a suitable for a broad spectrum of velocity fields, in two and three dimensions, with maximum acquisition frequencies being suited to solving phenomena encountered in practical applications on an increasingly large scale. With these techniques velocity fields, concentration, temperature,
turbulence, particle size can be determined, because by using the data processing software other statistical quantities derived from these measurable quantities can be determined.

PIV is often used in areas where thousands of vectors have to be measured simultaneously over the entire area or volume of the flow. Being a non-intrusive method, together with Laser Doppler Velocimetry LDV technique are used when fluid flow does not have to be influenced by external factors: aeronautics, biomedical, combustion, natural sciences, etc. These methods are also often used to validate CFD models.

2. Generalities on two-phase flow study

Certain industrial applications require knowledge of the simultaneity of the flow characteristic phases. For the complete characterization of these flows, it is necessary to determine the instantaneous velocity fields of the two phases and to process the experimental data obtained using specific processing and post processing software.

Flow induced by rotor in mixing/homogenization tanks is one of the areas where the study of multiphase flow is made by optical methods. Mixing represents hydrodynamic operation which aimed homogenization (reduction of concentration or temperature gradients) within the volume to be mixed until a uniform distribution of constituent materials or temperature uniformity. Physical or chemical processes are all the more complete, as the substances involved are in a homogeneous mixture. Mixing processes are used to accelerate chemical reactions, homogenization of multiphase fluids, dissolving, acceleration of some physical processes, improving thermal transfer, etc. To achieve efficient mixing, it is necessary to obtain high velocity gradients at all points of the fluid, which results

- producing velocity with different sizes and directions, in the mixer vicinity (local mixing); if possible, creating local turbulence diffusion
- relatively slow moving of the entire volume of material, so that, periodically, all the quantity of mixture from mixing tank passes through regions where the turbulence is more intense.

Mixing efficiency is influenced by the turbulence degree and movement velocity, estimated by required time to pass for the entire quantity of material to pass through a given area (for example, the area described by the blades of the mixer). Mixing can be seen as:
- main process operation: for the homogenization of multiphase fluids to obtain solutions, suspensions, emulsions;
- auxiliary operation: to increase the heat transfer and/or substance transfer, or accelerating chemical or biochemical reactions.

As regards the experimental study of mixing processes, this is difficult due to problems encountered to making experimental models which must approximate as accurately as possible industrial installations. Another issue is represented by lack of adequate measurement methods for non-transparent multiphase mixtures. Initially the research focused on the study of mixing processes from a chemical point of view. However, these techniques provide no information about flow pattern, phase distribution and turbulence parameters (kinetic energy, effort, etc.

Up to now, punctual measurements were mainly limited to the axial particle concentration profile at relatively low concentrations using electrical methods (intrusive conductivity, impedance of the analysed samples) or electromagnetic (X-ray tomography or nuclear magnetic resonance). However, these methods, provide limited information cannot be used to characterize concentrated suspensions or measuring three-dimensional distributions [2].

Mixing is a complex process whose efficiency depends mainly by the flow pattern generated by the rotor. Mixing requirements vary according to the problem to be solved. Therefore, selecting a suitable rotor for a specific type of mixture is determined primarily by the flow patterns and the velocity profiles that it is able to generate [3].

Issues related to the study of blending processes are approached both within the university centres, as well as in the research and design centres of the equipment manufacturers. Regarding the constructive optimization of mixers, the dynamics of research and design activity, boosted by the advancement of information technology has led to development of new mixer configurations,
according to the requirements of a growing market. At international level there are prestigious firms, specialized in mixing equipment: STELZER Rührtechnik International and EKATO Group from Germany, Dynamix Inc. from Canada, CHEMINEER and SPX FLOW from SUA, etc.

3. PIV application in mixing tanks

Recent advances in optical measurement techniques, such as PIV technology, offer great advantages in measuring flow parameters, such as high precision, non-intrusiveness, high spatial resolution, etc. PIV measurement can be used for:
- validation of CFD predictions [4]
- optimizing mixing tank design by selecting the tank geometry but also selecting the type, size, placement location and rotation speed of the rotors
- optimal positioning of the tank inlet in batch or continuous regime.

The investigations carried out [5] on the flow from the mixing tanks, both experimental and numerical, highlighted the following aspects:
- high complexity and three-dimensional nature of viscous flows in mixing tanks
- the need to define global measurement techniques to investigate and validate CFD code predictions of these flows
- for similar flows, most of the techniques previously used in the experimental investigation were either intrusive (Pitot tubes, thermal probes), or punctual (LDA) or qualitative (flow visualization techniques) and cannot provide the data required to fully characterize the mixing phenomenon

3.1 Characterization of flow in mixing tanks - case study

Further is an example of flow characterization in mixing tanks [6]. The tank used is transparent, cylindrical and contains three Rushton rotors, each with six rectangular radial blades, placed equidistant along the height of the vessel. The mixing tank is shown in Figure 1, and the testing was done under the following conditions:
- mixing was performed at two speed, 175 rpm and 575 rpm, corresponding to Reynolds numbers 38 and 124
- the signal from an encoder integrated in the mixing system shaft was used to synchronize the PIV acquisition phase
- a programmable delay time generator integrated into the processor synchronization module gave the ability to change relative acquisition time within one blade passage cycle
- within this cycle, for each speed two stages were investigated \( \theta = 0^\circ \), respectively \( \theta = 30^\circ \), where \( \theta = 0^\circ \) corresponds to the case when the blade is parallel to the laser plane.

Fig. 1. Flow characterization in mixing tanks [6];
Data processing was done by cross correlation of the double frame images and then validation of raw vector maps using peak and moving average. The resulting velocity vector maps are averaged to obtained a single vector map that corresponds to one measurement.

4 Design and building of the experimental setup

An experimental setup to study the flow induced by rotors in cylindrical tanks such as those used in the chemical, food, pharmaceutical, energy, was designed and developed. The system designed has taken into account constructive aspects specific to conducting experimental laboratory activities. Thus, to allow a good view of hydrodynamic phenomena from the inside, tank is made of transparent Plexiglas. Also, to reproduce as many types of flow typical of the industrial processes, setup allow changing the rotor mounting height or operating parameters (height and diameter of the liquid column, rotor speed, blade shape and pitch angle etc.).

The experimental setup consists of cylindrical tank with diameter \( \phi 300 \) mm, height \( H = 500 \) mm, wall thickness = 5 mm, provided with square covers and outflow valve Figure 2. A mixing system, consisting of a 10mm diameter shaft on which they can be mounted rotors of different types and sizes, ensures liquid flow into the setup. The mixing system is driven by a variable speed DC electric motor in the range 15 ÷ 2000 rpm, provided with a digital speed and torque indicator and fixed on tank cover.

In order to minimize optical distortions caused by curvature of cylindrical tanks, the cylindrical tank was introduced in a transparent Plexiglas rectangular tank (wall thickness 15 mm) (Figure 3). The material has been chosen so that the optical distortion is minor and can be corrected in the post image processing stage. Figure 3 shows the experimental setup for study dynamics in mixing tanks.

![Fig. 2. Cylindrical tank](image1.png)  ![Fig. 3. Experimental setup](image2.png)

5. PIV arrangement and Calibration process

5.1 The custom target

PIV image calibration is done using a custom target with very precise features that allows computation of the transfer function between image output of the camera and reference system of the measurement area. The laser sheet and the camera are focused on the target plane, which will become measurement plane (the target is removed during measurements) (Figure 4b). The target
is placed in the symmetry axis of the mixing tank. The calibration target was dimensioned to fit in the diametral section of the tank (Figure 4a).

![Custom target in the mixing tank](image)

**Fig. 4 a.** The custom target in the mixing tank.

Fig. 4 b. PIV setup

The distance between target marks was chosen so the conditions (1) and (2) to be respected.

\[
\sqrt{\frac{A}{N_{\text{max}}}} \leq d \leq \sqrt{\frac{A}{N_{\text{min}}}},
\]

(1)

where \(A\) is the measurement area, \(N_{\text{max}} = 1600\) and \(N_{\text{min}} = 100\) represent the maximum and minimum recommended number of marks \([7]\).

The superior limit of 1600 assure a good separation of the marks on the output image. For example, for a 1600 marks target and CCD sensor with a resolution of 1.3k × 1.3k pixels, the smallest mark is about 27 pixels in diameter.

Another condition \([7]\) is to have at least 5 marks on each direction of the target, which can is described by:

\[
d \leq \frac{W}{5}; \quad d \leq \frac{H}{5},
\]

(2)

where \(W\) is width and \(H\) height of the target.

To have a Zero mark in the target centre, the computations usually aim towards an odd number of marks per direction. Once the distance between marks is chosen, the mark diameters are chose using the following rules \([7-9]\):

Zero mark:

\[
\phi_{\text{Zero}} \leq d / 2;
\]

(3)

Axis marks:

\[
\phi_{\text{Axis}} \leq d / 4;
\]

(4)
Main marks: \[ \phi_{\text{main}} \leq d/3. \] \hspace{1cm} (5)

The resulting target has \( d = 10 \text{ mm} \), \( \phi_{\text{Zero}} = 4 \text{ mm} \), \( \phi_{\text{Axis}} = 2 \text{ mm} \), \( \phi_{\text{main}} = 3 \text{ mm} \), \( N = 1053 \) markers, covering an area of 400×280 mm.

5.2 PIV measurements

The experimental setup, designed for PIV measurements, is composed by a parallelepipedal tank filled with water, in which the cylindrical mixing tank is inserted (Figure. 4). The material used for the tank construction is Plexiglas® 0A000 XT. It has a refractive index of 1.49 for a wavelength of 527 nm, close to the water refraction index of 1.33 at same wavelength. The transmittance (transmissibility index) of the material is 92%. In this way, the optical distortion is mitigated before acquisition. Further correction is done in post-processing, using the transfer function determined on image calibration.

The light source consist on a DualPower TR 15-1000 laser, which is a pulsed Nd:YAG laser of 30 mJ with the wavelength of 527 nm and pulse duration of ~150 ns.

The camera, placed perpendicular to the measurement plane respectively to the laser sheet (Figure 4b), is a FlowSenseEO_4M-32, a monochrome CCD camera with resolution of 2072×2072 pixels. The camera is used in double frame mode with exposure time for frame 1 at 15 \( \mu \text{s} \).

As tracers, S-HGS particles - silver coated hollow glass spheres of 10 \( \mu \text{m} \) in diameter and density of 1.4 g/cm³, are used. The particles are chosen to respect the flow but also to assure a good SNR (signal to noise ratio) of the image, a clear peak in cross-correlation map and a uniform distribution of the tracers. DynamicStudio software from Dantec Dynamics was used for configuration, data acquisition, and post-processing.

Measurements were run for two rotating speeds, of 60 rpm and 120 rpm, with an acquisition rate of 4 and, respectively, 8 (double) frames per second.
Captured raw images were pre-processed to remove the areas outside of the study area and then Adaptive PIV analysis module was applied to transform the double frame images in a set of velocity vector fields. A local validation of the velocity vectors is done by DynamicStudio, considering an axial symmetric flow (Figure 5). Vector Statistics module was used to calculate the mean velocity vector from the data set, at each point from the right side vector field (Figure 6). A streamline representation of the vector field is shown in Figure 7.

![Fig. 7. Streamlines corresponding to rotating speed of 60 rpm (a) and 120 rpm (b)](image)

The database obtained can be utilized to solve problems specific to mixing phenomena: simultaneity and phase interaction [6], shape coefficient of the phases, the degree of homogenization etc.

6. Conclusions

An experimental setup was design and build for the study of the induced flows in cylindrical mixing tanks. In order to be able to reproduce many types of industrial processes, the setup allows adjustment of the rotor height, rotating speed and liquid column. Using the PIV technique, mean velocity fields and associated streamlines were determined for two mixing rotating speeds. The flow in the mixing tank can be observed as well near the rotor blade, as also in the all study area of the tank. The experiment can be used for identification of still zones in the mixing process and for the optimization of the mixing parameters (tank shape, rotor speed and mounting height, blade shape and pitch angle etc.). Future works will be performed to study these parameters.

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References


