

PIV study of flow field in Rushton turbine stirred vessel influenced by spatial resolution

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Abstract: - The article describes measurement of flow profiles in the mixed vessel with Rushton turbine. Measurements were made close to the outlet from the turbine using Particle Image Velocimetry (PIV) method with several degrees of spatial resolution. Velocity profiles reported the influence of spatial resolution on the character of vortices representation. Some comparisons of different PIV analysis processes were made and described in the article.

Key-Words: - mixing process, - PIV measurement, - spatial resolution

1 Introduction

Mixing process is used in several areas of industry. A huge amount of mass is mixed in vessels stirred by an impeller. Large agitated tanks with impellers are used in food industry, pharmacy, and also in mining industry, waste water treatment etc. The global trend in process optimization involves new technologies providing higher quality products with lower energy demands. Trend is to develop more efficient mixing equipment. The optimization of stirred vessel and impeller design is done with help of Computational Fluid Dynamics simulations. The importance of these simulations validation was in recent past overlooked. Today, we are returning again to verification and the value of experimental validation is increasing.

Experimental verification of numerical simulations can be done through HW Anemometry, CT and LDA methods. These methods are either a contact, which does not fully respect the flow behavior and influences the current measurement probe. The LDA method is then offered as a suitable non-contact alternative.

Measurement output should be, as with numerical methods, Specific kinetic energy of liquid (SKE)

flow or turbulent kinetic energy (TKE). In the case of TKE determination, three components of velocity u , v and w have to be obtained. The way to obtain the required data is to deploy 3 component measurement systems, whether LDA. However, the disadvantage of the LDA method is low resolution. This is basically a point method where the probe size is up to 1.5mm. [1,2]

In the stream behind the stirrer, there are mainly macro-instabilities, which have been frequently investigated in the past. At present, there is a predominance of minor turbulence structures that have a more influential effect on TKE determination. The PIV method is a method that offers a higher resolution and at the same time does not lose sight of flow behavior in the monitored area. The PIV method also allows for a 3-component arrangement, and then we talk about a stereo PIV or a PIV volumetric. However, the two methods are very costly to fit. For standard research to optimize the mixing process, the 2D PIV method is still sufficient. A possible simplification is partly isotropic flow, where one of the components of speed comes from the other two components.

The resolution of the PIV method is then dependent on the used optical components, especially the

magnification optical system, the camera measuring distance, the associated size of the scan area and, last but not least, the chip size of the camera, but also the evaluation methods. This is mainly about determining IA areas and appropriate overlap. The authors Unadkat (2011) are solving problem of identification micro-structures applying reduced IA sizes to 16x16px. We chose here the path of changing magnification by zooming the measured area and compare the results as velocity profile scaled to central point.

In this article, we observed the effect of the system's approach and approach to detecting smaller vortex structures that already affect the above-mentioned macro-structures.

2 Experimental Methods

2.1 Stirred Vessel Setup

Model of the stirred vessel was made with the cylindrical tank $D = 400$ mm and height $H=D$, position $C = 1/4H$.

Standard Rushton turbine impeller was fitted on controlled electric motor, so we were able to set requested rounds of the impeller from 300 to 700 round per minute. Dimensions of the impeller were as follows: $D_1 = 133$ mm, $w = 25$ mm, $l = 33$ mm and $t = 2$ mm. The vessel was set with four baffles of width $B/D=1/10$, so was $B = 40$ mm fixed evenly around circumference of the vessel. The height of the liquid level was covered.

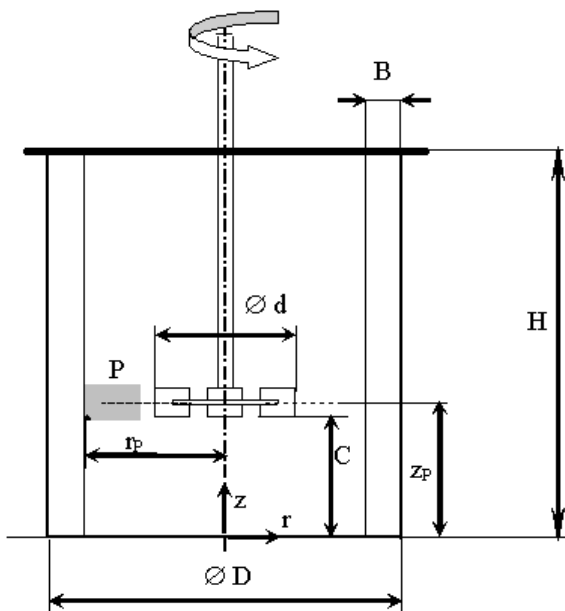


Fig. 1. Geometry of stirred vessel.

There was used degassed water as a working liquid (density $\rho = 1000$ kg.m³, dynamic viscosity $\mu = 1$ mPa.s).

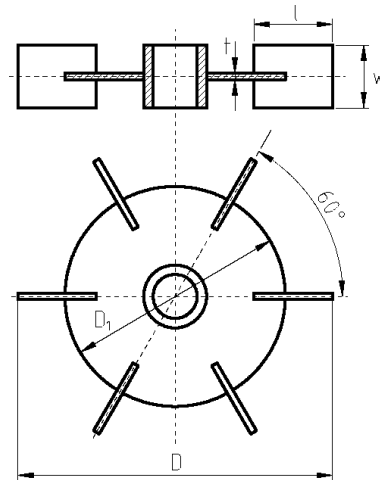


Fig. 2. Sketch of Rushton turbine impeller.

2.2 Time Resolved PIV method

The measurement were made with the Time Resolved PIV system from Dantec Dynamics. System consists of high speed pulse laser Litron LDY 300 with the energy of each pulse 15mJ on 1000 Hz. The scene was captured with the Nanospeed camera 9020 synchronized to the laser on 1000 double-images per second with the resolution 1280x800 pixels. To eliminate the image distortion caused by the cylindrical vessel a rectangular transparent housing was built around the vessel, the space between the vessel and housing was filled with the same liquid. The camera was mounted to a 3axes traverse system, controlled from a software. Positioning of the camera was very precise, accuracy of the position 0,1mm.

Main goal of that project was to compare result of the flow recorded and analyzed with several spatial resolutions. Camera was all the time fitted with the same lens, different resolutions were obtained traversing the camera closer or further from the laser sheet. Center pixel of the camera was always focused to the same spot. The sketch of the captured images is on Fig. 3.

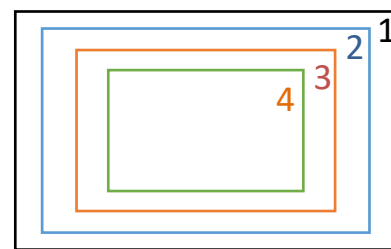


Fig. 3. Full fields of view of the camera on different resolutions 1 -4.

Basic images with the full fields of view were cropped to get images with the same absolute size (same field of view) 25.6mm x 16mm. That size corresponds to the image magnitude $M=1$, in fact it corresponds to the size of the camera chip. Maximal spatial resolution is recorded in the Resolution 4, with the full chip covering the area of interest. Following table defines the resolution degrees on the area of interest 25,6mm x 16mm.

Resolution	Number of pixels	Number of vectors	Size of vector cell
Res 1	640 x 480	20 x 13	1.28 mm
Res 2	748 x 468	24 x 15	1.07 mm
Res 3	940 x 588	30 x 19	0.85 mm
Res 4	1280 x 800	40 x 25	0.64 mm

Table 1. Spatial resolutions definition

Fields of view were set to get overlap in Res 1 and Res 4, so interrogation areas of Res 4 splits each interrogation area in Res 1 into four. That set up allowed us to compare the recorded spatial resolutions and in second step also different correlation analysis.

2.3 Data processing methods

Each regime of the stirring process was measured with the Time Resolved PIV system for 8s with the frequency 1000 Hz. PIV double images were correlated with cross correlation method included in Dantec Dynamic software. Interrogation areas for the cross correlation was set to 32 x 32 pixels for each resolution. Absolute size of the interrogation areas (size of vector cell) is contained in the Table 1. Two validation methods were used to eliminate wrong vectors from raw vector map. In the first step the Range validation method was used. All vectors with the size larger than 3m/s were eliminated. Second validation method was based on the moving average filter. Vector which does not correspond to its neighborhood was eliminated and replaced with the average value. Each dataset consists of 8000 of validated vector maps. Statistical analysis was used to calculate the average vector map from 8000 validated maps.

To compare flow field of each regime in all degrees of resolution and also to compare results with other author the vector profiles were obtained. Flow profiles were calculated for radial (U) and axial (V) components of the flow in the distance of 1.2xR, 1.3xR, 1.4xR, where R is the radius of the impeller (R = 66.5mm).

In the second step the different cross correlation parameters were compared on same data set. Data recorded with Res 4 were calculated with the size of interrogation area 32 x 32 pixels and also with the size 64 x 64 pixels. That data were compared to the corresponding area size from Res 1.

3 Results and Discussion

Results published in that article compare the flow field only from the measurement in the water, for impeller rounds 300RPM. PIV data were analyzed with the same procedure described in the chapter 2. First vector map represents the average vector field of the flow on the outlet from the impeller. Vector map size is 25.6mm x 16mm.

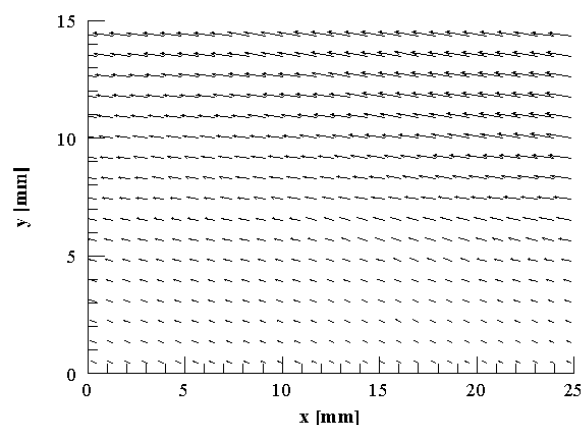


Fig. 4. Average flow field on the outlet from the impeller

Mean velocity flow field does not contain any vortices, it is a smooth flow from the impeller, in the lower part of the flow field is a significant suction effect of the water from the lower part of the vessel. Maximum speed close to the impeller (2mm behind the right edge of the vector map) reaches 1.8m/s.

Following vector map represents one immediate validated vector map from the dataset. That map contains some inaccurate vector, but sufficiently represents the immediate state of the flow.

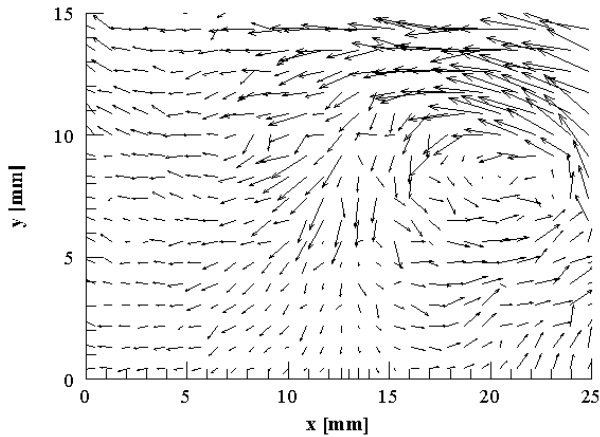


Fig. 5. Immediate state of the flow field on validated vector map

The immediate state of the flow on Fig. 5. shows the vortex moving from the impeller across the area of interest. Vortex passage is periodical, it depends on the number of impeller blades and rounds. Frequency analysis of the flow characteristic is not the theme of that article. Statistical analysis of that immediate states averages the vortices into the shape of the flow field shown on Fig. 4. As known for the PIV methods, representing of vortex structures depends strongly on spatial resolution, so different resolutions evaluate the shape of vortices differently. That phenomenon could also influence the shape of average flow profiles.

As mentioned before flow profiles of radial velocities were calculated for several distances from the impeller axe. These profiles were calculated for each of four spatial resolutions. Series of flow profiles are presented on the series of Fig. 6., 7., and 8.

Velocity profiles in the distance 1,2R

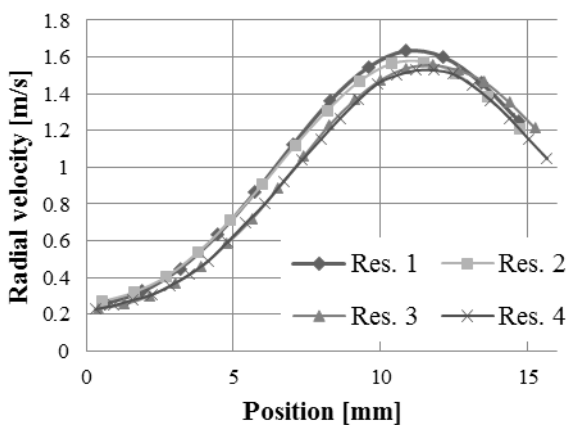


Fig. 6. Radial flow profiles in the distance 1.2R

Velocity profiles in the distance 1,3R

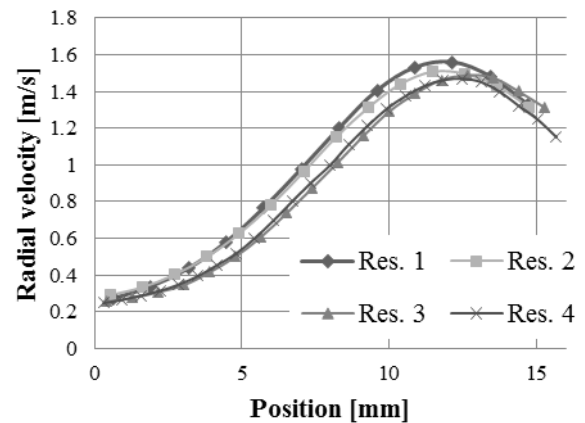


Fig. 7. Radial flow profiles in the distance 1.3R

Velocity profiles in the distance 1,4R

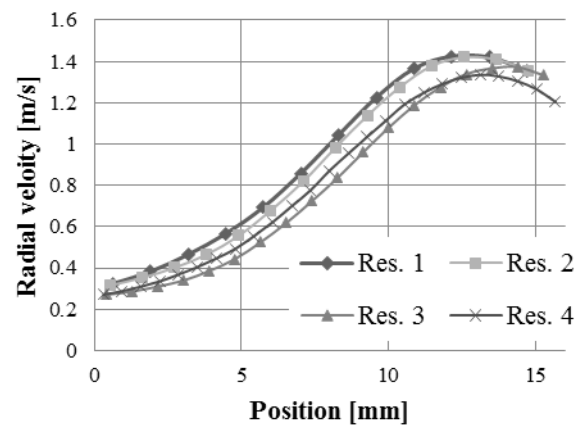


Fig. 8. Radial flow profiles in the distance 1.4R

All profiles from several distances document dependence of the shape and especially maximal velocities on the degree of spatial resolution. Rough resolutions as Res 1 reach on all distances significantly higher velocities than finer resolution Res 4. These results were visible also on other flow regimes as different liquids and rounds of the impeller. Reason for that decrease of maximal velocities lies in the representation of running flow vortices described on Fig. 5. Because the interrogation areas of Res 1 is twice as large as on Res 4, the velocity gradient in the vortex are not evaluated as precisely as on finer resolutions and that cause the averaging of the vectors in the vortex. Running vortices are not represented in the statistical calculation of the mean velocity field as sharply and the maximal velocities are not reduced as much as in the Res4.

To eliminate the influence of wrong data, change of conditions and stirred conditions, we proceed with the correlation analysis of the data recorded on Res 4 with larger interrogation area. Image data were correlated with interrogation area 64 x 64 pixels. This interrogation area corresponds in absolute dimensions to the area of 32 x 32 pixels recorded on Res 1 (1.28mm). Radial velocity profiles were compared on Fig. 9 to Fig. 12. Velocity profiles in distances 1.2R and 1.4R are followed by standard deviations.

Velocity profiles in the distance 1,2R

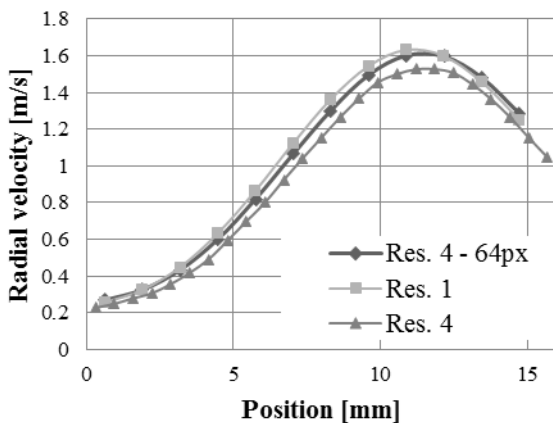


Fig. 9. Radial flow profiles in the distance 1.2R

Standard deviation in distance 1.2R

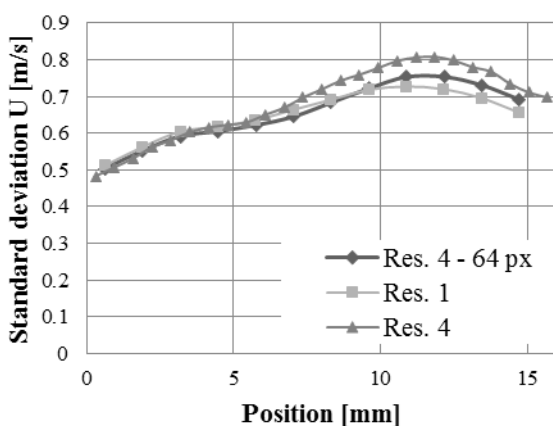


Fig. 10. Standard deviations in the distance 1.2R

Velocity profiles in the distance 1,4R

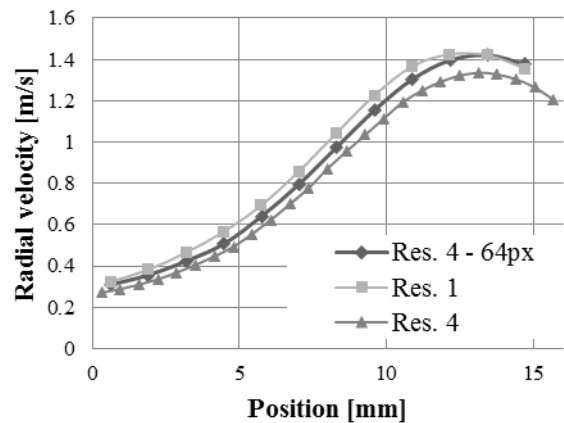


Fig. 11. Radial flow profiles in the distance 1.4R

Standard deviation in distance 1.4R

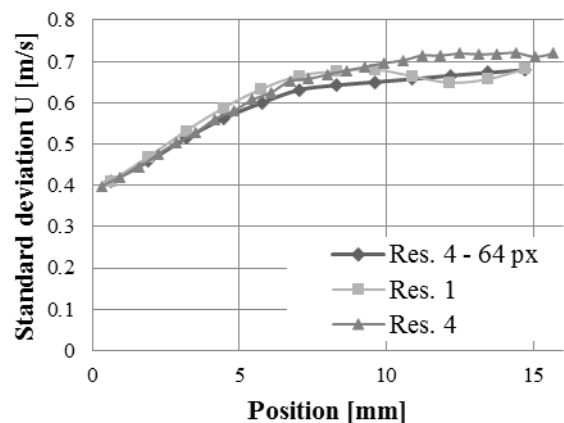


Fig. 12. Standard deviations profiles in the distance 1.4R

As seen on Fig. 9. And Fig 11. The profiles of radial velocity on both distances differ similarly on both distances from the impeller axe. Profiles on Res 1 reach higher maximal velocities, what was discussed before. Analysis for interrogation area 64 x 64 pixels were made also for Res 4, that velocity profile corresponds to the velocity profile of measurement on Res 1, so the data and the flow regime proved to be recorded correctly. Figures 10. and 12. show standard deviations of statistically evaluated velocities in profiles. Standard deviation in finer resolution Res 4 reach higher values, standard deviation on lower resolution Res 1 and (same absolute size) larger correlated Res 4 on interrogation

area 64x64 pixels. Higher values of standard deviation in finer Res 4 are caused by sharper interpretation of vortex structures running across the area of interest. And obviously that sharper caught vortexes with expressible borders and shapes decrease the mean velocities of the flow.

4 Conclusion

Mixing process is currently under research using different types of methods and analysis. PIV method gives perfect opportunity to discover vortex structures contained in the flow behind the mixing impeller. Parameters of mixing process, losses, dissipation coefficient, effectivity and many others can be obtained from these PIV results. This study proved the ability of PIV system to get data suitable for that type of analysis, but also revealed details of measurement procedures which must be taken under consideration.

The flow behind the impeller has turbulent pulsating characteristic. When statistical analysis of the data is made, mean velocity flow field and flow profiles are influenced by these vortexes. Study proved the dependence of the mean flow field, respectively mean velocity profiles on the degree of spatial resolution of recorded PIV data. Finer resolution of images causes sharper vortex structures, higher standard deviations and from that effected decreased maximal velocities in the flow profile. That dependence was proved in different flow regimes (rounds of the impeller) and also in different liquids – water, ethylenglycol at different concentration.

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