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An Effect of Fractal Baffles and Impellers with Double Stage 4-Blade Rushton Turbine to Fluid Flow Behaviour in Stirred Tank

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Abstract. The stirred tank is widely used in many industries to obtain the desired type of fluid mixing. In the context of mixing process, two different fluids and have a different properties will mix in a single equipment to produce another fluid with a new property. In this research, a new approach of stirred tank which is containing a new design of baffles and impellers was proposed for fluid mixing. The new design of baffles and impellers that proposed here are used a fractal pattern for both parts in the stirred tank. Implementing a fractal pattern for baffles and impellers in stirred tank believe will influence the flow characteristic inside the stirred tank, hence will improve a mixing performance. In order to investigate the kinds of flow properties, a Particle Image Velocimetry (PIV) technique with 1 µm seeding particle was used. Four configurations were tested which are normal baffles and normal impellers, normal baffles and fractal impellers, fractal baffles and normal impellers, and the last configuration is fractal baffles and fractal impellers. In this study, dual Rushton impellers with 4 blades were used with the configurations mentioned. The result shows the significant flow field capture by PIV measurement on each configuration. By using fractal impeller some vortex are shown in the tank and high velocity vector on flow field compare with normal impeller while normal baffles gives high velocity vector depends on the configuration were used. From the results, it was showed that the fractal design can give a certain level of mixing efficiency in stirred tank. The PIV technique also gives good flow visualization in order to determine the flow pattern in stirred tank with a new concept of baffles and impellers.

Introduction

Mixing tank was widely used in many industries such as in chemical industry, mineral water processing, petroleum, solid-liquid mixing, and improving mass transfer and chemical reaction in it [1]. In chemical industry for example, the stirred tank used to mix a reactant in close contact and in adequate stoichiometry so that the mixing process can occur. Also, stirred tank was used for dispersing the synthesized products included the molecule of interest as well as toxic products, inhibitors and other secondary products [2]. Most of the mixing operations are performed by mechanical stirred tank. Stirred tank comes with various design and configurations, according to purpose of the stirred tank. One of the challenges in designing a stirred tank is to full fill the main requirement of the stirred tank itself which is for mixing purpose. Therefore, the best choice for the stirred tank type can vary widely, depending on the purpose of operation carried out in the stirred tank. In mixing process, an efficiency become the main issues and the company who produced the stirred tank always try to come out with a new solution in designing the stirred tank which is to produce a high efficiency mixing with a low cost of operation [2].

Efficiency here were measured on how fast the mixing completed their process while at the same time can maintain or even reduce the operation cost. According to the interest in designing the most effective stirred tank, many researches, was focused on the optimization of the design of the stirred tanks and impellers geometry. For example, Kchaou et al. [3] was compared an effect of the flat-blade turbine with 45^o and -45^o pitched blade turbines on the hydrodynamic structure of the stirred tank. For the the effects of different inclined angle of impellers, Driss et al. [4] developed a computational study of the pitched blade turbines design effect on the stirred tank flow characteristics with inclined angle of 45^o, 60^o and 75^o, on the local and global flow characteristics. Another configuration of impellers which is dual impellers also takes a part of interest among the researchers. Weng et al. [5] was performed an experimental work on the flow pattern in the dual Rushton impellers system using the photographic method. During their study, they found that the spacing between impellers significantly affected the flow pattern. Besides that, Mishra et al. [6] was investigated the flow occurring between dual Rushton impellers and the instantaneous velocity gradients distribution in the outlet of impeller blade using Laser Doppler Anemometry (LDA). They were found that the velocity distribution in the impeller stream was very different from the single impeller. For the effect of the number of impellers implemented in stirred tank, Franco et al. [7] was found that the effect of the vortex at the impeller blades shows turbulent fluid flow and mixing time shorter than one impeller.

In order to carry out an analysis for the stirred tank, there are various technique was used. For example, Zalc et al. [8] was simulated a laminar flow in an impeller stirred tank using CFD tools. They were studied an effect of mixing time performance as a function of the impeller speed. The simulated flow behaviours are validated extensively by Particle Image Velocimetry (PIV) which is also one of the methods that can be used to study the flow fields in stirred tank. Another method that also most popular are known as Laser Doppler Anemometry (LDA). Montante et al. [9] was used this technique to study the recirculation zone of the flows in the model of transition in a tank agitated. In the study, they try to look on effect of the impellers position and the influence of the baffles on the hydrodynamics of the flows in stirred tanks. Other technique is known as Laser Doppler Velocimetry (LDV). Costes and Couderc [10] was studied the fields of the average velocities by using this technique in the plane of the baffles and the median plane of a stirred tank equipped by Rushton turbine. Computational Fluid Dynamics (CFD) is the most popular method in an analysis of the flow behaviour in stirred tank. Since the CFD can simulate various configuration of the stirred tank included the impellers and baffles, a lot of analysis can be done numerically.

On the basis of the literature review highlighted here, we can say that the literature is very rich by the mechanical stirred tank studies and particularly those equipped by various numbers of blades for Rushton impellers. However, there is lack of some particular system which is discuss regarding the design the blade itself and at the same time the rule of baffles to enhance the mixing process. In this paper, an experimental work has been carried out by using PIV technique to determine the fundamental mechanisms of mixing with a new pattern four-blade Rushton impellers equipped with fractal design in a stirred tank. At the same time, an effect of baffles in the stirred tank on the mixing performance also been discussed. For the experimental work, the authors have focused on the low Reynolds number mixing regime because this situation are the most common problem occurs in practical applications. The objective is to understand the fundamental hydrodynamic processes in stirred tank in order to choose the most effective system.

Fractal concept. Fractal is basically a repeated shape and self-similarity to an infinitely small scale [11]. In other word, the patterns are repeated to the small scale infinitely. It is usually complicated and has many designs. According to Karl Weiertrass, the mathematician who was introduced Weierstrass function in 1923, the fractal is continuous everywhere but differential nowhere. Helge Von Koch in 1904 then refined the definition of the Weierstrass function and adds on a more geometric definition that called Koch snowflake. As a high turbulent level occurred when a fluid flow through the fractal pattern [12], we expect that the fractal shape can give a significant effect on mixing effectiveness due to their self similar shape. Another advantages of the fractal pattern that motivated us to apply as a pattern for baffles and impellers in stirred tanks because of low pressure drop across them [13]. Research on the space filling fractal were carried out by Hurst & Vassilicos [14] who found that the static pressure drop for the space filling fractals is independent of the thickness factor; moreover, away from the grids the homogeneity is improved as a function of the thickness factor. In this research, square grid fractal was chosen as a pattern that will apply to the baffles and impeller for the purpose of research. The square grid fractal is as in Figure 1 below.

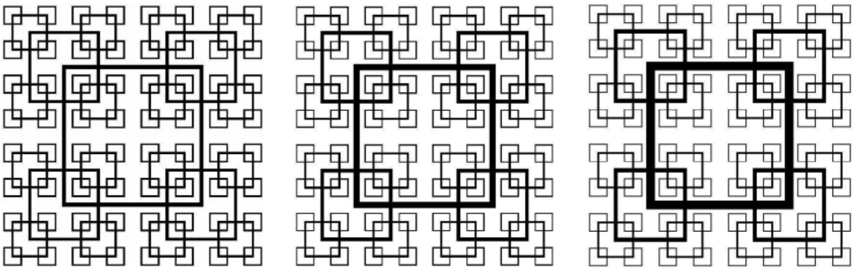


Fig. 1: Square grid space filling fractal with a different thickness ratio [14]

Experimental Work

Test rig setup. In this experiment, the model of stirred tank was build to investigate flow behaviour in the stirred tank equipped with a fractal impellers and baffles. The model of stirred tank used here is a clear cylindrical tank with a diameter, T = 300mm. The rest of stirred tank components dimension are referred to the diameter of the tank. This tank was equipped with 4-blade Rushton impellers with the impeller shaft located at the axis of the tank, a flat bottomed and fitted with four symmetrical baffles at a 90° interval against the tank wall. Schematic diagram of a baffled tank with a Rushton impeller are shown in Figure 2 and the dimensions of the tanks are given in Table 1. The working fluid was air.

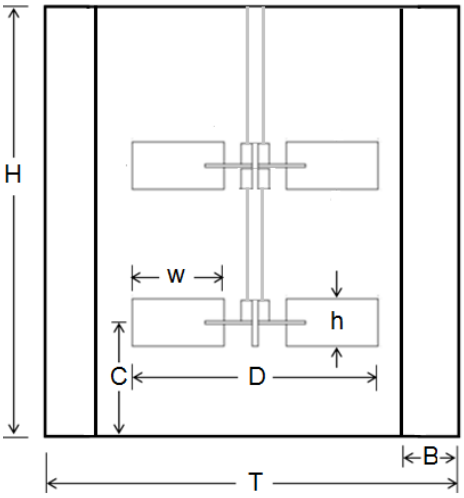


Fig. 2: Schematic diagram of a baffled tank with a dual Rushton turbine impeller.

Table 1 Dimensions of the stirred tank designed

General parameters	Dimension (mm)
Tank diameter, (T)	*300*
Depth of liquid, (H)	*1T*
Impeller diameter, (D)	*T/3*
Impeller blade width, (w)	*D/4*
Impeller blade height, (h)	*D/5*
Baffles width, (B)	*T/10*
Impeller clearance, (C)	*T/3*

For the experimental purpose, four configurations of the experiment were set up and the configurations were chose in order to determine the effect of each configuration for the flow pattern in the stirred tank. The configurations are Normal Baffles and Normal Impellers (*NBNI*), Fractal Baffles and Normal Impellers (*FBNI*), Normal Baffles and Fractal Impellers (*NBFI*) and Fractal Baffles and Fractal Impellers (*FBFI*). The design of impellers and baffles with fractal design is showed in Figure 3 below.

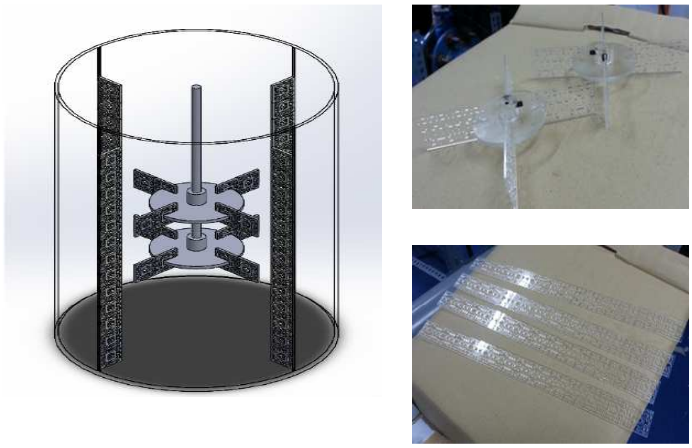


Fig. 3: Installation diagram for the stirred tank with fractal baffles and impellers

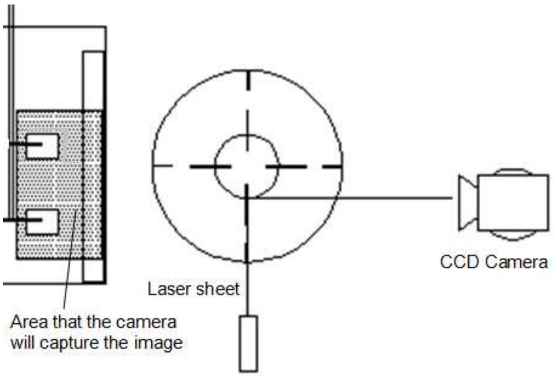
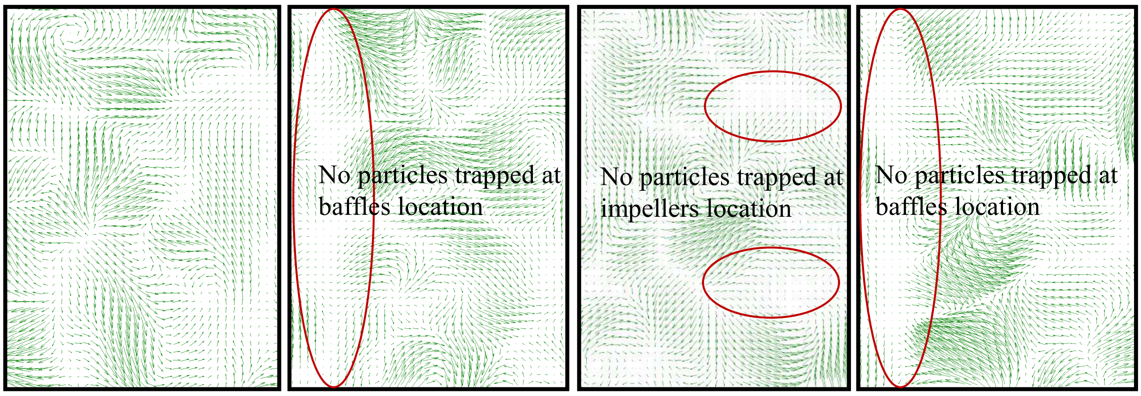


Fig. 4: Arrangement of laser and CCD camera

PIV Procedure. For the experimental work, PIV was used to determine the movement of particles inside the stirred tank. The particles used had a size of 1 μm and the impellers speed was set to N=200 rpm. The laser sheet plane was set in front of baffle. In PIV measurement, the motion of particles in the section illuminated by the laser sheet was recorded with a digital camera. In present work, the flow field was measure by one block taken at middle of tank covering an area of dual impeller region, as illustrated in Figure 4. In 2-D PIV measurement, the motion of particles in the section illuminated by the laser sheet was recorded by using the CCD camera. In present work, the flow field was measured by one block taken at the middle of the tank covering an area of impellers region.

Results and Discussion

The results for the flow visualization of each experiment were obtained from the velocity statistic field from 87 random sample images. Figure 5 summarized the finding of the flow pattern inside the stirred tank with the configuration that chose for the experimental work.

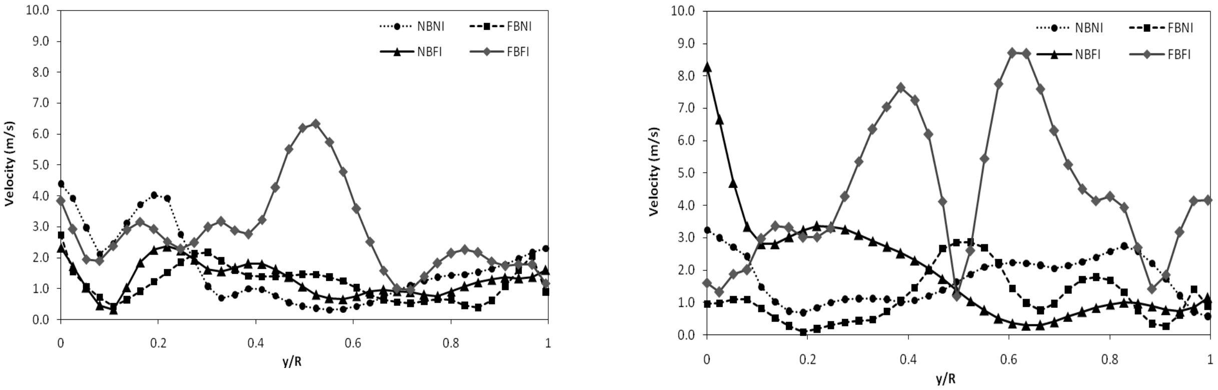


NBNI *FBNI* *NBFI* *FBFI*

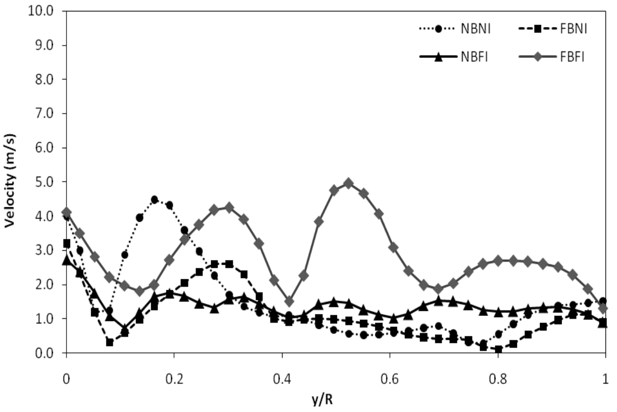
Fig 5: Average filtered vector image

Figure 5 shows a flow pattern on a stirred tank for all configurations tested which are the average filtered images for the velocity vector. The first image represents the first configuration which is normal baffles and normal impeller. Basically this is a reference and common flow occurred in current stirred tank available nowadays. For this combination, the flow distribution are mostly scattered in all region around the tank and a little bit small vortex occur between the impellers. The fluid also concentrated at the top of the moving impeller. This condition will cause a high pressure drop and hence increase the power consumption for the mixing process.

Second configuration which is FBNI, it showed that the flow have a nearly similar pattern as in the first configuration. However the flow moved smoothly around the baffles and this give advantages due to low pressure drop when the fractal baffles implemented to the stirred tank. Again for the implementation of fractal baffles for the third configuration, NBFI, the flow pattern are clearly similar when it cross the fractal impellers and the flow around the impellers had a good movement without any concentrated particles around that. The last configuration which is the implementation of fractal pattern for both baffles and impellers give the best configuration in this study. The results showed in the last image in Figure 5 above gave a clear view on how the fractal pattern influenced the flow in the stirred tank. The fluid particle seems to be fairly distributed in the tank and there is no fluid concentration on the fractal baffle as compared to normal baffle on other configurations. The results gave a good agreement with a previous research which is the fractal pattern can generate high turbulent level; hence enhance the mixing in the stirred tank.



y=100mm y=150mm



y=200mm

Fig 6: Velocity distribution along the horizontal line at distance 100mm, 150mm and 200mm from the bottom for all configurations tested

Besides the flow pattern that clearly gave a good result in term of the implementation of fractal baffles and impellers for a stirred tank, the velocity plot along a selected horizontal location in the stirred tank also were come out as a result in this paper. Figure 6 showed a velocity distribution along the horizontal line at distance 100mm, 150mm and 200mm from the bottom for all configurations tested. As we can see from the figure, high velocity occurred at the centre of half tank where it is important for a fluid mixing to have a high velocity to ensure a homogeneous mixing in the tank. For the location y=100mm and y=200mm from the bottom, there is a location of the impellers. Therefore the velocity was decreased in the region compare to high velocity at the centre of the tank.

Conclusion

As a conclusion, this research study of the new approaches of fractal baffles and impellers have successfully done by fulfilling the requirement of main objectives for this study. The concept of the square grid was developed based on fractal pattern and has been applied to generate new approach of baffles and impellers in stirred tank. The visualization of fluid flow by velocity plot on the requirement area shows the different flow pattern in stirred tank by using fractal design on four blade dual blade Ruston turbine and baffles is archive. Result shows less concentration fluid flow at the baffle region and the impeller disc where give an influence in mixing criteria in stirred tank. Besides that, by using dual impeller disc almost fluid flow are changes and probably can increase a mixing performance in stirred tank. Although this idea is a basic concept, it can be improved in order to provide better results in term of fluid mixing and also the flow pattern in stirred tank.

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