CFD Simulation of Fractal Impeller and Baffle for Stirred Tank Reactor with a Single Stage 4 Blade Rushton Turbine

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Abstract. Implementing the fractal design for baffles and impellers in stirred tank believe will influence the flow characteristic inside the stirred tank. Since the fractal pattern was proven as a good turbulent generator, a new concept of baffles and impellers which used a fractal design was proposed in a stirred tank to predict the fluid flow pattern and study an effectiveness of the new design in term of mixing performance. In order to investigate the kinds of flow properties, a commercial CFD software package was used to simulate the behaviour of flow pattern inside the stirred tank equipped with fractal baffles and also fractal impellers. Four configurations were simulated 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. The normal baffles and normal impellers were used as a reference for determination of mixing performance and the simulation was carried out by using the standard $k$-$\varepsilon$ turbulence model. The results show that the stagnant regions were reducing significantly when the fractal baffles applied in the stirred tank. Besides that, high concentration of the velocity occurred when normal baffles used while the concentration just above the normal impellers was reduced by the usage of fractal impellers. It showed that the implementation of the fractal design was gave a certain level of mixing efficiency in stirred tank. The simulation by using the CFD software package also gives a good agreement with the experimental results and gave a high confidence for the results in order to determine the flow pattern in stirred tank with a new concept of baffles and impellers.

Introduction

Stirred tank reactor was commonly used in many industries such as chemical biotechnologies, chemical, food processing and many more [1]. Many design and specification were come out for stirred tanks and they were different according to its use [2]. Most of the study is to make the optimum stirred tank design configuration with good efficiencies of mixing process. Factors that influence the performance of mixing process are, mixing time, the type of blade, blade numbers, sizing and speed of the rotating blade and the use of baffle [3].

The performance of the stirred tank here was referred 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 the effect of the number
of impellers implemented in stirred tank, Franco et al. [4] 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. [5] 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. 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 previous research, there are a lot of study had been conducted on the mechanical stirred tank, particularly those equipped by various numbers of blades. 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, a simulation work has been carried out by using ANSYS Fluent software package to determine the fundamental mechanisms of mixing with a new pattern multi stage stirred tanks with fractal pattern baffled. At the same time, an effect of baffles in the stirred tank on the mixing performance also been discussed. For the simulation work, the authors have focused on the low Reynolds number mixing regime because this situation are the most common problem occurs in practical applications.

Fractal concept. Fractal is basically a repeated shape and self-similarity to an infinitely small scale [6]. 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 [7], 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 [8]. Research on the space filling fractal were carried out by Hurst & Vassilicos [9] 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 Fig. 1 below.

![Fig. 1: Square grid space filling fractal from initiator to higher order iterations up to the 4th level of fractal](image)

Simulation Model

For the simulation work, 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, \( T = 300\) mm. The rest of stirred tank components dimension are referred to the diameter of the tank. This tank was equipped with 4-blade multi-stage impellers with the impeller shaft located at the axis of the tank, a flat bottomed and fitted with four symmetrical baffles at 90° interval against the tank wall. The model of stirred tank that was set up for the simulation work is shown in Fig. 2 and the dimensions of the tanks are given in Table 1.
Table 1 Dimensions of the stirred tank designed

<table>
<thead>
<tr>
<th>General parameters</th>
<th>Dimension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank diameter, ( (T) )</td>
<td>300</td>
</tr>
<tr>
<td>Depth of liquid, ( (H) )</td>
<td>( HT )</td>
</tr>
<tr>
<td>Impeller diameter, ( (D) )</td>
<td>( T/3 )</td>
</tr>
<tr>
<td>Impeller blade width, ( (w) )</td>
<td>( D/4 )</td>
</tr>
<tr>
<td>Impeller blade height, ( (h) )</td>
<td>( D/5 )</td>
</tr>
<tr>
<td>Baffles width, ( (B) )</td>
<td>( T/10 )</td>
</tr>
<tr>
<td>Impeller clearance, ( (C) )</td>
<td>( T/3 )</td>
</tr>
</tbody>
</table>

In this simulation, four configurations of the simulation models 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 Standard Baffles and Standard Impellers (SBSI), Fractal Baffles and Standard Impellers (FBSI), Standard Baffles and Fractal Impellers (SBFI) and Fractal Baffles and Fractal Impellers (FBFI). Summary of the configurations are shown in Table 2 below. The simulation model and the meshing were shown in Fig. 3 below. In order to investigate the effect of the baffles and impellers configuration, the working fluid used in this simulation was air.

Table 2. Configurations used for simulation work

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Baffles</th>
<th>Impeller</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^{st}) (SBSI)</td>
<td>Standard</td>
<td>Standard</td>
</tr>
<tr>
<td>2(^{nd}) (FBSI)</td>
<td>Fractal</td>
<td>Standard</td>
</tr>
<tr>
<td>3(^{rd}) (SBFI)</td>
<td>Standard</td>
<td>Fractal</td>
</tr>
<tr>
<td>4(^{th}) (FBFI)</td>
<td>Fractal</td>
<td>Fractal</td>
</tr>
</tbody>
</table>

Simulation Model

The simulation results for the fractal impeller and baffle for stirred tank reactor with a single stage 4-blade rushton turbine were presented by a velocity contour at the vertical cross section of the tank and also at the blade cross section as in Fig. 4. A significant effect of the fractal pattern in the stirred tank in clearly showed in the figure in term of velocity distribution. The first image was a figure for SBSI which is a common flow occurred in current stirred tank available nowadays. The combination of standard baffles and impellers shows the flow distribution are mostly scattered in all regions around the tank and a little bit small vortex occur between the impellers.

Second configuration which is FBSI, 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, SBFI, 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 Fig. 4 above gave a clear view on how the fractal pattern influenced the flow in the stirred tank. The velocity contour 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.

Fig. 5. Velocity distribution along the vertical line at distance T/4 from centre of stirred tank
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 vertical location in the stirred tank also were come out as a result in this paper. Fig. 5 showed a velocity distribution along the vertical line at distance $T/4$ from the centre of stirred tank. As we can see from the figure, high velocity occurred at the area near the impeller tips. More interesting here is the highest velocity occurred at the fractal impeller where it is important for a fluid mixing to have a high velocity to ensure a homogeneous mixing in 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 had been applied to generate a new approach of baffles and impellers in stirred tank. The simulation results were showed that the velocity contour and velocity magnitude have a different flow pattern in stirred tank by using fractal design on four blade single-stage impellers and baffles. Besides that, the highest velocity occurred at the fractal impellers tips and it gave advantages of the fractal designed impeller where the highest velocity can give an influence in mixing criteria 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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References