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Flow Visualization of Perforated Baffles and Impellers for Stirred Tank Reactor with Single Stage Rushton Turbine

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Abstract: Implementing the perforated baffles and impellers in stirred tank believe will influence the flow characteristic inside the stirred tank. Hence in present study, a new concept of baffles and impellers which used a perforated design was proposed in a stirred tank to predict the fluid flow patterns and study an effectiveness of the new design in term of 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 configuration were tested which are normal baffles and normal impellers, normal baffles and perforated impellers, perforated baffles and normal impellers, and the last configuration is perforated baffles and perforated impellers. The result show that the fluid concentration on baffles were reducing significantly when the perforated baffles applied in the stirred tank. On the other side, high concentration of seeding particles occurred when normal baffles used while the concentration just above the normal impellers was reduced by the usage of perforated impellers. From the results, it was shows that the perforated design can give a certain level of mixing efficiency in stirred tank. The PIV technique also gives good flow visualization in other to determine the flow pattern in stirred tank with a new concept of baffles and impellers.

Keywords: Stirred tank, Rushton turbine, perforated baffles, perforated impellers

1. Introduction

Stirred tank reactor was commonly used in many industries such as chemical biotechnologies, chemical, food processing and many more [1]. Stirred tank comes with many design and configuration, 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. 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.

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 [2]. Generating a high turbulent flow while mixing is desired by most as it will fasten the mixing time and increases its efficiency. Baffles were one of the proven solution to reduce the swirl motion and convert it to a common flow pattern which is axial or radial flow [3].

1.1 Stirred Tank Reactor

Stirred tank are often used for mixing solutions, transferring mass and heat in a controlled space with a desire parameters which includes impeller speed, temperature and many more [4]. It is widely used in the present and has a variety of configuration, size and use. Stirred tank standard parts includes the main body, baffles, impeller and stirrer. This standard parts plays an important role in determining the efficiency of any stirred tank reactor. There were currently two types of stirred tank which is continuous stirred tank and batch stirred tank.

The batch stirred tank were used commonly in fine chemical industry batch by batch. It has a time variant according to the usage and desire. It is a close system well mixed transient. The production is not continuous which is a good and a bad thing. Batch stirred tank is flexible enough that it can be used for multiple purpose [4]. However, batch stirred tank is known to be time consuming because of the fact that it needed to be empty, clean, fill before it can be used for another purpose.

Continuous Stirred Tank Reactor used in a mass production of one product. It is an open system steady state well mixed. The solutions usually is in steady state after start-up and there is no variation of time. The reaction rate is constant due to the continuous operation of the stirred reactor and the steady state will only be develop after a start-up period [4]. Most of large scale production used continuous stirred tank reactor. The tank is usually more complicated than batch tank but the operation cost is usually low.

It is known in any stirred tank that the turbulent flow is much desired. Turbulent flow can lead to turbulent mixing which will dramatically effects the mixing process such as fluid blending, mass transfer, heat transfer and fluid dispersion. Fractal design is said to be a good turbulent generator. That being said, the investigation on how fractal will effects the flow in stirred

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tank will be carried out using a proper configuration. Hence, this research will try to develop an experiment test rig for flow visualization of perforated baffled and fractal impeller in stirred tank reactor. The test rig will use to investigate the effect of the perforated baffles and impellers on the fluid flow.

2. Baffles and Impellers

In most stirred tank, an unwanted phenomenon such as vortex and swirling always occurs due to the centrifugal forces of impellers at high speed. This high centrifugal forces throws the fluids to the walls. This is where vortex happens and it can even reach down to the impeller resulting in air entrainment into the fluid [5]. Baffles, are installed in the tanks to avoid such phenomenon. Baffles can convert the flow from rotary to a mixing rotary to a mixing pattern. There are many types of baffles which is wall mounted baffles, bottom baffles and floating surface baffles. The most common baffles were the wall mounted baffles. The number of baffles also are variable according to its process objectives.

Baffled tank however, distributed the particle evenly along the stirred tank. The usage of baffles in any stirred tank will increase the power consumption [5, 6]. To minimize the power consumption, baffles width should be 1/10 to 1/12 of the tank outer diameter. Baffles however, stabilize the power draw to the radial shaft and more uniform which allows the shaft to be longer. Fig. 1 shows the results on how baffling in turbulent operations affects two primary agitator characteristic. The impellers used is radian-flow impeller such as Rushton turbines, mixed-flow impeller such as pitched-blade turbine and axial flow-impeller such as high-efficiency impellers [7]. Baffles used in the experiment is standard width baffles (T/12).

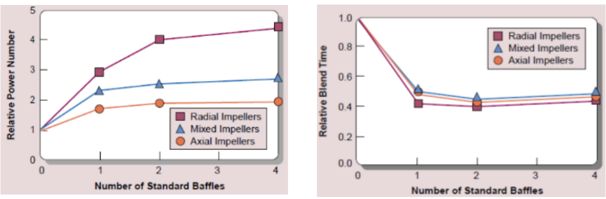


Fig. 1 – An effect of number of standard baffles to the relative power number and blend time

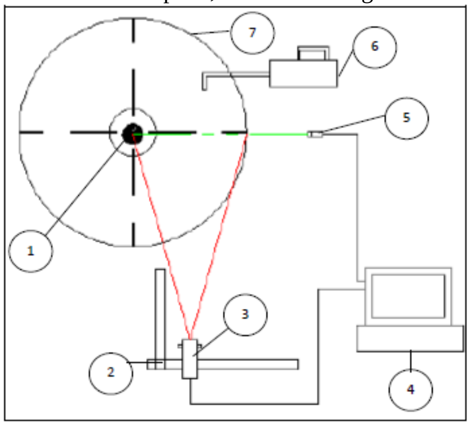
3. Experimental Set-Up

The vessel used in this study is a cylindrical tank with flat bottom (H=T=300mm) equipped with 4-blade Rushton turbine and four baffles (b_w=3.2mm). To obtain accurate measurement of the perforated baffles and impellers, the thickness of baffles used is 32mm which is contrary to the standard baffles thickness which is (T/10=30mm) width of the vessel. However, the extra 2mm from the measure which is just about 6.25% more than the standard size is acceptable. The impeller clearance from the tank bottom is (C=T/3=100mm). The material used for the vessel is acrylic since for the experiment, it will be ensure that every light and photograph taken by PIV can penetrate the body of the vessel. There are four configuration on the experiment and the difference between each configuration were determine. The configuration can be seen on Table 1.

Table 1 - Experiment Configuration

Configuration	Baffles	Impeller
1st	Standard	Standard
2nd	Fractal	Standard
3rd	Standard	Fractal
4th	Fractal	Fractal

The schematic diagram for the experiment which can be divided into seven main parts, as shown in Fig. 2.



1) Electric Motor
2) Traverse
3) High Speed Digital Camera
4) Central Processor Unit (CPU)
5) Dantec Dynamic Laser
6) Fog Generator
7) Stirred Vessel

Fig. 2 – Schematic diagram of experiment apparatus

3.1 Flow Field Measurement

Measurement of the flow field was done when the calibration of the experimental setup is achieved. After filling the vessel with fog by fog generator, the motor then turn on to rotates the impeller. The flow field resulting from this rotating impeller will then captured by the camera. Laser pulse and the camera capture timing is synchronised by the computer. The delay between successive capture is automatically controlled by the Dantec software and the images obtained are recorded on the computer system which is ready for post-processing. All the details about the setting on the Dantec software can be seen in Table 2.

Table 2 - 2D stereoscopic outline procedures

Flow visualization	
Seeding Particle	
Average diameter, *dp*	1 µm
Standard deviation, *Sp*	0.01 µm
Light source	double pulse Nd: YAG laser
Wavelength	1064 ηm, 532 ηm
Pixel pitch	7.4 µm
Thickness of laser sheet	2 mm
Trigger rate (Hz)	8 Hz
Time between pulses, Δt	150 µs
Number of images	87
Acquisition mode	Double frame mode
Image Detection	
Camera	One CCD camera
Spatial resolution	1600 x 1200 pixels
Angle of camera	90°
Gray scale resolution	10 bit
Maximum trigger rate	15 Hz
Data Processing	
Analysis	Cross correlation, average filter, statistic velocity
Interrogation area (IA)	64 x 64 pixel

Cross-correlation make sure the images are broken down into smaller and smaller investigation areas until the specified size is achieved. Each investigation area is the processed using statistical correlation technique which the displacement of the seeding particle is analysed and compared. The visualisation of flow field can be obtained from this correlation technique. After obtaining the cross-correlation vectors, the next step is to use carious filters to eliminate the "bad" vectors. These "bad" vectors are typically anomalies in the flow field resulting from low seeding particle concentration and general signal noise.

There are many filter used which is peak filter, range filter and moving average filter. The peak filter eliminates vectors by considering the ratio between signals peak and noise peaks. There are certain ratio which if the ratio drops, the vectors is eliminated. The ranges filter is used to ensure that the magnitude of vectors remains within a set ranged determined by the "good" vectors. The last filter is moving average filter which taking a sample set of vectors around one vector and calculating the mean. If the conflict between actual vector and averaged calculated vector by considering the surrounding vector is greater than a given ratio, the central vector is either replaced by the mean or can be completely eliminate.

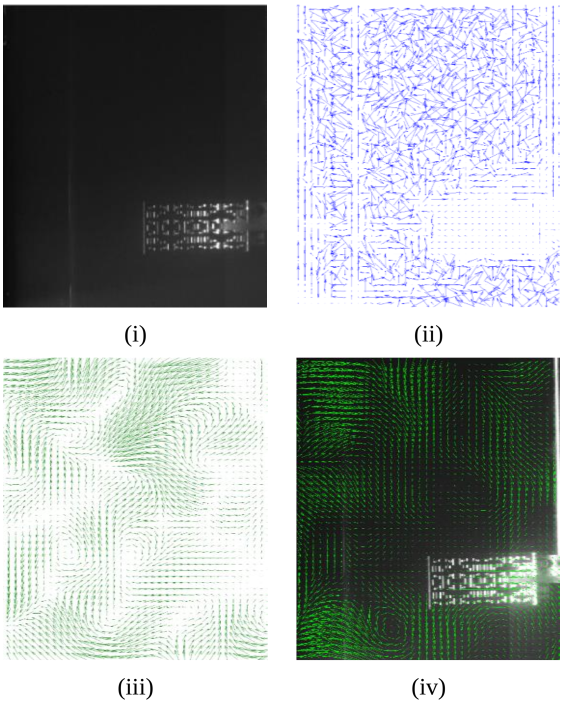


Fig. 3 – The process flow of post processing (i) Image capture (ii) Cross correlation (iii) Average filter (iv)Vector statistic

4. Results and Discussion

The discussions will be highlight the result on fluid flow, fluid concentration and the fluid velocity at baffle and impeller by four different configuration. It will then be compared to each other to see the effects of fractal in fluid concentration and velocity at baffle and impeller. The discussion will be discussed on the 4 configurations setting, as mentioned in Table 1 based on the following aspects.

i) The observation of flow visualization, cross-correlation, averages filter, and vector statistic.
ii) The flow velocity on three side which is at:
   - Baffle
   - Area between baffle and impeller
   - Impeller

The result shown did not compare to any past research result because this is the first time the perforated plate were implement on stirred vessel. The result will be solely discussed base on the observation and velocity graph on each different configurations.

4.1 Normal Baffle and Normal Impeller

The first configuration for the experiment is by using normal baffle and normal impeller. Fig. 4(a) show the air flow from the experiment. The flow cannot be see clearly because of thin layer of fog were used. The image are then undergone cross-correlation analysis to show the movement and direction of each fluid particle. It will provide a raw velocity vector that are scattered randomly around the investigation area which can be seen in Fig. 4(b).

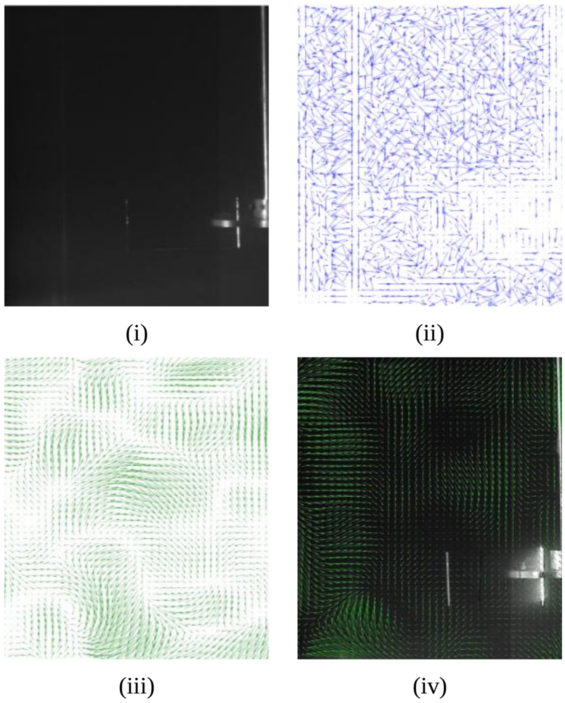


Fig. 4 – The flow of normal baffles and impeller (i) Image capture (ii) Cross correlation (iii) Average filter (iv)Vector

The figure also shown that there are fluid movement at the impeller. This is due to the fact that most of the flow is going out from the normal impeller blade. The cross-correlation is then calculated using average filter to show the direction of the fluid movement that can be seen on Fig. 4(c). The velocity statistic can be gotten from 87 images of average filter to form one velocity statistic which is portrays in Fig. 4(d). The fluid flows from the impeller were moves towards the tank wall. The half ring vortices seems to be form just after the fluid leaves the impeller. This is believed to be happening because of the low pressures that are formed between the impeller tip and baffles. The fluid particle also can be seen concentrated at the baffles. This is due to the baffle that block the fluid movement. Also, the fluid concentration is also can be seen just above the rotating impeller.

4.2 Normal Baffle and Perforated Impeller

The flow pattern in Fig. 5(d) shows that the use of fractal impeller have direct impact of flow movement as compared to the first configuration. The absence of flow at the impeller in Fig. 5(b) causes by the porosity of the fractal impeller that makes the fluid going inside it. The formation of one stable ring vortices and two unstable half ring vortex can be seen on Fig. 5(d). The number of this vortex shows that the fluid is become more active as compare to the first configuration. This is believed to be caused by the influence of fractal at the impeller. The concentration of the fluid at the baffle also can be seen to be reduced as compare to the first configuration. The fluid still concentrated at the baffle but it is reduce on the middle.

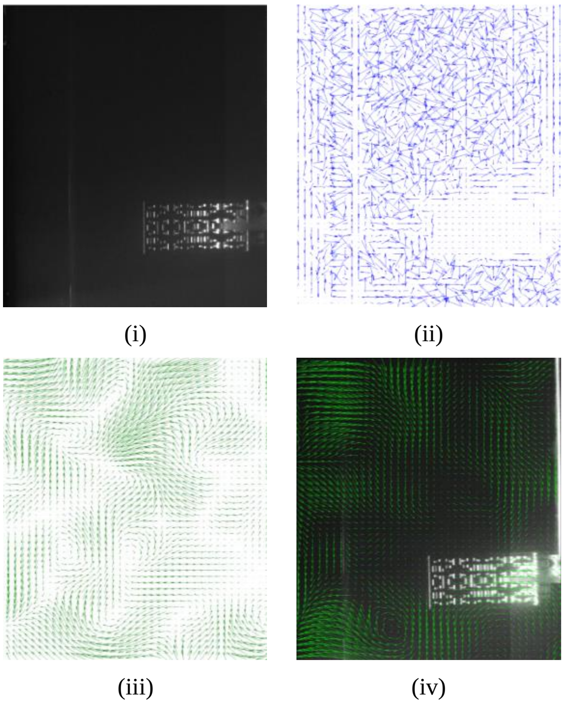


Fig. 5 – The flow of normal baffles and perforated impeller (i) Image capture (ii) Cross correlation (iii) Average filter (iv)Vector

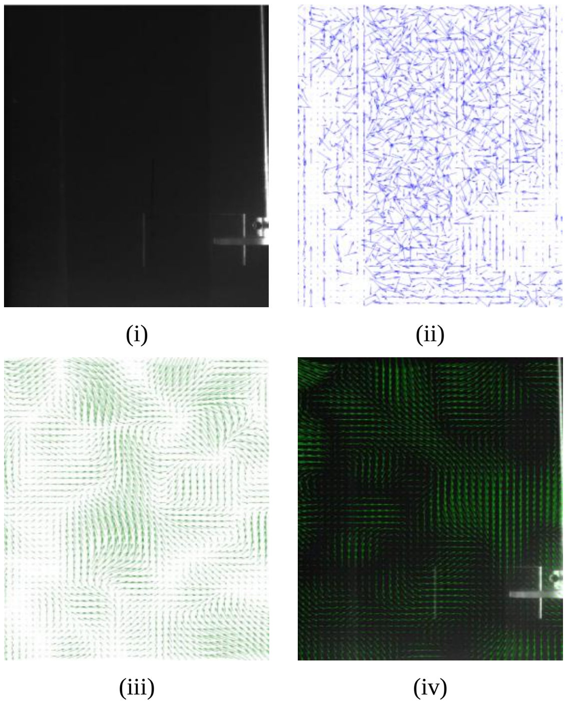


Fig. 6 – The flow of perforated baffles and normal impeller (i) Image capture (ii) Cross correlation (iii) Average filter (iv)Vector

The fluid concentrate at the top and below on the baffle while it did not concentrate at the middle, seen in Fig. 5(d). It is also can be seen in the figure that the concentration of the fluid above the impeller were reduced. High pressure drop causes by fractal forces the fluid going into the impeller as compare to first concentration, where there fluid accumulated just above the impeller.

4.3 Perforated Baffle and Normal Impeller

The third experiment were carried out using the third configuration which is fractal impeller and normal baffle. The flow visualization again cannot be seen with bare eyes but the flow can be seen on the cross-correlation figure in Fig. 6(b). The flow seems to reduce at the baffles. Low concentration of fluid also can be seen in Fig. 6(d) contrary to the normal baffle in Fig. 4(b) and 5(b). It can be conclude that the fractal directly influence the fluid concentration on the baffles. The porosity of the fractal causes the fluid to go through it, which directly reduce the fluid concentration on the baffles. However, the number of vortex is reduce greatly as can be seen on Fig. 6(d) where only half lower ring vortex can be seen to be formed just under the impeller. The fluid concentration also can be seen to form just above the impeller, which is the same as the first configuration that also uses normal impeller.

Again, the flow cannot be seen with bare eyes as at Fig. 6(a). The fluid particle can be seen on cross-correlation figure at Fig. 6(b) where there are reduced fluid activity on baffle and impeller. This is because the fluid goes through the porosity on the fractal baffle and fractal impeller. Fig. 6(d) shows there are no vortex formation on the fluid flow as compared to second configuration using normal baffle and fractal impeller.

4.4 Perforated Baffle and Perforated Impeller

The last configuration for the experiment using perforated at both baffle and impeller. The flow visualization for the last configuration can be seen in Fig. 7 below.

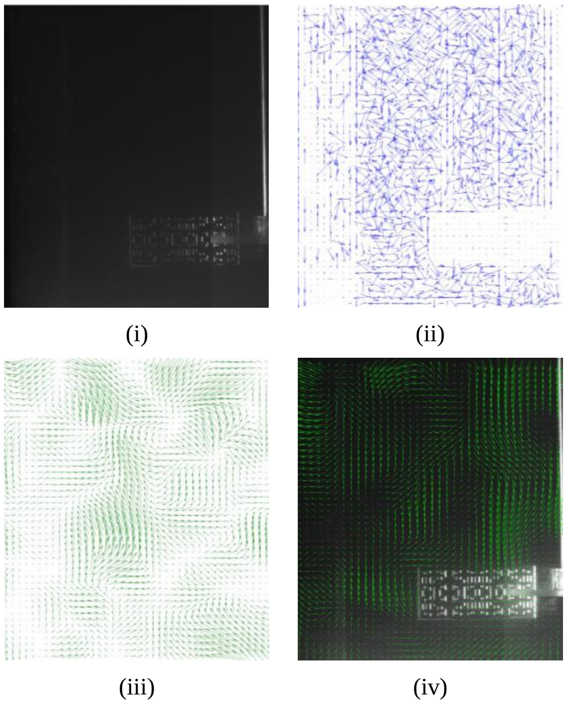


Fig. 7 – The flow of perforated baffles and impeller (i) Image capture (ii) Cross correlation (iii) Average filter (iv)Vector

Again, the flow cannot be seen with bare eyes as in Fig. 7(a). The fluid particle can be seen on cross-correlation in Fig. 7(b) where there are reduced fluid activity on baffle and impeller. This is because the fluid goes through the porosity on the fractal baffle and fractal impeller. Fig. 7(d) shows there are no vortex formation on the fluid flow as compared to second configuration using normal baffle and fractal impeller.

4.5 Velocity Analysis

The velocity analysis is taken from 0 to 135mm on *x*-axis while the y-axis is at 100mm. The analysis will be carried out in three area which is baffle area, area between baffle and impeller, and impeller area. The baffle area is at 0 to 32mm, while the second area is from 32mm to 69mm and the impeller area is from 69mm to 135mm. The result for all configuration are shown in Fig. 8.

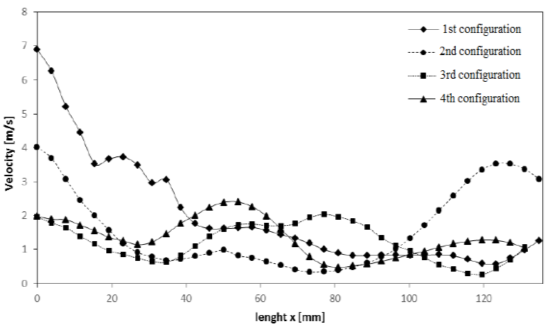


Fig. 8 – Graph of velocity vs length of four different configuration

Graph shows the velocity of fluid particle versus the length between impeller and tank wall. The graph can be divided into three area. For the first area, which is at the baffle (0-35mm), it can be seen that the velocity is increases at it goes nearer to the wall. This is because the pressure is increases as the fluid moves to the wall. The maximum velocity is 7 ms^{-1} at the first configuration which is normal baffles. The minimum velocity valued at 2 ms-1 at the third and fourth configuration which uses fractal baffle. This is happening due to the fact that the fluid particle is being block by the baffle. This creates high pressure on the normal baffles which makes the velocity to be higher as compared to fractal baffle. The porosity of the perforated baffle resulting on the particle flows towards is, making the radial velocity is low at fractal baffle as compare to normal baffle.

The second area shows the velocity of fluid particle between baffle and impeller. The flow seems to be increasing as it leaves the impeller tip at 69mm, and it reduces as it goes nearer to the baffle at 32mm. The maximum velocity is 2.5 ms^{-1} which is at the fourth configuration using fractal baffle and fractal impeller. Meanwhile the minimum velocity is valued at 0.5 ms-1 where it happened at the second configuration.

The third area shows the velocity fluid particle at the impeller where the length is from 69mm to 135mm. The maximum value for the velocity is 3.5 ms^{-1} at the perforated baffle and impeller where it reduces drastically to 0.5 ms-1 at the tip the flow particle speed decrease as it leaves the impeller. Meanwhile, the flow characteristic for normal baffle is opposite to the fractal impeller where the flow seems to increase as it leaves the impeller. This is to be believe caused by the porosity of the fractal, where most of the fluid goes into the fractal. Meanwhile, normal baffle show normal characteristic where the maximum velocity is at the tip of the baffles and the impeller.

5. Conclusion

In the study, the velocity statistic was measured by two-dimension Particle Images Velocimetry system to study the effect of flow pattern by using perforated impellers and baffles. The experimental work has been done and the data such as flow visual, velocity statistic and velocity analysis are being collected and analysed. The study found that flow pattern is changing with four different configurations. The flow pattern can be seen to be directly influence by the usage of perforated baffles and impellers. The fluid concentration at the baffles seems to be reduced significantly under the influence of perforated baffles as compare to normal baffle. Also, there are an increasing number of vortex formation at the perforated impellers and normal baffles configuration compared to normal impellers and normal baffles configuration. The fluid concentration just above the impeller also seems to be reduce under the effect of perforated design.

In conclusion, perforated design influence the fluid flow of the stirred tank. Fluid concentration of the baffles can be reduce significantly using perforated and fluid concentration above the impeller can also be reduce.

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