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Investigation of the Fluid Motion with Various Clearances in Biodiesel Reactor by Using CFD

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Abstract – *A method based on Computational Fluids Dynamics (CFD) was used to analyse the flow behaviour in the Biodiesel reactor with 6-blade at 45° pitch blade turbines. The study, which was based on the turbulent flow, had been associated with three sizes of the blades installed in the reactor by using the standard k-ε turbulence model. The study also included the pitch blade turbines that were installed at three clearances from the bottom in the reactor by using the standard k-ε turbulence model. The results showed that the flow behaviours differed for the three various locations, which were installed at C=T/4, C=T/2, and C=3T/4 for D=T/3. The results also showed that the flow behaviour had been different for the three impeller diameters installed at C=T/4. Besides, good quantitative agreement for velocity distribution was obtained. Good velocity distribution in the reactor was produced by D=T/3. Moreover, a comparison between the three impeller diameters in terms of velocity distribution suggested that the discharge flow from the smaller impeller had stronger axial flow during the mixing process.*

Keywords: Turbulence, Computational Fluid Dynamics, Impeller diameter, Impeller clearances, Flow pattern, reactor.

1.0 INTRODUCTION

The transesterification, or better known as the mixing process, is the one of the processes carried out for biodiesel production. Mixing is defined as a process where two or more substances enter a reactor or tank where they are mixed together. Mixing is an important variable in the transesterification reaction. It is because; the vegetable oils or fats are immiscible with catalyst-alcohol solution. Since two phases are mixed together and the reaction is started, stirring is no longer needed. Usually, the mixing process is carried out to create a reaction between two or more particles for processing and uses stirred reactors to complete the mixing process [1].

Transesterification process is the displacement from an ester to the alcohol by another alcohol and the commonly suitable alcohols used are ethanol and methanol. Ethanol and methanol are commonly used in biodiesel production as they are low in cost, as well as physical and chemically beneficial [2]. Moreover, although there are various ways and solution methods to produce biodiesel fuel, most of the manufacturing facilities in the globalization era nowadays usually produce it through the transesterification process because the process is easy and low in cost.

Since 80 years ago, biodiesel produced from vegetable oil have been used as diesel fuels, but it was used for emergency situations only. Nevertheless, an increasing trend for biodiesel as an alternative fuel has been observed because in the automotive industry, the fuels can reduce emissions like the particle matter (PM) and Carbon dioxide (CO2). The reduction of Carbon dioxide is an essential requirement for the environment. In fact, the term 'biodiesel' refers to the Fatty Acid Alkyl Esters (FAAE), which is produced from vegetables oil, animal fats, or waste cooking oil feedstock [3].

Usually, the mixing process creates a reaction between two or more particles with stirred reactors to complete the mixing process. Generally, the stirred reactor, in which one or more impellers are used to generate flow and mixing within the reactor, is used for numerous applications. A basic mixing system comprises of a vessel, a container or reactor, which can be baffled or non-baffled, open or covered by a lid, fluid or solid particles, as well as an agitator that is mounted on a shaft. Perhaps, the agitator is the most critical part of the mixing system as it provides the source of the mixing energy and also determines the pattern of the flow, the pumping, and also the circulation rate in the reactor [3].

Generally, flow is defined as one or two components resulting from the action of the mixer impeller in the reactor or tank. Usually, the flow pattern created by an agitator becomes the first indication of its suitability for a particular process. The distribution of the dispersion of gas and solid particle in a liquid commonly depends on the type of the flow pattern that is produced by the particular agitator in a given tank or reactor [4].

Commonly, in the reactor, during the transesterification, it is challenging to generate a fluctuating flow [5]. That is the reason for the flow to become turbulent in the reactor. Besides, low mixing intensity poses certain disadvantages during the mixing process. In general, a mixer with a small diameter impeller at a high speed will result in the fluid seeing the applied power as mostly shear. By comparing the low speed mixer with a larger diameter impeller, it will discharge a higher volume of fluid, and thus, results in a high flow in the reactor. Moreover, most studies stated a similar reason about the flow pattern in such condition. Besides the fact that it will slow down the reaction in the reactor, low mixing intensity is also responsible for the delay in the response of the system during the transesterification process [6]. Furthermore, in studies conducted by [7, 8, 9], the reactor geometry also contributed to good mixing process.

2.0 METHODOLOGY

The biodiesel reactor used in this study was a standard configuration cylindrical vessel of diameter T=0.202 m and the liquid column height of H=T, as shown in Figure 1. Impellers with diameter D=T/3 was used at three clearances from the bottom of C=T/4, C=T/2, and C=3T/4. The fluids domain was Fatty Acid Methyl Ester (FAME) with a density of 843 kg/m^3 and viscosity of 0.00272 kg/(m·s). The impeller rotational speed was 300 RPM and the Reynolds Number verification was applied in the turbulent regime.

Three impellers with various diameters were used; D=T/3, D=T/2, and D=3T/4 at the clearances from the bottom of C=T/4. The fluids domain was Fatty Acid Methyl Ester (FAME) with a density of 843 kg/m^3 and viscosity of 0.00272 kg/(m·s). The impeller rotational speed was 300 rpm and the Reynolds Number verification was employed in the turbulent regime. For

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the simulation, the unstructured mesh used a medium mesh type and the inflation was applied. The mesh consisted of the number of elements for all case studies in a range of 814390-887328.

The impeller was subtracted from the modelling before mesh was applied. All solid boundaries with a no-slip condition were utilised for the flow field calculations. For the solver setup, three-dimensional simulations were performed by using the FLUENT version 14 and the standard k-ε turbulence model was employed. The solutions of the velocity field and the pressure were calculated by using a second-order discretization scheme for the pressure, the SIMPLE scheme for the pressure–velocity coupling, and a second-order upwind scheme for the momentum calculation. As for the post-processing, the various simulation data visualization tools of the Computer Fluid Dynamics solver setup had been applied to observe the results.

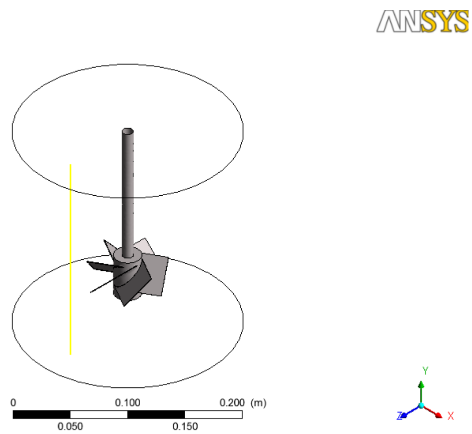

Figure 1: Reactor geometry

3.0 RESULTS AND DISCUSSION

3.1 Streamlines

Figure 2 shows that the streamlines fluctuated due to the rotating blade that affected the motion of the fluid. Since the blade started to move with an increasing speed, the solids began to suspend at the bottom of the vessel and resulted in the well-known loop of the flow pattern. Hence, when the blade rotated, the fluid began to swirl around the blade in the reactor. With a small clearance at C=T/4, the fluid would be most turbulent in the upper zone and at the bottom zone in the reactor. However, by increasing the clearance from the bottom to C=0.101 m, the streamline showed that most of the flow translation had been at the upper zone compared to the bottom zone.

In addition, by increasing the clearance to C=T/2, the streamline was almost accumulated at the upper zone of the reactor, while the bottom region still created the fluctuating flow, but not really strongly. With increment in the clearance, the bottom zone was less turbulent because the blade forced the circulation of the fluid, which created contact with each other. Moreover, turbulent is a very complex physical phenomenon and it is developed from high flow rate. In this case, the blade rotated at about 300 RPM and that was enough to create turbulence in the reactor. However, increasing the clearance at the bottom reduced the turbulent region in the reactor. Besides, the velocity streamline clearly showed that the turbulent was fully developed when the blade was located near the bottom of the reactor. Most importantly, the turbulence

Penerbit Akademia Baru
Journal of Advanced Research Design
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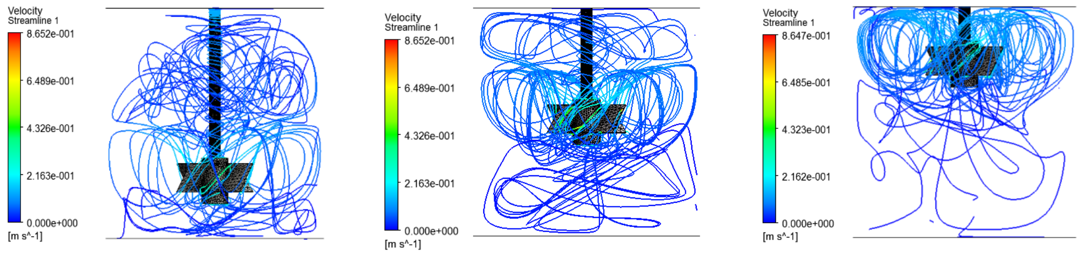
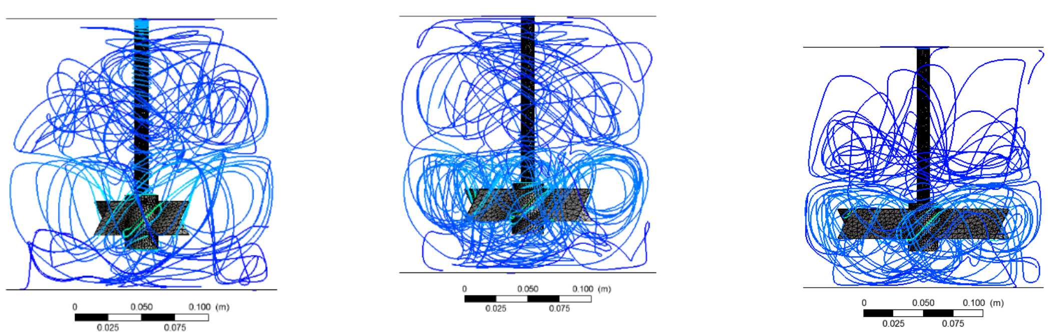
regions were created closer to the rotation blade region as well. High velocity occurred at the blade and led to strong axial flow.



(a) (b) (c)

Figure 2: Streamlines created for the three clearances of the 6-blade 45° pitch blade turbines at (a) C=T/4 (b) C=T/2 (c) C=3T/4

Figure 3 shows that the streamlines fluctuated due to the rotating blade that affected the motion of the fluid. Since the blade began to move with increasing speed, the solids started to suspend at the bottom of the vessel and resulted in the well-known loop of the flow pattern. Hence, when the blade rotated, the fluid started to swirl around the blade in the reactor. With a small clearance at C=0.0505 m, the fluid was most turbulent in the upper and the bottom zones in the reactor. An increase in the diameter of the blades produced strong turbulence and good mixing based on the velocity of the streamline. In this condition, the mixing process can be done successfully. Although the turbulent region is mostly at the upper zone in the reactor, the turbulent region is also strong at the bottom zone. Moreover, it has been shown clearly that the flow contained eddying motions that filled the whole reactor and they swirled to each other. Basically, the turbulent flow made the fluid to be mixed irregularly and swirl to each other. Besides, the solids need to remain suspended in the fluid to avoid settling or blockages and it can make the turbulent flow desirable.



(a) (b) (c)

Figure 3: The fluid streamline at (a) D=T/3 (b) D=T/2 and (c) D=3T/4 at C=T/4

3.2 Velocity Vector

Figure 4 shows the velocity vector of the fluid for three clearances from the bottom of the reactor. The results showed that the axial circulation loop formed at the tip of the blade and the

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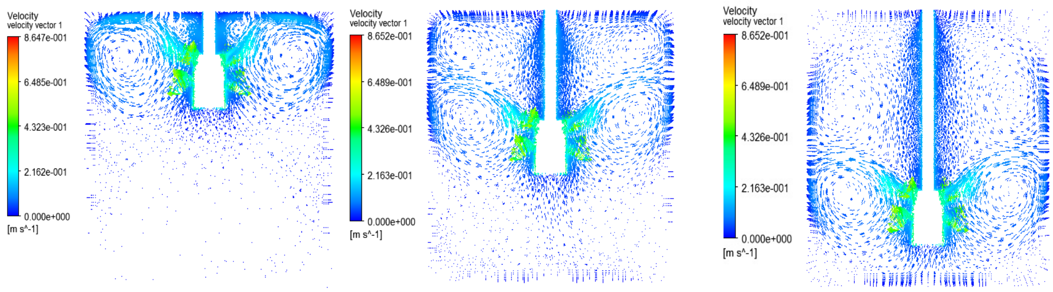
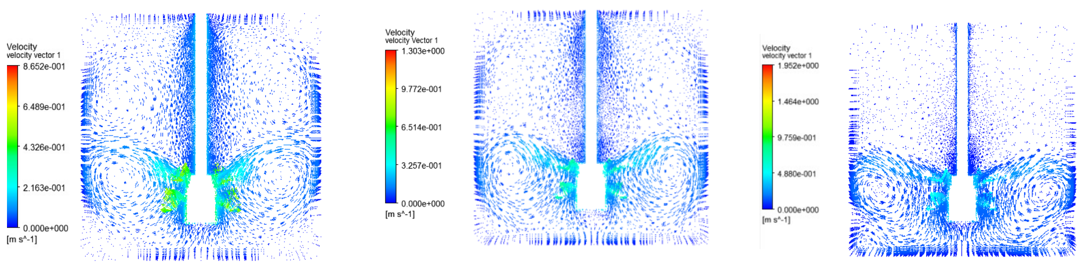
strongest axial loop was created by the blade at the clearance of T/4. Two loops of the flow had been created at the upper and the bottom of the reactor. When the axial flow hit the wall, it created the recirculation of the flow, where the flow was forced to flow back as it began to move.

Since the clearance from the bottom was increased, the axial flow still created two loops, but these were not as strong as those found at the lowest clearance condition. Nonetheless, the bottom zone differed from the upper zone because the turbulence flow region was less than the upper region. Increasing the clearances from the bottom caused a secondary lower loop to be generated below the blade. In both instances, the secondary loop had been smaller compared to the first loop, which was bigger.



(a) (b) (c)

Figure 4: Velocity vector in the reactor during the mixing process based on the three clearances of the 6-blade 45° pitch blade turbines at (a) C=T/4 (b) C=T/2 (c) C=3T/4



(a) (b) (c)

Figure 5: Velocity vector in the reactor during the mixing process based on the three diameters of the 6-blade 45° pitch blade turbines at (a) D=T/3 (b) D=T/2 (c) D=3T/4

Figure 5 shows that axial circulation loop that had been formed at the tip of the blade and the strongest axial loop was created by the blade with a condition of D=T/4. Besides, two loops were created at the upper and the bottom of the reactor when the blades were installed at the bottom. When the axial flow hit the wall, it created a recirculation of the flow, where the flow was forced to flow back as it began to move. Since the diameter of the blade was increased, the flow hit the side wall because of the limited space. Although two loops of fluid were created at this condition, the second circulation loop at the bottom had almost vanished because of the unsuitable diameter of the blade. Generally, with less liquid circulating loops were created in the reactor, the mixing performance became poor because the fluid was not mixed properly.

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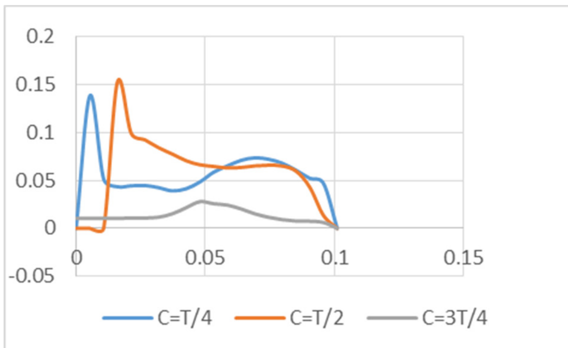
3.3 Velocity Distribution

The velocity distribution graph was plotted based on the vertical plane and the horizontal plane. Based on the analysis, the best and the most suitable condition of the blades diameter and clearances had been selected. In addition, the graph only focused on the velocity result because velocity could help determine the flow pattern in the reactor, either high or low turbulence regime during the mixing process. Figure 6 shows the velocity distribution at the middle of the tank by using D=T/3 for each clearance at C=T/4, C=T/2, and C=3T/4. The results obtained from the horizontal plane were actually based on the coordinate that had been exactly exerted in the middle of the reactor.

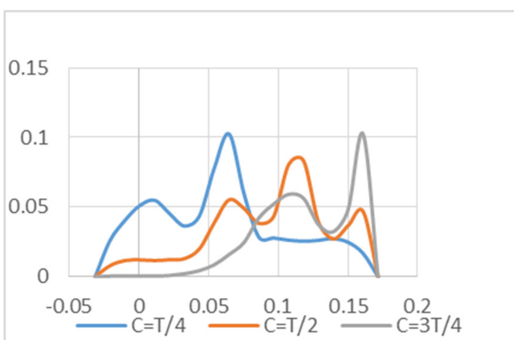
Velocity (m/s)



Displacement (m)

Figure 6: Velocity distributions at the middle of the tank by using D=T/3 at the C=T/4, C=T/2, and C=3T/4, which were extracted from the horizontal plane

Velocity (m/s)



Displacement (m)

Figure 7: Velocity distributions at the middle of the tank by using D=T/3 at the C=T/4, C=T/2, and C=3T/4, which were extracted from the vertical plane

Meanwhile, Figure 7 shows a changing pattern of the velocity results based on the clearances from the bottom due to the same diameter of blade. Besides, Figure 4 shows that when the blade was installed at the bottom of the reactor, which was C=T/4, the velocity was better and had become stable at the middle region of the reactor. Compared to C=T/2, the velocity was

Journal of Advanced Research Design
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higher because the reference point was exactly at the location where the blade was installed. In this case, installing the blade at the top of the bottom did not provide good mixing because low velocity was obtained at the middle of the reactor. This phenomenon confirmed that at the bottom, the velocity had been the lowest compared to the middle region. This contributed to poor mixing process in the reactor due to the poor velocity distribution.

4.0 CONCLUSION

In this study, a simulation of 6-blade 45° pitch blade turbines had been carried out in the turbulent regime. The effect of the clearances at the bottom of the reactor had been investigated. The position where the blades were installed played a significant role in developing the structure of the flow. The results showed that small clearances, C=T/4 for instance, created a strong axial flow in the reactor. This condition played an important role to ensure that the fluids domain could be mixed together and to accomplish the mixing process. This condition also made the fluids to fluctuate and mix together. Besides, this condition had been suitable because it successfully mixed the fluid particles together where the transesterification process included two phases with high viscosity particles that accumulated at the bottom of the reactor. Moreover, it seemed that by installing the blades at the top of the reactor, the fluids domain failed to mix well because only fluids in the upper region moved in high velocity compared to the fluids at the bottom reactor, where the particles only moved at a lower velocity. This phenomenon proved that the conditions had been unsuitable to accomplish the mixing process.

In addition, the effect of the blades diameter in reactor had been investigated. The size of the blades played a significant role on the flow structure, where smaller blade created a strong axial flow in the reactor. This condition played an important role in ensuring that the fluids domain could be mixed together and in accomplishing the mixing process. From the results, the best condition of the blades that had been suitable for the mixing process was the smallest blade with D=T/3. This condition also made the fluids to fluctuate and to mix well. This condition was also suitable because it successfully mixed the fluid particles together as the transesterification process included two phases with high viscosity particles that would accumulate at the bottom of the reactor.

REFERENCES

[1] P. Mavros, Flow Visualization in Stirred Vessels: A Review of Experiment Technique, Chemical Engineering Research and Design 79 (2001) 113-127.

[2] H. Fukuda, A. Kondo, H. Noda, Biodiesel Fuel Production by transesterification of oils, Journal of Bioscience and Bioengineering 92 (2001) 405-416.

[3] W.A. Wali, K.H. Hassan, J.D Cullen, A. Shaw, A.I. Al-Shamma'a, Real time monitoring and intelligent control for novel advanced microwave biodiesel reactor, Measurement 46 (2013) 823-839.

[4] R. Zadghaffari, J.S. Moghaddas, J. Revstedt, A study of liquid-liquid mixing in a stirred tank with 6- blade rushton turbine, Iranian Journal of Chemical Engineering 9 (2008) 12-22.

Journal of Advanced Research Design
ISSN (online): 2289-7984 | Vol. 10, No.1. Pages 1-8, 2015

[5] G.R. Kasat, A.R. Khopkar, V.V. Ranade, A.B. Pandit, CFD Simulation of liquid.phase mixing in solid-liquid stirred reactor, Chemical Engineering Science 63 (2008) 3877-3885.

[6] A.S.R. Brasio, A. Romanenko, L.O. Santos, N.C.P. Fernandes, Modelling the effect of mixing in biodiesel production, Bioresource Technology 102 (2011) 6508-6514.

[7] S. Ljevar, H.C. De Lange, A.A. Van Steenhovan, Comparison of rotating stall characteristics between the viscid and inviscid two-dimensional model, WSEAS Transactions on Fluid Mechanics 5 (2006) 480-487.

[8] J. Feng, F. Benra, H.J. Dohmen, Numerical study on impeller-diffuser interactions with radial gap variation, Proceedings of the 4th WSEAS International Conferences on Fluid Mechanics and Aerodynamics, Greece, 2006, pp. 289-294.

[9] G. Pengcheng, L. Xingqi, L. Weili, Z. Xiaobo, L. Peng, Effect of blade geometric parameters on the operating stability of the hydraulic turbine, Proceedings of the 4th WSEAS International Conferences on Fluid Mechanics and Aerodynamics, Greece, 2006, pp. 315-318.