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Pressure distribution around mixing blades in biodiesel reactor using computational fluid dynamics (CFD)

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Abstract. This paper presented simulation analysis of pressure distribution along a mixing blades propeller used in biodiesel reactor tank. The mixing blade types used are: (1) three bladed mixing propeller, (2) pitch turbine blade and (3) Rushton blade. ANSYS FLUENT software was used to run the simulation. The highest pressure distribution along the mixing fluid was created by pitch turbine blade type. When comparing the pressure distribution at all three blade types, the Rushton blade gives the highest pressure at the tips of the blades. The Rushton blade is the best blade used for biodiesel reactor. The selection of the right type mixing blade can improve the biodiesel production and lower the maintenance cost. The result obtained from the simulation is agreed well with the published data.

Introduction

Biodiesel is the new energy source for replace the petroleum usage. Biodiesel is an alternative diesel fuel generated by vegetable oils or animal fats [1]. Many advantages using the biodiesel, such as decrease dependency on import oil markets, substitution for diesel fuel or blends with diesel and decrease vehicle emissions [2]. The most importance process in produce the biodiesel is the mixing process. The mixing process has two main factors; a chemical (or biochemical) reaction, and a physical change in the nature of the phase which is usually related to the structural modification in the fluid [3]. All the mixing process accomplished in a tank.

The fluid dimension in the tank and the dimensions and arrangement of equipment in the tank are the main factors for the reactor performance. Right choice for baffle, tank and impeller type is important to increase reactor performance. When impeller rotated in a fluid, flow can be generated and shear can happen to it. High density fluid flow in reactor tank can develop stress for the blades. When high stress applied to the blade, it can exceed the limit of material strength and can lead to a permanent change of shape or physical failure. Physical failure can involve the maintenance and increase the cost for biodiesel process.

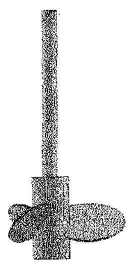
Reactor is the most importance equipment in the biodiesel process. All the chemical reaction process happened in the reactor. There are two categories of reactor, batch reactors and continuous reactors. In the batch reactor, the amount of reactants fed into the reactor was determined. The reaction of reactant operated in a closed reactor, and the desired reaction conditions are set. In general, increasing the reaction temperature increases the reaction rate and, hence, the conversion for a given reaction time and stress on the bladed [4]. Stress analysis is to determine the stress distribution on the structure of the blade. Normally, maximum stress occurs at the small area on the blade hub fillet region which is due to the non-uniform distribution of stress field in this area. The non-uniform stress distribution always happened at the filleted area.

Three bladed mixing propeller blades have been used by [5] to see the performance of this blade when in high speed rotation. Pitch blade turbine are used in many research especially in mixing vessel [6] involving with flow pattern characteristic when used different location and pumping direction. They concluded that this type of blade in up-pumping direction if in correctly sized and position can give very effective for ingesting floating solids. Many researchers used pitch blade [7,8] and also Rushton blade [8,9] to see the the blade performance for mixing.

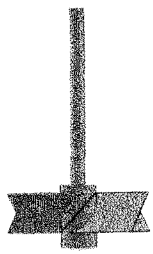
Stress is defined as the average force per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them. The atomic structure will strain, being compressed, warped or extend when a load is applied to a metal. The external load applied and area value must be known to measured value. The aim of this study is to investigate the difference stress distribution along three types of mixing blade. This is accomplised by obtaining the pressure distribution along the blades and comparing this, and stress analysis data in Solidwork 2012, with the predictions of publish data from open litearature.

Methodology

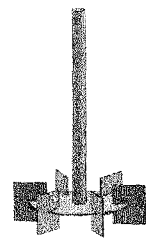
The three type of blades propeller were designed using SolidWorks 2012 as shown in Fig.1.



(a) Three bladed mixing propeller



(b) Pitch turbine blade



(c) Rushton blade

Fig. 1: Mixing propeller in biodiesel reactor (a) Three bladed mixing propeller, pitch turbine blade (c) Rushton blade

The CAD model was created in Solidwork 2012 and transferred to FLUENT workbench for boundary setup and solving the simulation. Grid independent test were carried out to reduce mesh error and increase accuracy. Turbulences model from the viscous model panel was selected. The FAME fluid properties were used, where the density was 843 kg/m^3 and viscosity was 0.00272 kg/ms. The blade defined as moving wall with 31 rps. The tank wall was defined as stationary wall. SIMPLE scheme was selected for the pressure-velocity coupling while for spatial discretization section, the green-gauss node based was set. The second order upwind was used for the momentum, turbulent kinetic energy and turbulent dissipation rate to arrive at the best solution.

Results and Discussion

Moving blade in the tank with constant speed will distribute pressure along fluid in the tank. The different pressure distribution when using different type of blades with a same rotational speed were oberserved as shown in Fig.2 (a), (c) and (e). The pressure distribution along blade also shows different location distribution and value for different blade type as seen in Fig. 2(b), (d) and (f).

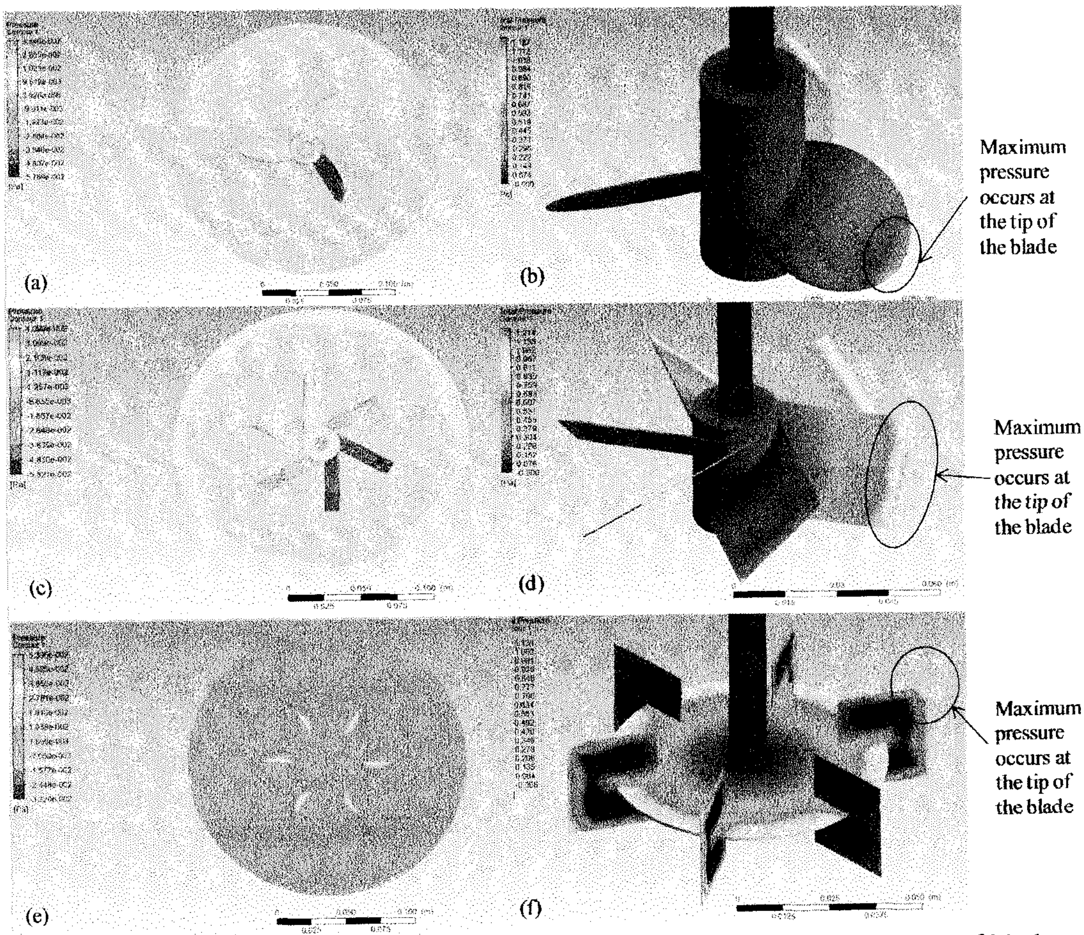


Fig.2: Pressure distribution in the fluid and at the blades for three different types of blades; (a) & (b) three bladed mixing propeller; (c) & (d) pitch turbine blade; (e) & (f) Rushton blade respectively

Fig. 2(a) shows a pressure distribution in the mixing tank when using three bladed mixing propeller. The maximum pressure occur around blade was 0.03846 Pa and minimum pressure was 0.00274 Pa. Negative value means the value is in the reverse direction from the counterclockwise direction. The average pressure in the tank using three bladed mixing impellers was 0.01 Pa. Fig.2 (b) shows pressure contour for three bladed mixing propeller type The maximum pressure is observed at the tip of blade. The maximum value for stress is 1.187 Pa and the minimum pressure value is around 0.1 Pa. In addition, the high pressure occurs at the tip of the blades. This is due blunt shape of the blades that increases the pressure. The blade tips are most exposed to the fluid surroundings and cause a higher shear between the fluid and the blade.

The pressure distribution in the reactor tank when using the pitch blade type is shown in Fig. 2(c). It showed that the maximum pressure occurs at 0.04 Pa and minimum pressure at 0.02 Pa. The average distribution pressure is 0.02 Pa. The blade flat surface is inclined with 45 degree for pitch turbine blade. The surface area of the blade tips is bigger than the three bladed mixing propellers. Therefore, the fluid with high velocity experienced more impact at the blade tip during the mixing process. The shearing force is also at the maximum at the tips compared to the blunt shape of propeller, Figure 2(d) for this type of blade. This will enhance rapid mixing.

As for Rushton blade as seen in Fig. 2(e), the pressure distribution in the mixing tank occur at 0.05 Pa for the maximum pressure and near to 0 Pa for the minimum pressure. Fig. 2(f) shows the contour of pressure along Rushton blade. The shape for Rushton blade is different with the other two, with one thin circular hub, one circular disc and six vertical blades. It can be clearly seen that the pressure distribution is higher at the circular disc compared to the blades. This is due to the higher hydrostatic force acting on the horizontal flat disc compared to vertical flat blades, due to the fact that the surface contact area at the disc is larger than the blades. The maximum stress occurs at the tip of blade surface but it only occurs at the corner of the tip. The maximum stress value is 1.42 Pa and near to 0 Pa for the minimum value.

The pressure distribution in mixing tank only shows a small variation on the average pressure for all blade types, Fig. 2(a), (c) and (e). This is due to the same speed of rotation blade and assuming the flow is incompressible. It can be seen that from Fig. 2(c), the highest pressure distribution along the mixing fluid was created by pitch turbine blade type. When comparing the pressure distribution at all three blade types, the Rushton blade gives the highest pressure at the tips of the blades.

Conclusion

In conclusion, the three different biodiesel mixing blade type has shown different pattern of pressure distribution. The Rushton blade type has shown the highest pressure distribution at the tips of the blade. This is due to the shape and design of the blade. Therefore, a careful selection of blade types and design is essential for enhancing the mixing performance of the biodiesel.

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