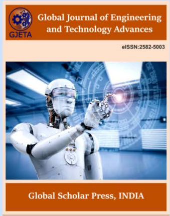
Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/



(Research Article)

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Simulation of the fluid flow pattern and property estimation for bio-diesel plant design

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Global Journal of Engineering and Technology Advances, 2025, 22(01), 038-045

Publication history: Received on 29 November 2024; revised on 08 January 2025; accepted on 10 January 2025

Article DOI: https://doi.org/10.30574/gjeta.2025.22.1.0234

Abstract

The fluid flow pattern that occurs in the bio-diesel production process is related to viscosity, flow velocity, and pressure. Fluid flow is a paramount cause of failure in pipes in several industries. The heat transfer cause across pipes needs to be analyzed to avoid failure during operation.

The simulation and visualization of fluid flow in the plant pipes were developed for the pressure drop along with the length of the pipe. Flow patterns was analyzed using a Computational Fluid Dynamics model approach (CFD). The CFD within the ANSYS environment has three important stages, namely pre-processing, finding solutions, and post-processing. Mesh was generated and the material properties were assigned. The boundary conditions were stipulated, and the process analyzed to ensure convergence of the solution in a stable state.

High density of the blend was observed for 40% bio-diesel blend and low density at 5% bio-diesel blend. The results of the correlation analysis shows that density is directly proportional to bio-diesel content. The density-composition depict a uniform increasing density value with percentage bio-diesel mixture content. The viscosity slightly increases with bio-diesel content. There is a clear trend of viscosity increasing proportional to bio-diesel content. The simulation ensures that the parameters for the design and fabrication of the bio-diesel reactor as obtained from the simulation results is optimal.

Keywords: Bio-diesel; CFD; Catalyst; Blend; Fluid; Viscosity; Volume fraction; Blend-density; Pipes

1. Introduction

Bio-diesel is a transesterification process that produces fatty-acid-methyl-ester from the mixing process of methanol and triglycerides. The reaction begins when alcohol, such as methanol, is catalyzed, usually by sodium hydroxide (NaOH). This mixture is then added to oil that is derived from oil seeds or animal fats. The process is relatively simple and does not produce any waste products. It is important to note that this is a required process in the use of bio-diesel, and raw oils should not be used as substitutes [1]. It is important that the reacted methanol should be in large quantities, or greater than the stoichiometric ratio of the transesterification reaction in bio-diesel production so that the reaction process is balanced. The reaction equilibrium could be obtained with 3 moles of methanol reacting with 1 mole of waste vegetable oil. The static mixing reactor (SMR) mechanism usually produces smaller mixed particles to make them easier to blend during mixing by increasing the turbulence that occurs in the flow in the mixing process of methanol and triglycerides. The use of SMR can also produce mixing in a short time and does not require high temperatures to accelerate the reactions that occur. It is necessary to study this fluid flow pattern to determine the type of flow that

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occurs in the use of a static mixer. The collision between the particles during the fluid mixing process determines the success in the fluid mixing process. The higher the particle collisions that occur, the better the mixing results obtained and vice versa. The flow pattern that occurs in the bio-diesel manufacturing process also determines the quality of the bio-diesel produced.

The fluid flow pattern that occurs in the bio-diesel production process is related to viscosity, flow velocity, and pressure. Flow patterns can be analyzed accurately using a computational fluid dynamics model approach or CFD (Computation Fluid Dynamics). CFD has three important stages, namely pre-processing, finding solutions, and post-processing. Fluid flow is a paramount cause of failure in pipes in several industries. The heat transfer cause across pipes needs to be analyzed to avoid failure during operation.

This study centered on understanding the bio-diesel production process, the bio-diesel processor design, modeling, and optimization using the computerized fluid dynamics method (CFD) towards achieving a global improvement in the design of the processor and production process and control of bio-diesel as an alternative source of energy. The study focused on fluid dynamics and using computational fluid dynamics (CFD) to visualize and analyze bio-diesel fluid motion. It is important to analyze and understand the fluid flow in the pipe's inner side at each distance, starting from the inlet to the outlet of the system. Some novel core computational tools can be used for such a study like ANSYS Fluent and MATLAB software [2].

CFD techniques were developed over the years with the hard way of trial and error, refine and many validation and assessment procedures. Some other model such as the Standard k-ε turbulence model also known as two equation turbulence model had been successfully used for modeling such fluid flow [3].

The basics of computational fluid dynamics (CFD) are recalled, and the place of CFD in engineering and education is described. Software and hardware requirements were elegantly discussed. By that time one can assume that the first stage of development was carried out with remarkable results that built bridges of confidence between researchers and the used on the application side (industry and Power generation sectors) [4]. The use of ANSYS Fluent software can be the best approach that displays clear predictions. The CFD techniques can predict the flow of fluid and related phenomena, momentum behaviors of heat, and mass transfer by solving the governing mathematical models using numerical solving method. The mathematical model includes conservation of mass, momentum, energy, species, and effects of internal and external forces. The ANSYS Fluent is an advance software for analyzing the effect of fluid properties on fluid transport through any systems. Another advantage on the ANSYS Fluent is the developed image for the flow behaviors at inner pipe can be easily visualized with color full picture that can be analyzed well. Since viscosity provides flow resistance [5], high viscus fluids have high shear force, and it takes long time to reach to the target position. So, the study under the viscosity-based investigation have been chosen. In this study, MATLAB coding program was incorporated to comparing the results with ANSYS Fluent results for the fluid flow through the pipe. Then, simulation and visualization of fluid flow in pipe were developed for the pressure drop along with the length of the pipe. In addition, the velocity profiles at different position in the pipe were also developed. Further, the analysis was carried out for the effect of viscosity on velocity profile and residence time with respect to fluid flow [6]

2. Material and methods

The following materials were used to construct the bio-diesel processing plant. These include the Reactor tank containing heating element and a stirrer motor, the Methoxide tank in which mixing the methanol and lye are mixed together and injected into the reactor, Waste Vegetable Oil tank which contain the Waste Vegetable Oil pumped into the reactor tank for processing, the Settling tank also called Sedimentation tank for glycerol recovery, the Glycerin tank connecting to the settling tank for storage of the recovered glycerol, the Wet Wash tank which serves as a purification process of wet washing with hot water, Dry Wash tank for the trapping of water content of the product after wet washing process, the Storage tank which is used to store the bio-diesel product and the Water Heater tank placed at the top of the bio-diesel processing plant to heat up water that would be pumped into the wet wash tank and the 1.5 hp centrifugal pump [7]. The construction of the bio-diesel plant is obtained in Openibo et al, [12]. The plant is as shown in Figure 1.

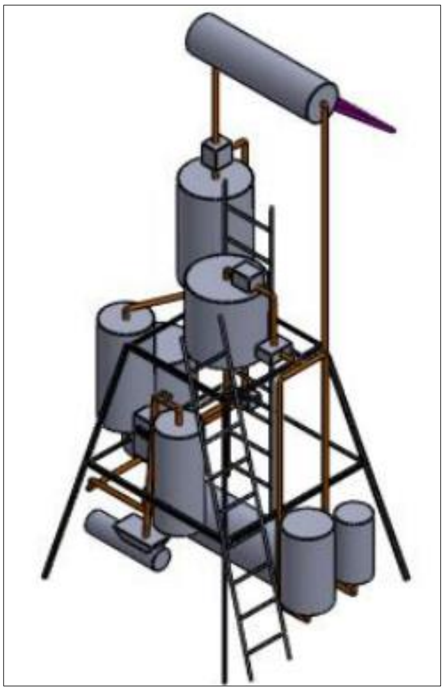

Figure 1 Developed bio-diesel Processing Plant Source: Openibo et al., [12]

The process is simulated using ANSYS software. The ANSYS was used to determine how a product will function with different specifications, without building the test products [8].

Analyzing fluid flow in a bio-diesel plant using ANSYS involves defining the geometry of the plant by creating the 3D model of the plant including the tanks, pipes, and the reactor using the ANSYS design modeler. The mesh is then generated for the geometry using the meshing command. It is important to ensure that the mesh is refined in critical areas such as where the fluid flow changes or around components that significantly impact flow.

The material properties were assigned to each of the component involved in fluid flow, considering factors like viscosity and density of bio-diesel, water, or any other fluids in the plant. The boundary conditions were defined by specifying inlet and outlet conditions, pressure, temperature, and any other relevant parameters for a realistic simulation. The fluid flow analysis was then setup using ANSYS Fluent or CFX. Specify the type of analysis (steady-state or transient), turbulence models, and solver settings.

- **Solver Execution:** The simulation was set to run, and the program was allowed to solve the fluid flow equations. The convergence of solution was monitored to ensure it reaches a stable state.
- **Post-Processing:** The Post-process of the results was done using ANSYS CFD-Post or Fluent. The parameters which include velocity profiles, pressure distributions, and temperature gradients were analyzed to obtain the fluid behavior within the bio-diesel plant. The results were visualized through contour plots, streamlines, and other visualization tools provided by ANSYS to gain insights into the fluid flow patterns

3. Results and discussion

The simulation was iterated for modifications based on the subsequent results and additional runs were carried to validate the changes.

3.1. Volume fraction

The Diesel-bio-diesel blend in the flow process in the connection pipes of the plant do not interact. This agrees as studied in Lim et al. [9]. The liquids are completely miscible, non-polar and their volumes are additive practically when blended. In this study the kinematic viscosity and volume fraction are utilized instead of the absolute viscosity and mole fraction. Figure 2 shows the contour of bio-diesel volume fraction in diesel bio-diesel mixture after the blend process for 10 minutes with 60 rpm blade rotational speed in mixing tank. Lower region is mark following the bio-diesel composition and then patched for bio-diesel volume, either diesel is patched for upper level. As can be seen from the Figure 2, the bio-diesel phase distribution for B15 to B40 reported significantly uniform distributed than the other two compositions. Highest bio-diesel volume fraction can be seen at lower area of mixing tank. Poor design of mixing blade is one of the main causes the bio-diesel phases cannot uniformly distribute to entire mixing tank. Overall, yellow contour is the main output of this blending process. The yellow phase will influence more on final properties of the diesel bio-diesel mixture.[9]

3.2. Blend Density

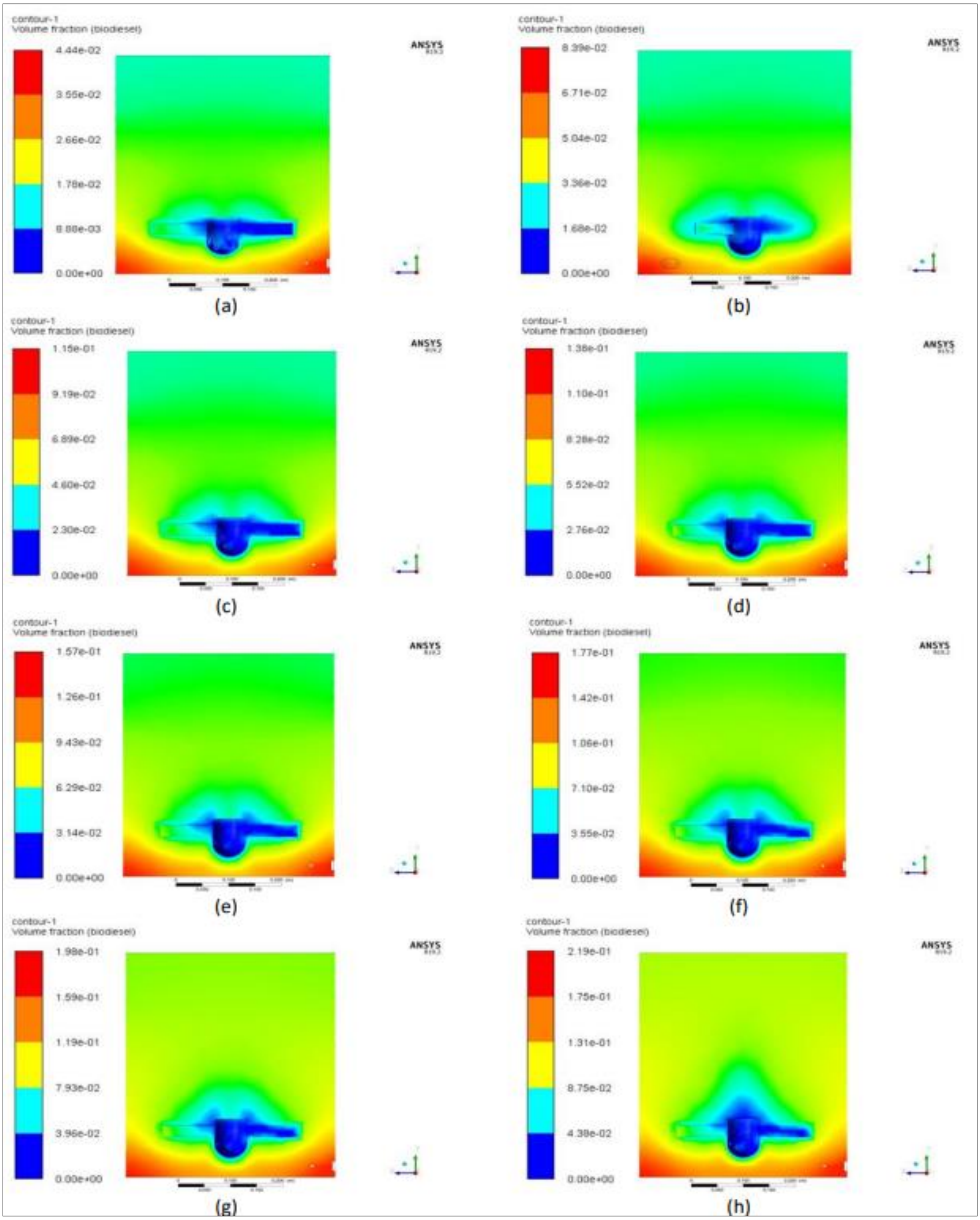

Figure 2 Volume fraction contour for diesel bio-diesel blend. (a)B5, (b)B10, (c)B15, (d)B20, (e)B25, (f)B30, (g)B35 and (h)B40

The variation in blend density with bio-diesel content is shown in Figure 3. High densities of mixture are detected at bottom of mixing tank. This phenomenon is detected because of the high-volume fraction of bio-diesel at this area. However, the lowest density of mixture is located at around the rotating blade represented with red color region. High fluid flow around blade causes this area has lowest density as is observed in Figure 3. This is understandable because the bio-diesel has high density compared to diesel. [10]The bio-diesel composition will influence the density of the mixture. Major density properties of this mixture are shown in the yellow region of the figure 3. High density detected in 40% bio-diesel blend Figure 3(h) and lowest density detected in 5% bio-diesel blend Figure 3(a). Further analysis of the mixture density can be referred to the figure below. The results of the correlation analysis are presented in Figure 4. As was expected, density is directly proportional to bio-diesel content. The density-composition curve shows that there is a uniform increasing density value with percentage bio-diesel mixture content. By using least square method as used by El-Araby et al., [10] to validate the result, the density of diesel bio-diesel blend is plotted as in Figure 6 and regression coefficient, R^2 is 0.988. The R^2 value shows prediction using least square method agreed with CFD simulation value [11]

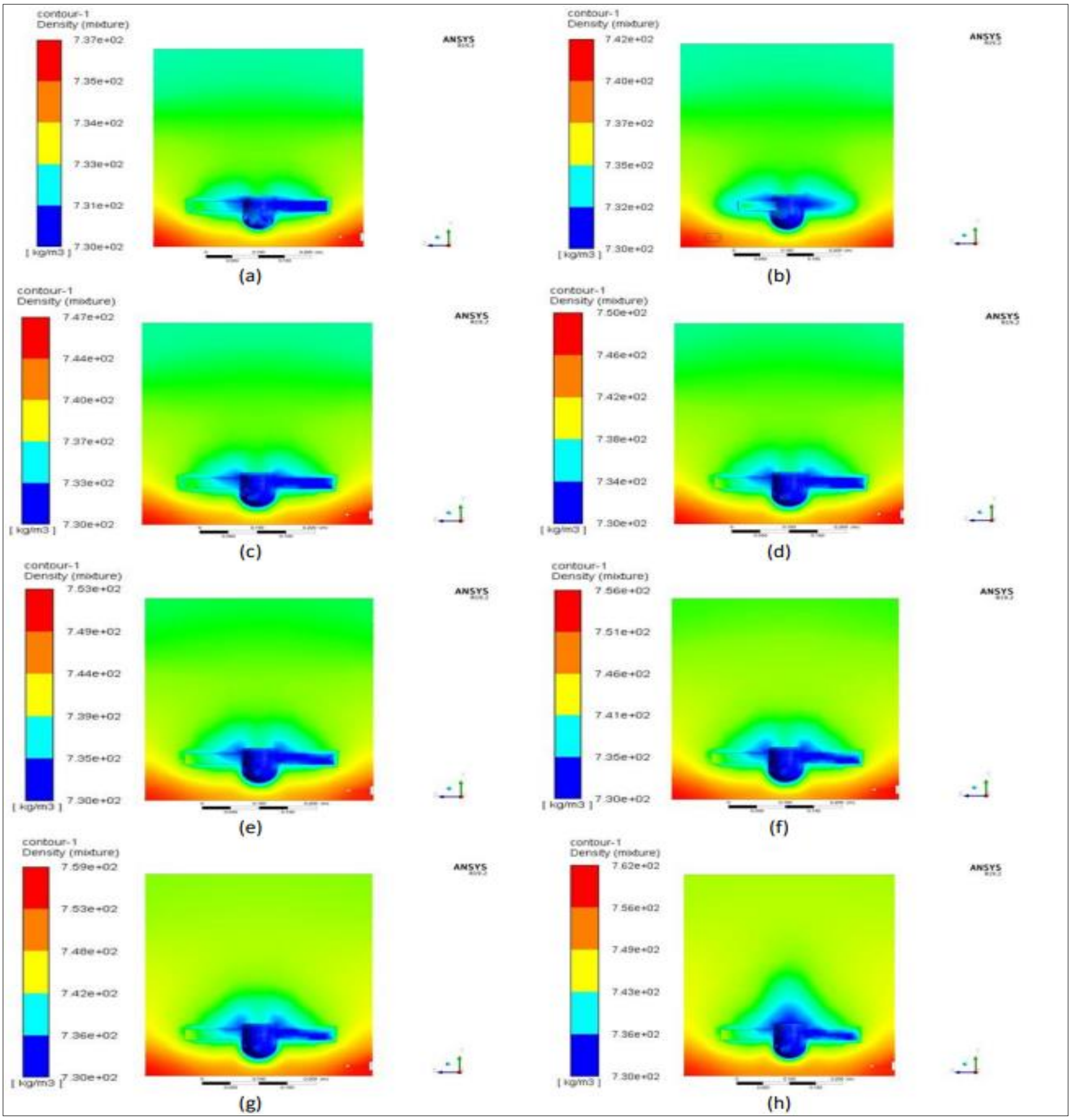

Figure 3 Density contour for diesel bio-diesel blend. (a)B5, (b)B10, (c)B15, (d)B20, (e)B25, (f)B30, (g)B35 and (h)B40

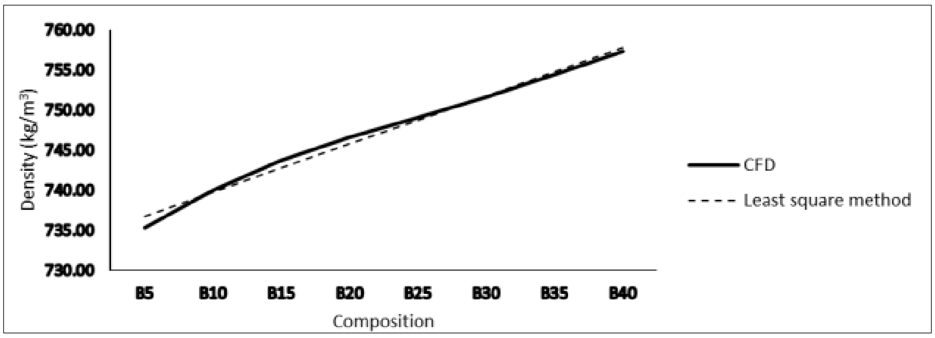

Figure 4 Density and composition relationship

3.3. Blend Viscosity

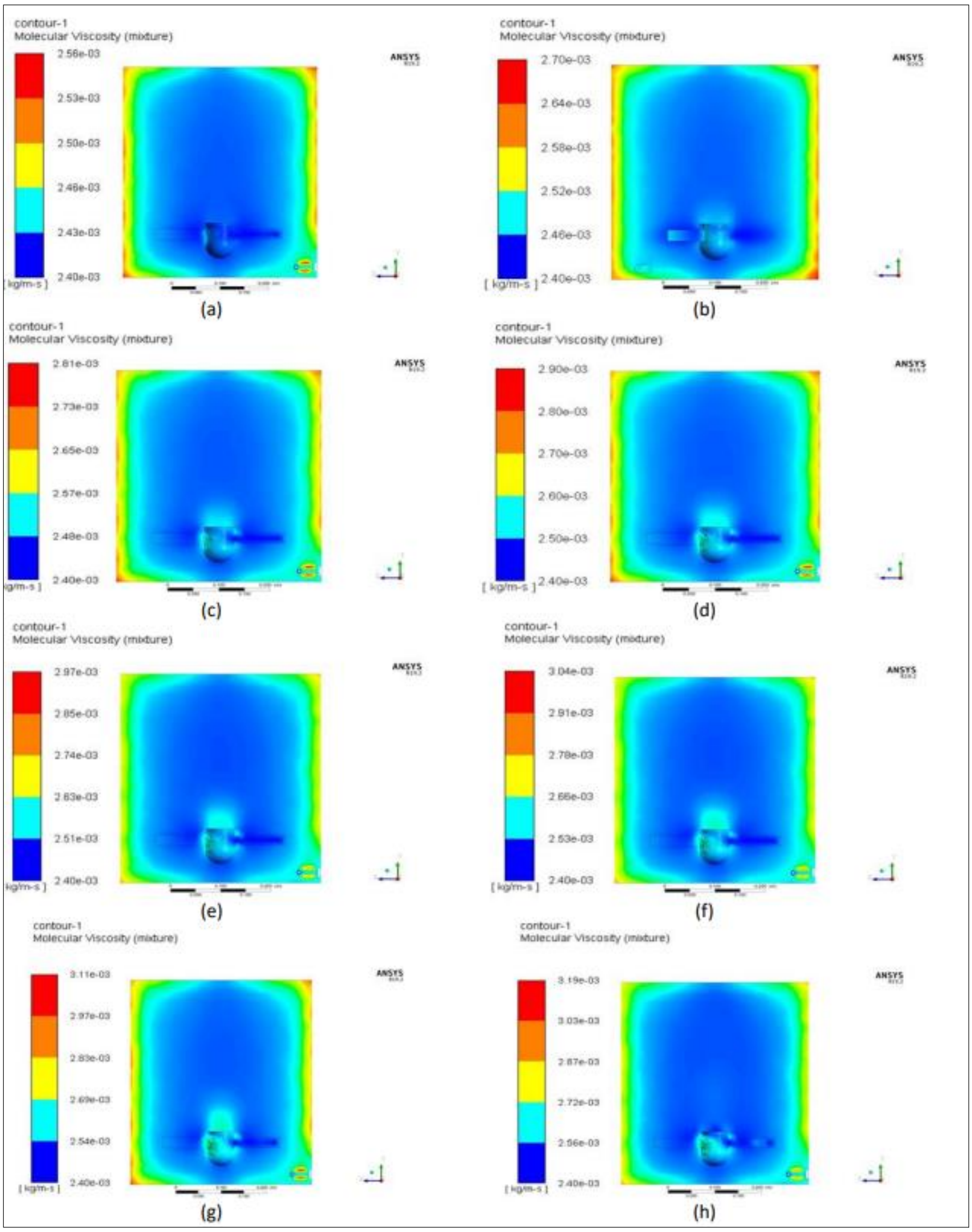

Figure 5 Viscosity contour for diesel bio-diesel blend. (a)B5, (b)B10, (c)B15, (d)B20, (e)B25, (f)B30, (g)B35 and (h)B40

Figure 5 shows the effect of bio-diesel content on the viscosity of the blends tested for eight representative compositions on diesel bio-diesel blend. All contour recorded high viscosity located at the bottom of mixing tank. This high viscosity was due to the high composition of bio-diesel located at this area represented by red contour area. Lowers viscosity can be seen located around blade area are represented by blue and cyan contour. This is because the high velocity of mixture was subjected to blade rotation. Except for B5 and B10, other blend process seems to have uniform mixer. As can be seen in Figure 6, viscosity slightly increases with bio-diesel content. There is a clear trend of viscosity increasing proportional to bio-diesel composition. Major phases formed in this blend process represented by yellow contour. This phase will have high properties influence on final mixture. However, there is no fully uniformly mix recorded in this blend process. It is due to poor blade design used in this study. More efficient blade design should be used for optimized the blend process. Verification of the result of this study is using least square method. The viscosity values using this method are plotted in viscosity versus composition graph and regression coefficient, R2 of this line is 0.954. This value shows the simulation results are acceptable and approach to actual value.

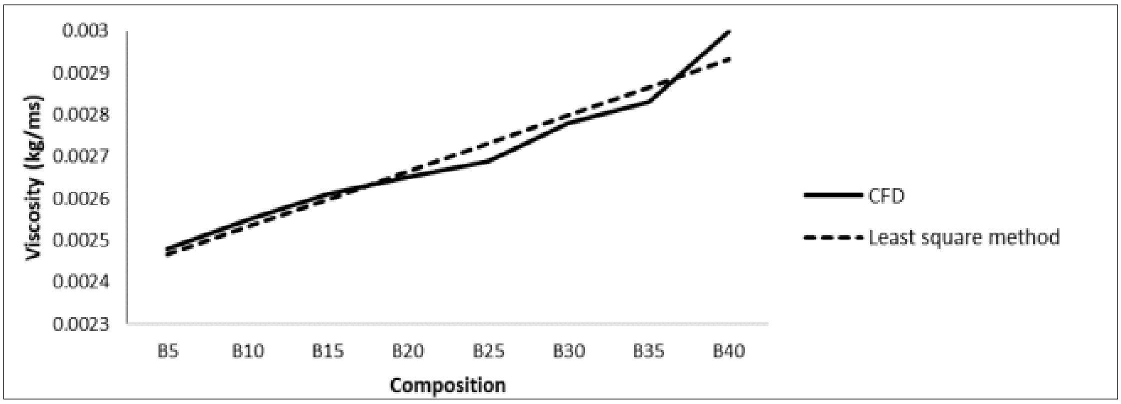

Figure 6 Viscosity and composition plot for bio-diesel blends

4. Conclusion

This study set out to obtain the relationship between density and viscosity with bio-diesel composition during blend process. Returning to the hypothesis posed at the beginning of this study, it is now possible to state that bio-diesel composition has influence on density and viscosity for bio-diesel blends. One of the more significant findings to emerge from this study is that bio-diesel density and viscosity are most influence factors for diesel bio-diesel mixture properties. However, the findings in this study were subjected to at least three limitations. First, only one blade design was used in this simulation. The volume friction contour shows this blade design cannot mix the diesel bio-diesel phases uniformly. The evidence from this study suggests that some modification on blade can be made for proper blend process. Second limitation is the time factors were not investigated in this study. Thirdly, the study did not evaluate the temperature influence during blend process. This research extends our knowledge on how diesel and bio-diesel phases mix during blend process in mixing tank. The findings from this study make several contributions to the current literature. First, suitable blade design can help diesel bio-diesel mix uniformly. Secondly, a suitable setup used will optimize this simulation process. This research will serve as a base for future studies on diesel bio-diesel blend process optimization especially on blade design.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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