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# Effects of Reaction Temperature on the Fluid Flow Pattern in a Bubble Column Reactor for Biodiesel Production

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**Abstract:** Bubble column reactors (BCR) are multiphase reactors that are extensively used in the production of biodiesel. To learn of the working conditions of bubble column reactors, computational fluid dynamics (CFD) analysis can be performed on the BCR. Reaction temperature plays a significant role during the process of biodiesel production. In this study, a CFD software which is ANSYS Fluent, is used to simulate the biodiesel production process in bubble column reactor while applying several different temperatures. The effects of reaction temperature were then analyzed based on the results of the simulation. The simulated results are then validated with a previous research paper of the same case study. For the BCR models, two different designs were generated, meshed and imported into ANSYS Fluent for simulation purposes. The reaction temperature of the BCR is set at 523 K, 543 K and 563 K. The findings from the simulation shows the different contours of the flow pattern, volume fraction, velocity, velocity vectors of the fluid and its streamlines at various temperatures. The highest reaction temperature produces the highest velocity inside the bubble column reactor. The same can be concluded with the gas holdup where higher reaction temperature causes greater gas holdup. It can be deduced that the reaction temperature affected the fluid flow pattern, velocity magnitude and gas holdup in the BCR.

**Keywords:** Bubble Column Reactor, Biodiesel, Computational Fluid Dynamics (CFD)

## 1. Introduction

Biodiesel is a form of diesel consisting of long-chain fatty acid mono-alkyl esters obtained from vegetable oils or animal fats. Like conventional or 'fossil' diesel, biodiesel is an alternative fuel. Biodiesel is produced by a chemical process called transesterification. As an alternative source of energy, biodiesel has shown a remarkable and promising performance as its prosperities are similar and sometimes exceeding the usual conventional types of fuels that are widely available in the market nowadays. There are several ways of producing biodiesel. The most common and are widely used around the world are by using biodiesel reactors. A bubble column reactor is a device used to produce and regulate gas-liquid chemical reactions and is used extensively due to its efficiency and performance in the biodiesel production process [1-3].

The concept of the research is to investigate the pattern of the fluid flow inside a bubble column reactor. The main variable that is involved in this investigation is the temperature inside the bubble column reactor when the transesterification process occurs. The problem that are considered is whether increasing or decreasing the specific temperature in a bubble column reactor affects the process of transesterification in any way.

### 1.1 Biodiesel Production in Bubble Column Reactor

A biodiesel reactor shortens the amount of time needed to process the biodiesel and makes the process becomes semi-automated or fully automated. To define a correct choice of reactors that is to be used, optimum pressure, temperature of reaction and production size are the factors that need to be considered. In general, any reactor types should provide appropriate residence time, heat exchange, and mass transfer for efficient product formation [4-6].

Bubble column reactors are preferred as it can be used for conducting a variety of two phase and three phase reactions. Some advantages of bubble column reactors are they have excellent heat and mass transfer characteristics, require little maintenance, and have low operating cost

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[7,8]. For bubble columns to work efficiently, several conditions must be complied. These working conditions include temperature, pressure, superficial gas velocity, velocity magnitude and fluid flow pattern.

To analyze and solve problems that involves fluid flows, computational fluid dynamics (CFD) can be used to achieve this objective. CFD analysis uses numerical analysis and data structures to perform calculations required to fabricate the simulation of the flow of the fluid, along with its interactions and constraints [9]. The simulation of CFD acts as a convenient tool for predicting process characteristics and their dependence on design and operating variables [10-12]. The general steps for the simulation are firstly, the geometric model must be generated beforehand via a suitable modelling software and imported into the CFD software. Next, the model undergoes meshing, hence allowing the setup to be set and calculated.

## 2. Designs and Methodology

A simulation on the bubble column reactor requires the geometric model of the bubble column reactor, the meshing of the geometry model and proper boundary conditions for the setup initialization.

### 2.1 Geometry Modelling

For the geometric modelling of the bubble column reactor, SOLIDWORKS 2018 software is used to construct its design. The format of the geometry model is converted into IGES (.igs) format beforehand to import the model into ANSYS Fluent. The bubble column reactor design and parameters are according to the past research that involve bubble column reactors. The basic parameters of the bubble column reactor are specified in Table 1 while Fig. 1 shows the geometry of the BCR model.

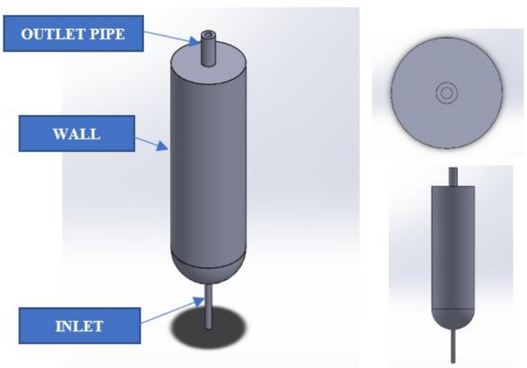


**Fig 1 - Geometry of the bubble column reactor**

**Table 1 – Parameters of the bubble column reactor**

| Parameter | Definition |
|---|---|
| Size of column | L x d = 192 mm x 55 mm |
| Size of inlet pipe | L x d = 45 mm x 10.5 mm |
| Size of outlet pipe | L x d = 25 mm x 10.5 mm |
| Type of obstacle | Perforated plate |
| Number of holes | 24 |
| Diameter of holes | 3 mm |

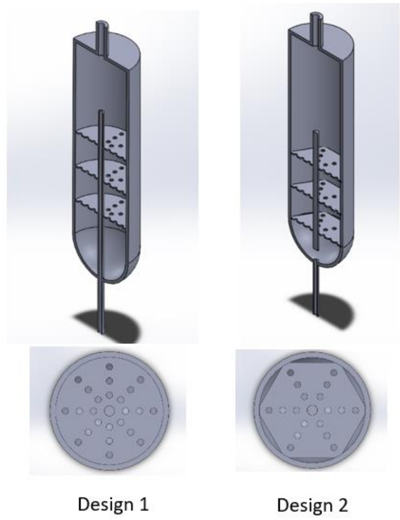


**Fig. 2 - Cross-sectional view and top view of the plate for both designs**

Two different designs of the bubble column reactor were constructed. The perforated plate inside the bubble column reactor for Design 1 is circular shaped, while for Design 2, the perforated plate is hexagonal shaped. Fig. 2 shows the cross-sectional view and the top view of the plate for both designs.

### 2.2 Meshing

Meshing is a process where grid formation is generated on the geometry. The process allows the software to run calculations based on the domain. The domain is then reduced into smaller cells and the calculation is calculated at the node or cell location. The meshing process involves some changes of mesh settings to produce better accuracy and smooth iteration in the solution. An automatically generated mesh usually has bad skewness and orthogonal quality of the mesh generated. Highly skewed cells can decrease the accuracy of the simulation and destabilize the solution.

There are three named selections, which are inlet, wall and outlet, that are created as the boundary conditions. Next, face sizing is applied to the critical parts of the meshing, components by components, so that the skewness can be reduced. Fig. 3 and Table 2 depicts the locations and details of the face sizing.

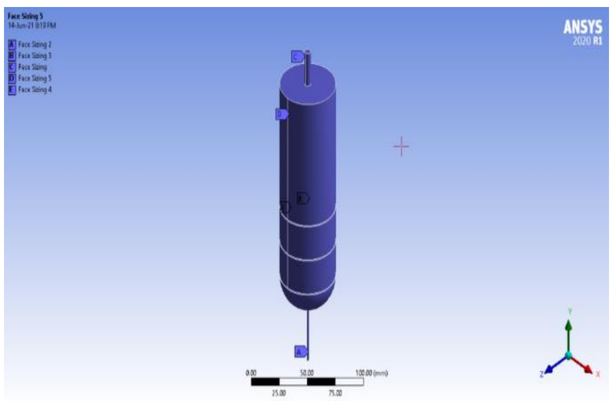


**Fig. 3 - Locations of face sizing**


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Two different designs of the bubble column reactor were constructed. The perforated plate inside the bubble column reactor for Design 1 is circular shaped, while for Design 2, the perforated plate is hexagonal shaped. Fig. 2 shows the cross-sectional view and the top view of the plate for both designs. The meshing of the bubble column reactor is shown in Fig. 4.

**Table 2 – Details of the face sizing**

| Label | Part | Faces | Element size |
|---|---|---|---|
| C | Outlet | 3 | 0.9 mm |
| A | Inlet | 3 | 0.6 mm |
| B | Shaft | 10 | 1.0 mm |
| E | Perforated plates | 151 | 1.0 mm |
| D | Wall | 8 | 1.0 mm |

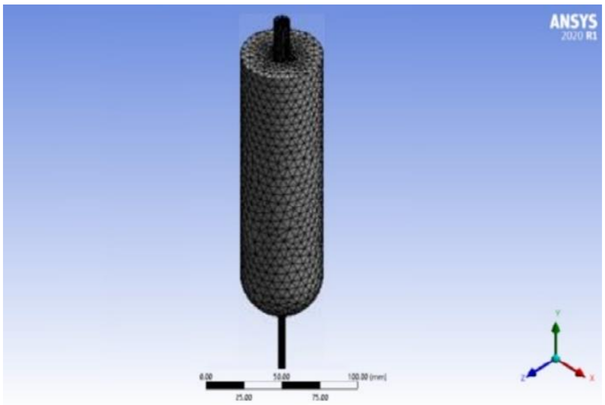


**Fig. 4 - Final meshing of the BCR**

## 2.2 Boundary Conditions

Boundary conditions are constraints compulsory for the solution of a boundary value problem. The inlet boundary condition was set up as the mixture of methanol vapor and triglyceride, with a constant velocity of 2 m/s and the outlet boundary condition as pressure boundary condition, which was set at 100 000 Pascal (atmospheric pressure). The backflow oil volume fraction value at outlet was set to one. Wall boundary condition for vapor wall and liquid wall was set as stationary wall and no slip wall.

**Table 3 – List of boundary conditions for simulation**

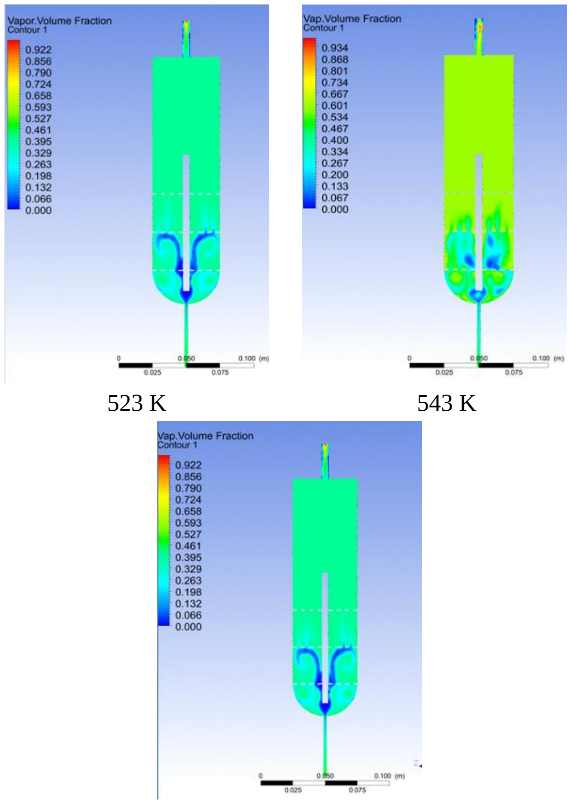
| Boundary condition | Parameter |
|---|---|
| Velocity inlet | 2 m/s |
| Thermal | 523K, 543K, 563K |
| Multiphase | Volume of Fluid |
| Turbulence | k-epsilon |
| Wall | No-slip |
| Inlet pressure gauge | 100 000 Pa |

## 3. Results and Discussion

The data obtained from the computational fluid analysis (CFD) simulation were sorted and studied. The data that was collected from the simulation includes gas holdup, the volume of fraction for methanol, velocity magnitude, velocity vectors and contours

## 3.1 Flow Pattern

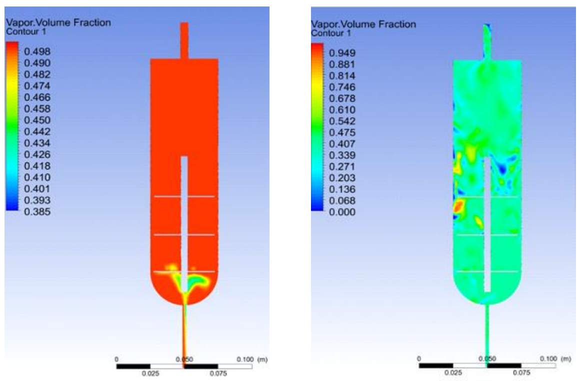
Flow pattern of a multiphase fluid system is the geometrical distribution of each individual phase that exists inside the fluid domain. Flow pattern emphasizes the flow conditions and regulates nearly all the flow parameters that are related to the simulation. The contours of methanol vapor volume fraction describe the distribution of methanol bubbles in the bubble column reactor. The time that was specified for all the simulations is for 10 seconds. During the 10 seconds, the flow of the methanol vapor in the reactor has reached the top of the reactor and begins to fill up along the walls of the reactor. The volume fraction of vapor for all three temperatures are distributed differently as the temperature changes. Fig. 5 and 6 shows the contours of vapor volume fraction for Design 1 and Design 2 respectively.



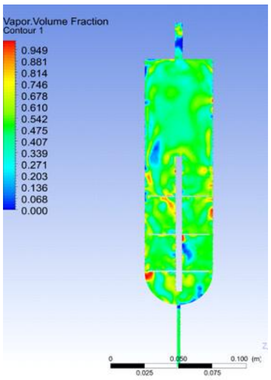
523 K 543 K

563 K

**Fig. 5 - Volume fraction of methanol vapor for Design 1**



523 K 543 K

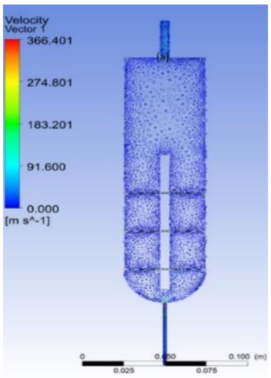



563 K

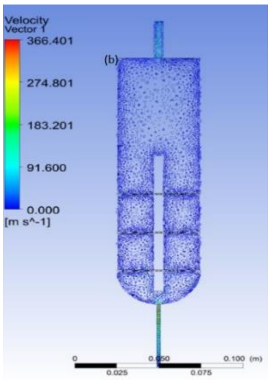
**Fig. 6 - Volume fraction of methanol vapor for Design 2**

### 3.2 Velocity vector

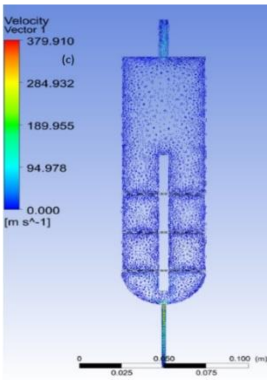
The velocity vector represents the rate of change of the position of the fluids inside the bubble column. The velocity vector is in an arrowlike shape to indicates the direction of the respective fluid. The circulation pattern of the fluid that occurred inside the bubble column reactor is at upward position and move downward towards the walls of the bubble column. This implies the production of turbulence flow inside the bubble column. Fig. 7 and Fig. 8 show velocity vectors at all three temperatures for Design 1 and Design 2 respectively. On the other hand, Fig. 9 displays the zoomed-in view of the velocity vectors at the lower part of the bubble column reactor.




523 K



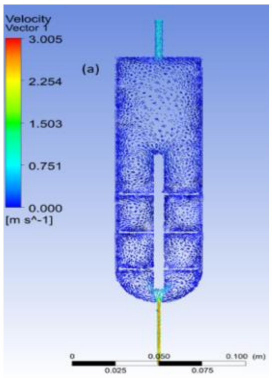

543 K



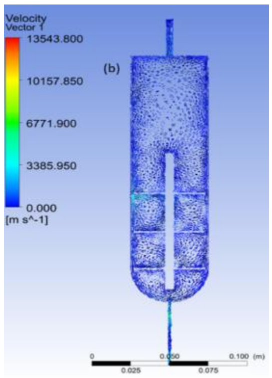

563 K

**Fig. 7 - Velocity vectors for Design 1**

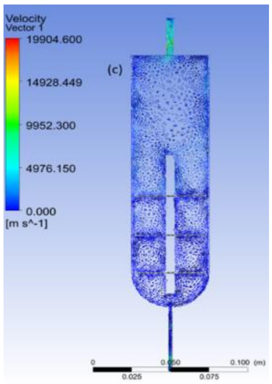
The value of the velocity increases as the reaction temperature increases. The swirling vectors around the perforated plates and the walls of the BCR signifies the occurrence of turbulence flow inside the BCR. The velocity vectors in Design 2 are more concentrated than the ones in Design 1.




523 K




543 K




563 K

**Fig. 8 - Velocity vectors for Design 2**

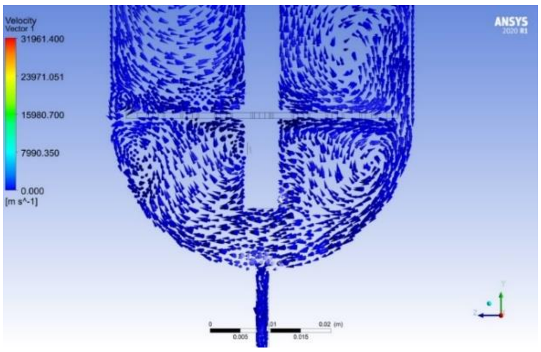



**Fig. 9 - Velocity vector at the lower part of the BCR**

### 3.3 Velocity Analysis

Velocity analysis can be performed by studying the graph of velocity against the distance inside the bubble column. Velocity is chosen as the parameter to perform the analysis due to the velocity affecting the flow pattern inside the bubble column. By plotting the results for all three temperatures, the analysis can conclude the best and suitable temperature that can be selected for the biodiesel production process.


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Fig. 10 shows the plot of velocity against distance for all temperatures of Design 1 while Fig. 11 shows the plot of velocity against distance for all temperatures of Design 2. From both figures, it can be observed that higher reaction temperature produces a higher curve for the velocity magnitude. However, the velocity magnitude values for Design 1 and Design 2 are greatly distinguished with each other, where the velocity curves for Design 1 undergo declination. As for the second BCR design, the curves are fluctuating except for the curve of 563 K, where the velocity roses significantly.

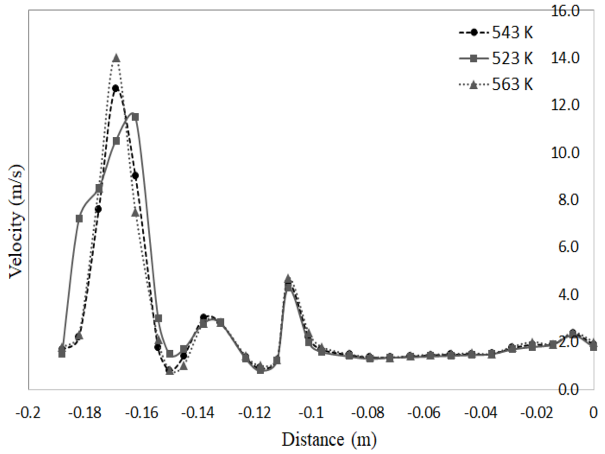


**Fig. 10 - Velocity vs distance for Design 1**

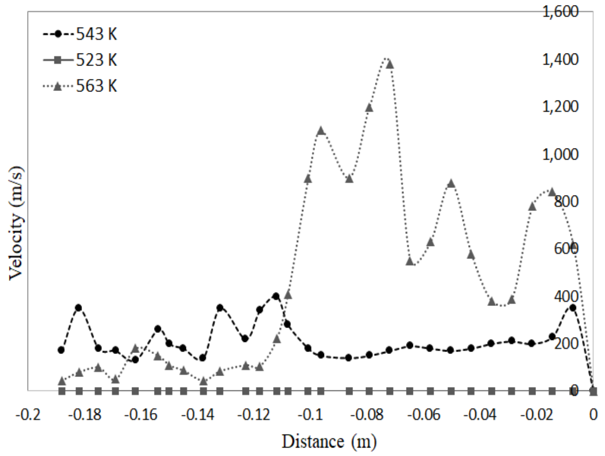


**Fig. 11 - Velocity vs distance for Design 2**

### 3.4 Gas Holdup

Gas holdup is the basic parameter that indicates the hydrodynamic characteristics of a bubble column reactor. It is one of the most important characteristics that are required to determine the effect of temperature towards the reaction rate and flow pattern. The gas holdup values that were obtained in this simulation are the value of methanol vapor volume that was present in the bubble column reactor. In another way, the reaction temperature also affects the gas holdup in the bubble column reactor. Therefore, the effect of the reaction temperature towards gas holdup was analyzed. Fig. 12 shows the graph of gas holdup against the flow time for all three temperatures.

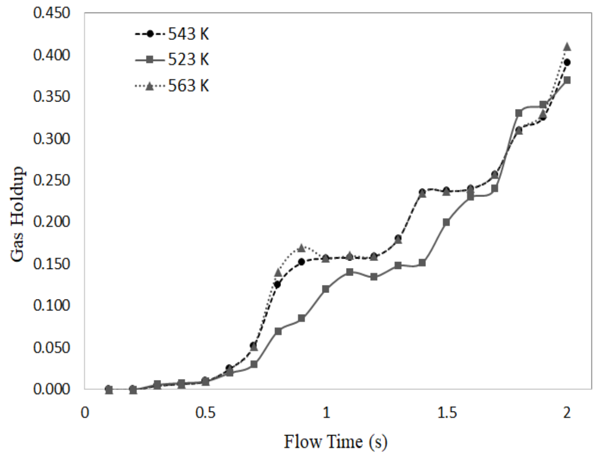


**Fig. 12 - Flow time against gas holdup**

During the period of 2 seconds, the gas holdup is increasing at a significant rate. From 0 until 0.5 seconds, the rate of gas holdup is rising at a slow rate and increased exponentially starting from 0.7 seconds. Also, the gas holdup curve for 543 K and 563 K are almost identical. The curve for 563 K is considered as the highest in gas holdup value

### 3.5 Validation

To perform the validation of the results that were obtained, the results are compared with the other study of the same case in certain aspects. Hence, the results are compared with the past previous study in by Suhaimi et. al [1]. Fig. 13 shows the graph of gas holdup against superficial gas velocity from the previous study that is used to validate the results obtained from the simulation. From the comparison of both graphs, the pattern of the curves is quite similar in a way where the gas holdup value is increasing. Thus, the results from the simulation are validated as the gas holdup is one of the important parameters in a CFD simulation.

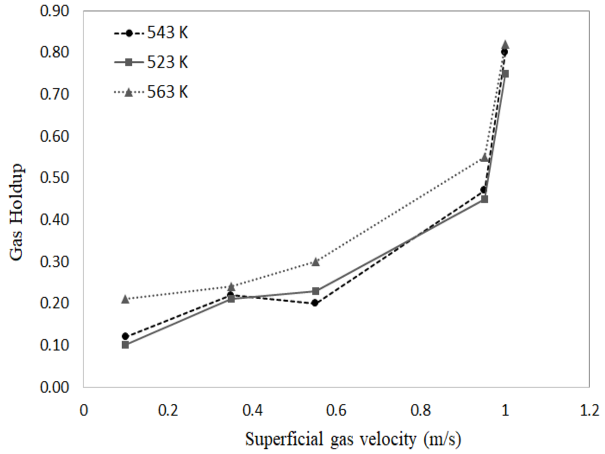


**Fig. 13 - Gas holdup against superficial gas velocity at several different temperatures** [1]


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## 4. Conclusion

The objective of this study is to determine the influence of three different temperatures on the hydrodynamics and fluid flow in a bubble column reactor used to produce biodiesel. Two distinct types of bubble column reactors were employed in this investigation, with the most noticeable variation being the form of the perforated plate. Thus, using the ANSYS Fluent program, the fluid flow inside the bubble column reactors was simulated and assessed. By employing a Computational Fluid Dynamics (CFD) method, the study of complicated fluid flow problems may be accomplished with little effort and expense. The first objective of the study, which is to conduct a simulation of a biodiesel production process in a bubble column reactor is achieved as the simulation of the fluid flow was successfully carried out and the analysis gives out the visualization of the flow pattern inside the bubble column reactor. Next, the effects of various reaction temperatures on the fluid flow pattern in the bubble column reactor were also managed to be predicted. The temperatures yield different results in the aspect of velocity, flow pattern and gas holdup. Lastly, the simulation test findings were then compared to those from a prior study of the identical scenario to validate them. There are many discrepancies between the results of prior study and this research, as previous research did not involve the use of perforated plates inside the bubble column. Having said that, the results were not significantly different from one another, and the results are regarded as acceptable.

## Acknowledgement

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