

# Novel Oscillatory Flow Reactor to Improve Biodiesel Production Continuous System

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**Abstract:** *The objective of this research is focused on the development of acceleration reaction in the process of continuous biodiesel production system by optimizing the oscillatory flow reactor (OFR). The activities of research including simulation, redesigning OFR, manufacturing, test system performance and product quality testing laboratory. Testing for the novelty OFR shows that the resident time can be shortened and the process can be accelerated of almost two times faster compared to the previous model and 12 times faster compared to batch process. Turbulent reactant flow patterns change in a good manner to ensure continuous reaction process takes place in the reactor. In addition, measurement of the biodiesel product quality shows that the properties are in the range of quality standards for biodiesel.*

**Keywords:** biodiesel, continuous system, optimizing, flow pattern, oscillatory flow reactor

## 1. Introduction

As a consequence of the growing Indonesia economy in the last 5 years, this was characterized by economic growth averaging 6.5% per year, resulting domestic fuel consumption increases. While the production of fossil fuels in the country drop from 1.4 to 0.9 million barrel per day in the last 10 years. If this condition is not anticipated to find alternative energy, it will have a negative impact on the economic development in the near future.

Development to increase the feedstock for biodiesel is already showing positive condition with the expansion and preservation of the plantation. Nevertheless, the productivity of domestic biodiesel is still very low. One of the reasons due to a production system is not optimal with a low level of productivity.

The objective of this research is to optimize the production process to obtain a prototype biodiesel plant with higher production capacity. To achieve this, the research has been carried out by optimizing a faster reaction stages in the process of continuous biodiesel production system. Redesign has been done on a continuous reactor unit, types oscillatory flow reactor (OFR) in order to obtain a more turbulent flow pattern and to assure a more homogeneous reaction even though the diameter of the reactor tube is enlarged.

### The State of Art

Research on biodiesel production process is mostly done concerning some issues related; type of raw materials, catalysts, methods and production system. The evaluation of biodiesel production conducted by Nabel et al [1] and Angelo et al [2] reported that the challenges in the development of biodiesel mainly comprises among other raw materials, production methods and catalysts.

The most widely used method to produce biodiesel (monoalkyl esters) is transesterification method [3,4], where the raw materials are derived from a variety of bio-oils (triglycerides) is reacted with methanol (CH<sub>3</sub>OH) or ethanol (C<sub>2</sub>H<sub>5</sub>OH) by addition catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) under conditions of temperature 65 °C approximately. In addition to biodiesel are formed, it is obtained glycerol by-product that can be used as raw material for organic cosmetics and soaps.

There are two types' biodiesel production system, namely batch and continuous systems. In early development, batch system was more popular to apply because its installation simple, but on the other hand this system has a shortage of the low production capacity. Development of a continuous system to overcome the low productivity in batch has been reported by some authors. Research of a continuous reactor system to overcome the low productivity in batch systems such as Harvey et al [5] developed the oscillatory flow reactor models orifice which produces eight times larger than batch processes. Rhei who studied a geometric of oscillatory flow tubular mixing models analyze the pattern of fluid flow of the reactants during the process that resulted in a model mathematics which is useful. Nouridine et al [7] developed a continuous system which emphasizes on stir tank reactors with the automatic control on the mixing of the flow reactants to increase production capacity with a better result than batch system. Likewise Kraai et al [8] who tested the effects of catalysts and continuous performance the contactor type separator (CCS) to get the production four times larger than the batch system. The study also have been conducted by the authors [9] who adopted the oscillatory flow reactor designs which was developed by Harvey et al, with minor modification. The results of the system can generate six times more than the batch system.

## 2. Methodology

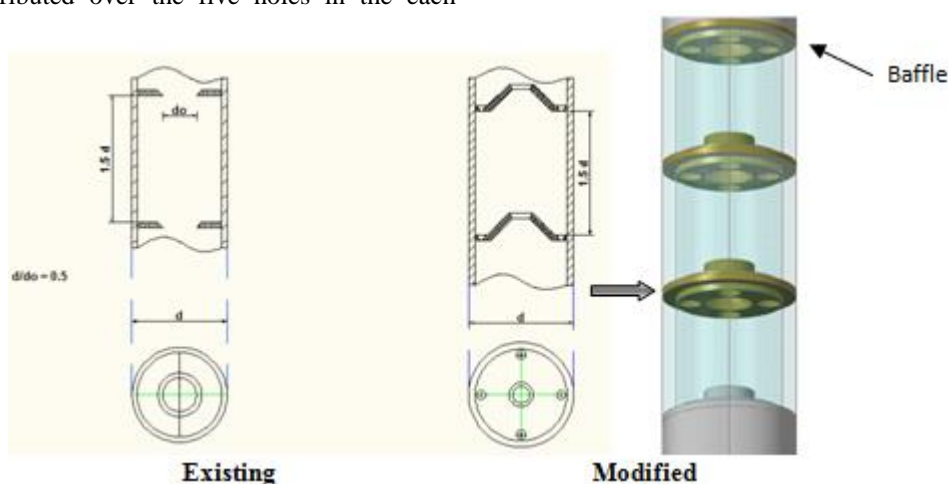
### 2.1 Novel Design of Continuous Reactor

The shorter resident time of the reactants in the reactor, has been achieved by making an innovation the OFR design. Redesign of the OFR done mainly on its baffle model which the baffle consists of five holes; one nozzle is located at the centre point of the cylinder cross-section of the reactor, and 4 other nozzles are located on the sides with a smaller diameter as shown in Fig. 1. The effect of pressure and speed has an upheaval flow when passing through baffles led to reactants react continuously along the reactor.

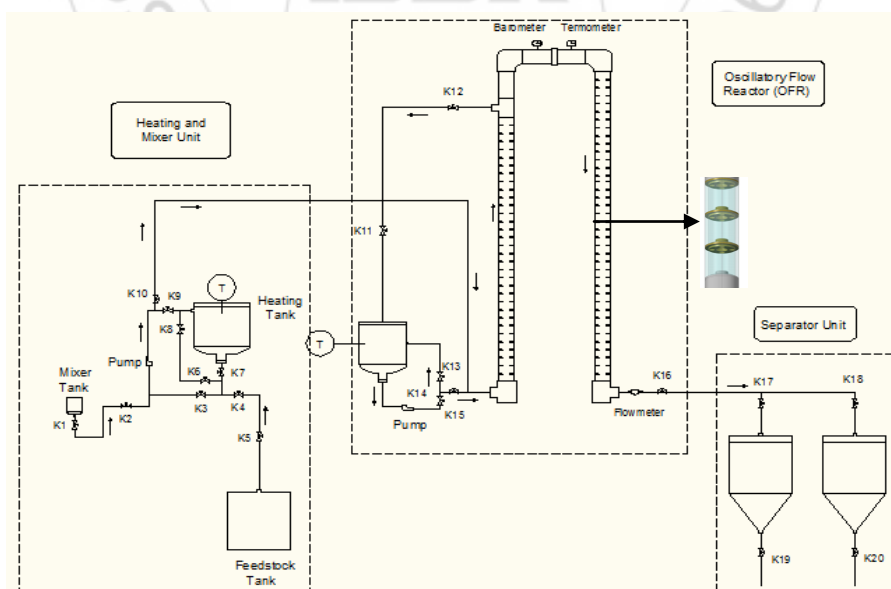
Baffles are made from steel material which has characteristic, strong and corrosion resistant. The cylindrical reactor is also made from steel (stom-simplex SCH 40) which is also corrosion resistant materials. The total area of baffles holes distributed over the five holes in the each

baffle. Half area for the four smaller diameter is at the side edge and a half area to one bigger diameter is in the middle, as shown in Figure 1.

The total length of the continuous reactor tube is 3.6 meters. There are 76 baffles installed series in a cylindrical tube, as shown in Fig. 2. The distance between the baffles is 1.5 times the diameter of the pipe reactor, where the value of this distance refers to the results of research conducted by previous researchers. A centrifugal pump is used to circulate the reactant in the heater tank. This pump also is used to pass the reactant through the reactor. The OFR is coated with insulators in order to retain heat. Scheme production process of the mini-plant is constructed as shown in Fig.2. The plant consists of three main parts namely: mixing and heating unit, reactor unit and separator unit. There is a pipeline installation equipped with valves connects units to ensure the process can take place properly.



**Figure 1:** Oscillatory Flow Oscillation (OFR), Existing and Modified



**Figure 2:** Scheme of the continuous system biodiesel production plant by using the oscillatory flow reactor (OFR)

### 2.2 Process and Materials

The process to produce biodiesel is transesterification method. The main raw materials are palm oil (triglyceride) and methanol ( $\text{CH}_3\text{OH}$ ) with the molarities ratio of 10: 1.7.

Catalysts used are sodium hydroxide (NaOH) with a ratio of 0.5 to 0.6% by mass.

First NaOH mixed with methanol which will form sodium methoxide in a mixer tank. In the mean time, the heater tank

is filled with the palm oil then heated until 45 °C. Next, sodium methoxide is mixed with palm oil in the heater tank and it is heated until reaching temperature 65 °C. The reactant is then pumped through the OFR in order to make them react continuously along the reactor.

Parameters which are monitored and controlled such as temperature, velocity and resident-times by installing several sensors and forwarded to the converter A/D next to computers for real-time data (data acquisition). The reactant flow pattern in the reactor is monitored using the video cam. To enable monitoring the flow pattern in reactor continue, it is using a transparent pipe on the monitoring point. Effectiveness of chemical reactions that occur in the novel reactor was determined by analyzing the chemical properties of the resulting product and the percentage of biodiesel products formed.

Analysis of the flow rate of the reactants in the reactor macroscopically (macroscopic flow patterns) that impact on the optimization of capacity and product quality biodiesel is by comparing data models of the existing model with the modified model. The reactant flow pattern that occurs actually in the modified OFR is also compared with the model simulation used SolidWorks tools. On the quality aspect is analyzed parameters such as density, viscosity, flash point, calorific value, and the freezing point of the product refers to the biodiesel standard RSNI 20551 (Indonesia) or ASTM-D975 (US).

### 3. Optimization Result

#### 3.1 The flow rate

Flow velocity in the reactor was calculated based on the discharge generated during the testing period. The experiments were performed several times with the same reactants molarities conditions as well as the heating temperature. Reactant flow velocity in the reactor gained an average of 0.254 m/s, the discharge range 0.129 litres/second or 464 litres/hour approximately. Resident time is 3.2 minutes on average for 23.2 litres capacity products.

The percentage product of biodiesel is 87% and the remaining 13% is glycerol.

The reactant flow velocity in the reactor compared with the results of the simulation is almost the same. The simulation flow speed is shown ranged from 0.221 m/s to 0.33 m/s, as shown in Fig. 4 which is characterized by the dominance of dark blue to light blue colour while the average test speed 0.254 m/s, as shown in Table 1.

**Table 1:** The experiment results with Novel OFR

Biodiesel Properties	Average Result
Debit [litre/sec]	0.129
Flow velocity [m/sec]	0.254
Resident time [minute]	3.20
Reynold Number (Re) [-]	1075
Biodiesel products [%]	87
Glycerol products [%]	13

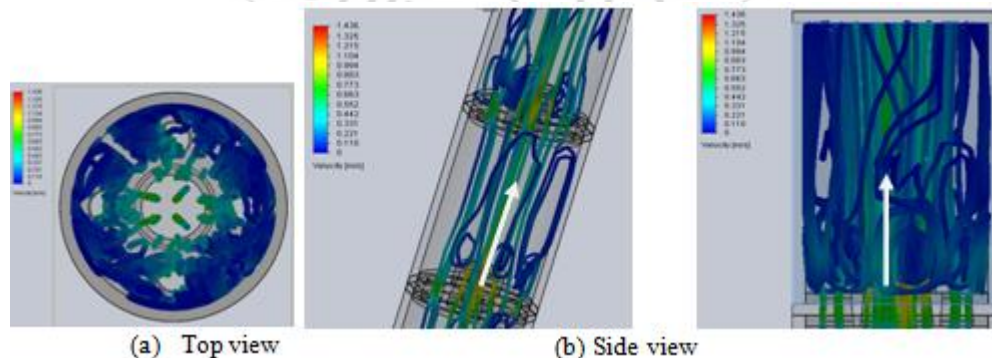
#### 3.2 The flow patterns

Reactant flow pattern in the reactor between the baffles is observed by using a high speed video cam and a digital microscope, where the result can be seen as in Fig.3.

When compared with the simulation as shown in Fig. 4, it is seen that the pattern of the flow pattern is almost the same test conditions, where the turbulent circular visible on the side of the bottom and move on to the top of the inside of the reactor between the baffles. This flow pattern allows the reactants to react continuously while moving along the reactor flows into the side of the tip.



**Figure 3:** The actual flow pattern of reactant in novel OFR



**Figure 4:** Simulation of the reactant flow patterns in the Novel OFR

#### 3.3 Quality Products

The results obtained from testing data by using the novel oscillatory Flow Reactor (OFR), indicates that the resident time of reactants in the reactor an average of 3 minutes 20 second. This means that when compared with the previous type developed OFR only a third (time resident previous

time is 8 to 10 minutes) on the capacity of the same product. Rapid fluid flow caused by the effect of nozzles which is placed in the middle of the baffles affects significantly the flow rate of the reactants model is in the reactor. While the orifice on the edge of baffles in the reactor led to the emergence of turbulence on which helps the reaction between reactants is going well, as shown in Fig. 3 and Fig.

4. The images obtained from the recorded video separated gradually by snapshot. The visible pattern of the flow at a certain periods experiencing turbulence models are changing rapidly and create different patterns on an ongoing basis.

The quality of the biodiesel products was in the range required in accordance with ASTM D6751 (US standard) and RSNI EB20551 (Indonesia standard). There are several properties of biodiesel quality that have not been measured carefully because of the limitations of measuring instruments, however viewed in the physical product, it looks dark yellow colour with a specific scent which indicates good quality.

**Table 2:** Biodiesel Quality Compare to RSNI and ASTM Standard

No	Standard of properties	RSNI EB20551	ASTM D6751	Result
1	Density (kg/m <sup>3</sup> )	850 -890	860 - 900	860
2	Viscosity, 41 °C, (mm/sec)	2.3 – 6.0	1.9 – 6.0	4.0 -6.0
3	Flash point, (°C)	Min 100	>=130	120 -134
4	Glycerol content, (% mass)	<=0.24	<=0.24	0.36
5	Heating Value, LHV (MJ/Kg)	N/A	N/A	41.16
7	Pour point, °C	18	0	5
8	Total Sulphur, %	<0.01	<0.05	0

#### 4. Conclusions

By using a novel OFR at the stage of the reaction system in the biodiesel production process can take place faster than the OFR previous model. In previous studies the production speed was obtained 8 times faster when compared to a batch process. Using the reactor with new innovations, the average production rate can reach 12 times faster. The product quality testing of biodiesel properties are in the range of quality standards of RSNI EB20551 and ASTM D6751.

#### 5. Outlook on Future Research

Experiment with the magnetic field effect is predicted to help stage the reaction becomes faster and homogeneous to be analyzed further. Another thing associated with advanced research is to design and make a prototype biodiesel production system that ensures all units can work continuously which can be adopted for the industrial-scale plant.

#### 6. Acknowledgement

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