Proceeding ICST (2021)
e-ISSN: 2722-7375
Vol. 2, June 2021

Application of induction heating in the biodiesel production process using oscillatory flow reactor

Suryanto Suryanto, Jumadi Tangko

Mechanical Department, The State Polytechnic of ujung Pandang, Makassar, Indonesia

suryanto@poliupg.ac.id

Abstract. Maintaining ideal temperature conditions in the reaction process of biodiesel formation is very important to obtain yield production. The objective of this study is to evaluate the effect of using induction heating in the biodiesel production process using the oscillatory flow reactor (OFR). The biodiesel formation process method uses a transesterification reaction with palm oil as raw material. The effect of using an induction heater in the reactor to maintain the reaction temperature at ideal conditions in OFR was evaluated, including the effect of magnetic fields on the transesterification reaction.The experimental results show that the temperature in OFR can be maintained at ideal conditions in the range of 65^0C. The yield of biodiesel reaches 90%. Analysis of the properties of biodiesel products shows that there is a tendency to increase in quality in some of its physical and chemical properties which are influenced by the effect of magnetic fields induced by OFR.

Keywords: Induction heater; biodiesel; continuous system; transesterification; oscillatory flow reactor

1. Introduction

The production process for the formation of biodiesel (monoalkyl ester) which is most widely used on an industrial scale is by using the transesterification reaction method [1]. When compared with thermal cracking and microemulsions, transesterification is the more cost-effective and energy-efficient process [2], [3].

In the transesterification method, raw materials derived from various vegetable oils (triglycerides) are reacted with methanol (CH3OH) with additional catalysts such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). Apart from biodiesel that is the main product of this reaction, a by-product is also obtained in the form of glycerol that can be used as raw material for cosmetics and soaps.

There are several factors that influence the biodiesel production process such as the reaction temperature, the feedstock composition, including different contents of free fatty acids (FFAs), the alcohol-to-oil molar ratio, the mixing speed, and the reaction time [4]Fernando. Research on ideal temperature conditions in transesterification reactions has been carried out by several authors [5] and

[6]. The reaction temperature that produces yield is in the range of 60 to 65 0C [5] with a time of 60 minutes to 90 minutes. Other factors that influence the yield of biodiesel are molar ratio, mixing speed (the type of reactor) and type of feedstock which also greatly affect the optimal biodiesel formation process, this has been studied in detail by authors including [7] and [4] with a kinetic model.

A study that has been conducted by the author who developed a continuous reactor that adopts the oscillatory flow reactor design [8], it was found that a continuous system on a pilot-plant scale using a circulating centrifugal pump in the reactor can produce six times more production capacity than a batch system. The results of this study have been reported [6]. The OFR design that has been researched and developed consists of a tube of a certain length, in which the inner side of the pipe is placed in series a number of baffles in the shape of an orifice with 5 holes. The distance between each baffle orifice is 1.5 times the diameter of the reactor tube, as in Figure 1. A reactor with such a construction allows the reactants to flow while oscillating along the reactor tube with the impulse of a pump power. The effect of the oscillating flow causes the reactants to react homogeneously along the flow in the reactor.

The results of the evaluation of the novel OFR show that there are obstacles in maintaining the ideal temperature conditions for the transesterification reaction in the reactor tube. This is due to the construction of the reactor in the form of an elongated tube (3.6 meters) and it there are several baffles along the tube made of metal. The use of an electrical-heater or microwave is difficult because it requires a more complex construction which results in high costs. The reactor tube has been isolated to reduce heat loss, but there is still a significant temperature drop at the exit side of the reactor tube.

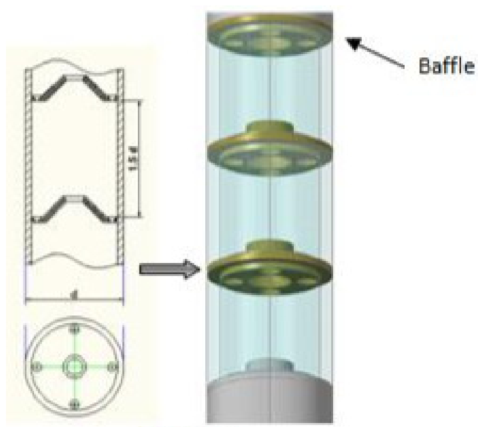

Figure 1. The Novel Oscillatory Flow Reactor

To overcome the decrease in reactant temperature in the OFR system, induction heaters are used to maintain the reaction temperature along the flow in the reactor. So far, the use of induction heaters is widely used for metal processing, medical applications, and cooking. According to the author [9] the use of an induction heater has several advantages such as efficient, cost-effective, precise and clean. Another author [10] who studied the effect of induction heater on bed reactor mentioned that the presence of magnetite could drive transesterification effectively when placed in an alternating magnetic field.

Induction Heating and the Effect of Magnetic Fields: Figure 2 shows the basic principle of conduction heating to be applied to the reactor tube.A magnetic field (*B*) is formed around a coil which is energized by an electric current (*I*), and its value can be calculated based on the following equation [11],

$$B = \mu o \frac{N}{l} I \tag{1}$$

Where *N*is the number of loop, *l* is the coil length and μo.

If on the inside or around the coil is placed a ferromagnetic material such as iron, copper or aluminium as electricity conductor, the electromagnetic waves will be converted into Eddy Current (Eddy Current). Eddy current will cause heat in the conductor due to the Joule effect. Where the power (P) converted into heat that appears on the conductor can be calculated based on the equation,

$$P = V.I, or\ P = RI^2 \text{[Watt]} \tag{2}$$

Where the value of *R* depends on the type of conductor, shape and length of the material, *I* is the amount of current and *V* is the voltage applied to the circuit. The amount of heat (*E*) that can be released by the conductor is a function of heating time (*t*) which can be written with the equation,

$$E = I^2 R.t \text{ [Joule]} \tag{3}$$

Because the OFR reactor tube is made from galvanized pipe material, the reactor tube becomes a load of the flowing current. It will get heat according to equation (3). The coil of the induction heaters are installed around the reactor tube. The reactants that flow in the reactor tube will get hot because of the induced effect of the reactor pipe. The reactor tube will pass heat by convection to the reactants flowing in it.

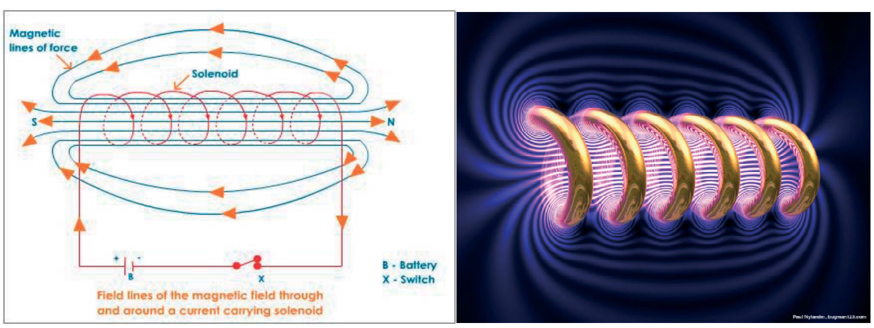

Figure 2. Magnetic field arises from a conductor coil which is energized by current.

In addition to the heat obtained by the use of induction heaters, the presence of a magnetic field that penetrates into the reactant stream can also affect the formation of biodiesel yield in the esterification reaction [9] thesis S3]. If in a magnetic field the specimen charge q with velocity v is flowed, then a force F which is perpendicular to v is obtained, the magnitude of which is;

$$F = q.v.B\ sn\ \theta \tag{4}$$

Where F = magnetic force (Newton), q = electric charge (coulomb), v = speed of charge (m / s), and θ = angle between v and B.

Theoretically, this can be explained that the atomic nuclei of an element can be grouped into two parts, atomic nuclei that have spin and atomic nuclei that have no spin. The atomic nucleus which has spin like hydrogen will cause a small magnetic field which is expressed as the nuclear magnetic moment of a vector. The atoms that have spin can be utilized in nuclear spectroscopic magnetic resonance (NMR), which can absorb energy at different frequencies.

Since a molecule containing hydrogen atoms (for example, triglycerides and methanol molecules) is placed in an external magnetic field. Then the magnetic moment of each hydrogen nucleus or proton takes one of two attitudes as seen from the external magnetic moment. The two orientations taken by the magnetic moment are parallel or anti-parallel to the external magnetic field. In parallel, the direction of the proton's magnetic moment is the same as the direction of the external magnetic field, whereas in the antiparallel state, the magnetic moment of the protons is opposite to the external field. Approximately half the protons are in parallel and the other half are in the anti-parallel state.

The amount of energy required to reverse the magnetic moment of a proton from parallel to anti-parallel depends on the amount of H_0 (outer magnet). Since H_0 is enlarged, the nucleus is easier to overturn and a proton moves from a parallel state to an anti-parallel state, it is said that the proton is resonating. The term nuclear magnetic resonance (nmr) means that the nuclei resonate in a magnetic field. The magnetic field suffered by a proton in a particular molecule is a combination of two fields, namely the external magnetic field (H_0) attached and the induced (induced) molecular magnetic field. In an nmr spectrum, the position of the absorption by a proton depends on the net strength of the local magnetic field surrounding it. This local field is the result of the applied H_0 where the induced molecular field surrounding the proton is opposite to the applied field. If the induced field around the proton is relatively strong, the magnetic field will oppose H_0 more strongly, therefore a larger applied field is needed to carry the proton to resonate. In this case the proton is to be protected and its absorption is located above the field in the spectrum, and vice versa.

The theory of the effect of magnetic fields on molecules resonance shows that the implementation of an induction heater in the OFR reactor will affect the biodiesel yield reaction. However, the analysis of the effect of the magnitude of the magnetic field on the optimization of biodiesel formation is not analysed in more detail in this paper.

2. Methodology

2.1 Implementation of induction heating

The total length of the OFR continuous reactor tube is 3.6 meters with a U shape. There are 76 baffles series installed in the reactor tube. The distance between the baffles is 1.5 times the diameter of the reactor tube. Centrifugal pumps are used to circulate reactants in the heating tank. This pump is also used to pass reactants through the reactor. The reactor tube is coated on the outside with an insulator to reduce heat losses. The mini plant production process scheme is constructed as shown in Figure 4. The plant consists of three main parts, namely: the mixing and preheating unit, the reactor unit and the separating unit. There is a pipe installation that connects the units. The installation is equipped with a number of valves (electronic solenoid valves) to allow the process to be controlled by an automation system

There are two induction heaters that are placed in the reactor with a power of 300 Watt each as shown in Figure 3. The alternating current (AC) power source is supplied through a power converter to convert the AC to direct current (DC). There are two temperature sensors placed in the reactor to send a feedback signal to the controller to maintain the ideal temperature of the reaction.The reactor tube coated with an insulator which reduces heat loss is also useful to avoid short circuits between the induction heating coil and the reactor pipe material which is made of metal.

2.2 Material and experimental setup

Material: The raw material used comes from vegetable oil, the type of palm oil produced by the palm oil industry in the province of South Sulawesi and methanol (CH3OH > 99%). The catalyst used is sodium hydroxide (NaOH).

Experimental Setup: Schematic of the production process prototype as shown in Figure 4. The prototype plant is a continuous process consisting of 4 mixer units which also function as a preheater with a capacity of 100 liters each. The four tank mixer units operate sequentially to supply reactants to one OFR reactor unit. The process of separating biodiesel and glycerol (a byproduct) uses the principle of gravity on a 1000 liter capacity separator unit equipped with a monitoring glass and transparent drain pipe. There is a central controller to regulate the pumps and valves (solenoid valves) which can work automatically to ensure a continuous process. The control signal is obtained from several sensors such as level sensors, temperature sensors and flow sensors that are installed on the tanks, reactors and pipelines.

Palm oil and methanol are mixed in a tank with ratio10:1.7 and added with sodium hydroxide (NaOH) catalyst at the molarity 0.7 % by mass, referring to previous studies [5]. The reactants are pumped into the mixing tank and heated to a temperature of 65 ^{0}C. The next process, the reactants were streamed to OFR to be reacted further to optimize the transesterification reaction to take place completely. The process of separating glycerol and biodiesel products is carried out in a separator unit.

The parameters monitored related to the OFR process are pressure, temperature, flow rate and resident-times. The reactant flow pattern in the oscillatory flow reactor is predicted by simulation using Solid Work software as shown in Figure 5.

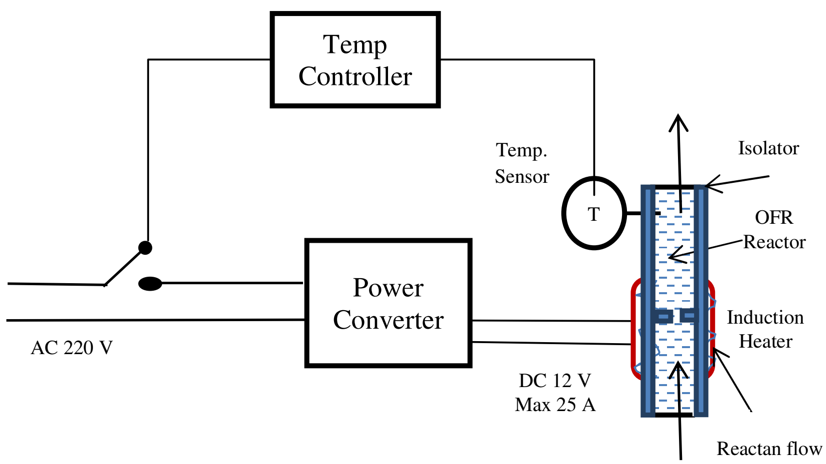

Figure 3. Schematic of controlling the use of induction heating on OFR

To determine the effectiveness of using an induction heater in the OFR reactor, experiments were carried out in two conditions. The first experiment was an experimental test without induction heating and another experiment was the implementation of induction heating on OFR. Evaluation is carried out by measuring the percentage of biodiesel products formed and testing several standard properties of the resulting product, such as density, viscosity, flash point, calorific value, glycerol content and product freezing point. The Indonesian biodiesel standard RSNI 20551 and the American biodiesel standard ASTM-D975 are the references.

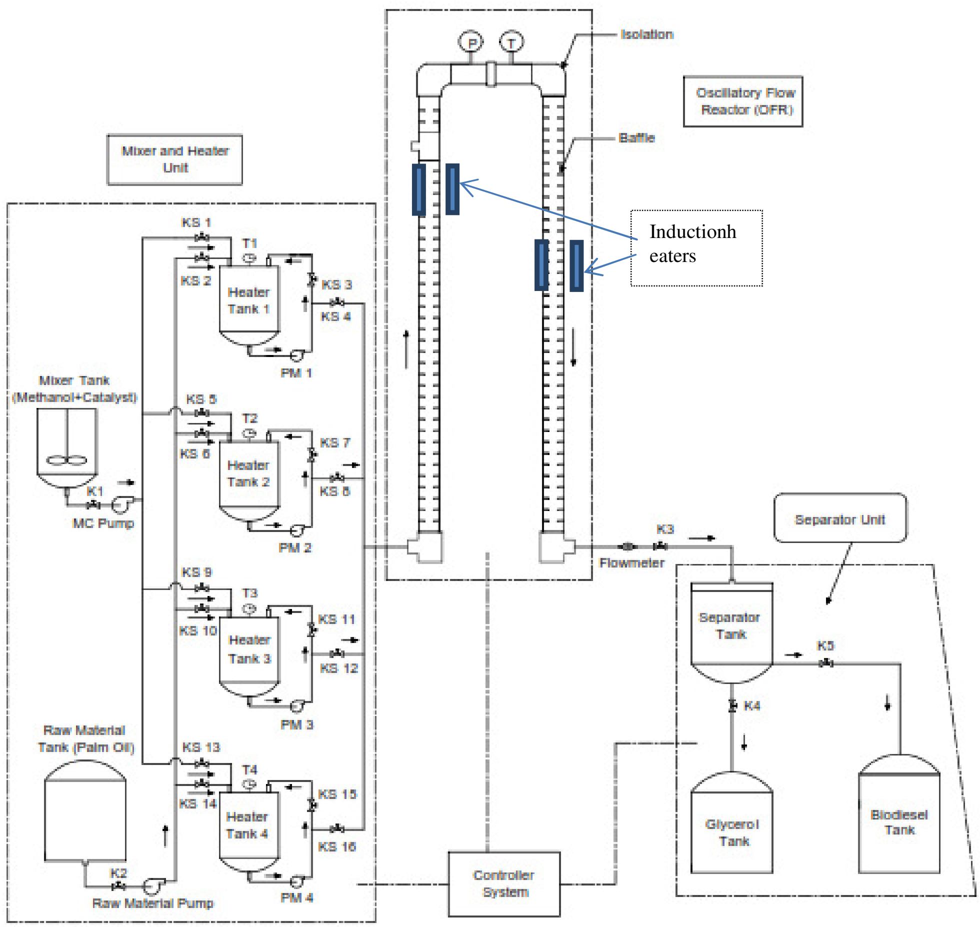

Figure 4. Schematic installation of a continuous system production process using an oscillatory flow reactor (OFR) equipped with two induction heaters.

3. Results and discussion

3.1 Effect of Induction Heating on OFR

Application of induction heating which is placed in a separate place (as in Figure 2) at OFR, the temperature of the reactants in the reactant tube can be kept constant at 65 ^{0}C. In addition, the presence of a magnetic field that appears around the heater in the induction heating coil affects the flow rate and reactants reaction.

The transesterification reaction was initially carried out in the heating unit and the mixing was then continued at OFR. Table 1 shows the experimental results showing the effect that the percentage of biodiesel produced increased by 3%, (from 87% to 90%) as a consequence the percentage of glycerol produced decreased by 3% (from 13% to 10%). The temperature decrease along the reactor is only 1 ^{0}C while when compared to not using induction heating, the temperature decrease can reach up to 7 ^{0}C. The flow rate of the reactants in the reactor decreased from 0.254 meters / second to 0.223 meters / second. This may be due to the magnetic field effect of induction heaters which tends to slow down the flow rate. Although the flow velocity is slowing down at OFR which can reduce the level of productivity, this can be overcome by correcting the pump power design.Because the flow rate decreases causing the reaction time in the OFR reactor to increase by about 30 seconds. This allows the biodiesel formation reaction to reach an optimum condition resulting in an increased percentage of biodiesel formation.

Table 1. Experimental data comparing using and without Induction Heating on OFR.

Measured Parameters	No Induction Heating	With Induction Heating
Debit[litre/sec]	0.129	0.124
Flow velocity[m/sec]	0.254	0.223
Resident time [minute]	3.20	3.50
Reynolds Number(Re)[-]	1075	1002
Biodiesel products[%]	87	90
Glycerol products[%]	13	10
The temperature deviation of the OFR inlet and outlet (^{0}C)	7	1

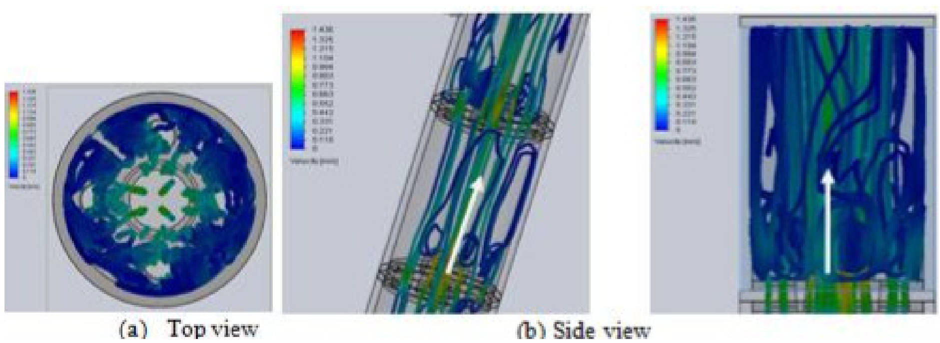

Figure 5. Simulation result of the reactant flow pattern in Oscillatory Flow Reactor

3.2 Properties of biodiesel

Table 2 shows a comparison of the quality of biodiesel production resulting from experiments with biodiesel standards enforced in Indonesia (RSNI EB20551) and biodiesel standards in America

(ASTM D6751). In terms of the quality of the biodiesel produced, it shows that on average there are changes in several biodiesel properties using induction heaters at OFR.

Table 2. BiodieselQualityCompareto RSNIandASTM Standard

No	Standard of properties	Biodiesel RSNI EB20551	Biodiesel ASTM D6751	Diesel (EN 590)	Result	
					Without Induction Heating	With Induction Heating
1	Density , at 15 ^{0}C (kg/m^3)	850 -890	860-900	820-845	865	867
2	Viscosity, 41^{0}C, (mm/sec)	2.3 –6.0	1.9 –6.0	2.0-4.5	4.0-6.0	4/0 – 6.0
3	Flashpoint,(^{0}C)	Min 100	>=130	>55	119-134	120-140
4	Glycerol content,(% mass)	<=0.24	<=0.24	0	0.30	0.28
5	Heating Value, LHV (MJ/kg)	N/A	N/A	43	41.10	41.17
6	Cetane Number	>49	>51	>51	N/A	N/A
7	Pour point,^{0}C	18	0	0	5	4
8	Total Sulphur,%	<0.01	<0.05	<10	0	0

The density measured at a temperature of 15 ^{0}C changes slightly from the value of 865 kg/m3 to 867 kg/m3. The results of the product viscosity measurement obtained values of 4 to 6 and these values are the same for the two experimental conditions that have been carried out. The calorific value, flash point and pour point also change when compared to the yield of biodiesel products without using an induction heater. In general, the biodiesel properties produced are within the range required according to the RSNI and ASTM standards.

4. Conclusion

Experiments on the use of induction heating in OFR type continuous reactors have been carried out. The results show that the use of induction heating in the unique construction of the OFR reactor can help maintain the temperature of the transesterification reaction at ideal conditions. In addition, there is a magnetic field that arises in the induction heater which helps the reaction process so that biodiesel production can be optimized and the quality of biodiesel can be maintained at the required standard value. Understanding in depth the effect of magnetic fields on chemical reactions, especially transesterication reactions to obtain yield conditions is still needed.

Acknowledgement
This research was funded by DIPA PoliteknikNegeri Ujung Pandang, with contract number B/40/PL.10.13/PT.01.05/2020, the featured applied research schemes.

References

[1] Vijai Kumar Gupta, Maria G. Tuohy, MeisamTabatabaei and MortazaAghbashlo (Editors) Biofuel and Biorefinery Technologies Vol. 8, Springer, 2019.
[2] Taher, H., et al., A review of enzymatic transesterification of microalgal oil-based biodiesel using supercritical technology. Enzyme Research, 2011. 2011.
[3] Juan, J.C., et al., Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: an overview. Bioresource Technology, 102(2): p. 452-460, 2011.
[4] Fernando Trejo-Zárraga,Felipe de Jesús Hernández-Loyo,Juan Carlos Chavarría-Hernández and Rogelio Sotelo-Boyás, Kinetics of Transesterification Processes for Biodiesel ProductionKinetics of Transesterification Processes for BiodieselProduction, Intechopen Chapter 8, 2018
[5] Madhu A., Sunny S., Kailash S., S. P. Chaurasiadan R. K. Dohare, Biodiesel Yield Assessment in Continuous-Flow Reactors Using Batch Reactor Conditions, International Journal of Green Energy, DOI: 10.1080/15435075.2011.647171, Vol. 10. p 28-40. Taylor & Francis, 2013.
[6] Suryanto, Wahyu Budi Utomo, Marwan, Novel Oscillatory Flow Reactor to ImproveBiodiesel Production Continuous System, International Journal of Science and Research (IJSR), 2015.
[7] Fabiano B., Reverberi A.P., Del Borghi A., and V. G. Dovi, Biodiesel Production via Transesterification: Process Safety Insights from Kinetic Modeling, Theoretical Foundations of Chemical Engineering, Vol. 46, No. 6, pp. 673–680, 2012.
[8] Harvey A. Process Intensification of Biodiesel Production Using a Continuous Oscillatory Flow Reactor, Journal of Chemical Technology & Biotechnology, The University of Cambridge, UK, 2011.
[9] CordeliaCordeliaZimmerer, , Toni Utech, , Kerstin Arnhold, Andreas Janke, Inductive Heating Using a High-Magnetic-Field Pulseto Initiate Chemical Reactions to Generate, Composite Materials, Polymers Jurnal; doi:10.3390/polym11030535, 2019.
[10] Arfa Nawaz, Magnetic Induction Heating and Magnetic CaO Catalyst for Biodiesel Production, PhD Thesis, School of Chemical Engineering,The University Of New South Wales, 2019
[11] Geetha V., Sivachidambaranathan V., An overview of designing an induction heating system for domestic applications, International Journal of Power Electronics and Drive System (IJPEDS), Vol. 10, No. 1, March 2019, pp. 351~356 , 2019.