A Novel Process Production of Calophyllum Inophyllum Biodiesel with Electromagnetic Induction

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Abstract: A novel method proposed in the production of *Calophyllum inophyllum* biodiesel has been investigated experimentally. In this study, we report the results of biodiesel processing with electromagnetic induction technology. The method used is to compare the results of *Calophyllum inophyllum* biodiesel processing between conventional, microwave and electromagnetic induction. The degumming, transesterification, and esterification process of the 3 methods are measured by stopwatch to obtain time comparison data. Characteristics of viscosity, density, and *Fatty Acid Metil Ester* (FAME) were obtained from testing of a *Gas Chromatography-mass Spectrometry* (GCMS) at the Polytechnic Chemistry Laboratory of the State of Malang. The results show that the biodiesel produced by this method satisfies the biodiesel standards and their characteristics are better than the biodiesel produced by conventional and microwave methods. The electromagnetic induction method also offers a fast and easy route to produce biodiesel with the advantage of increasing the reaction rate and improving the separation process compared to other methods. This advanced technology has the potential to significantly increase biodiesel production with considerable potential to reduce production time and costs.

Keywords: renewable energy, microwave, free fatty acid, crude oil

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1. Introduction

In the past two decades, the energy crisis has encouraged the development of alternative energy by seeking renewable energy resources. Alternative energy sources such as biodiesel have been developed to replace diesel or fuel oil. Generally, biodiesel is a liquid fuel processed from different sources such as palm oil [1-4], soybean oil [5-10], jatropha [11-18], cottonseed oil [19-25], recycled cooking oils [26-28], animal fats [29-33], and other potential triacylglycerol-containing feed-stocks [34]. Vegetable oils are also known as triglycerides have a chemical structure composed of 98% triglycerides, and the remainder is diglycerides [35]. Biodiesel is treated with a mixture of fatty acid methyl esters with methanol or ethanol [36, 38].

One of the potential biodiesel plants is *Calophyllum inophyllum* or *Nyamplung* in Indonesia language. The benefits of *Calophyllum inophyllum* as biofuel are seeds that have a higher yield than other crops (jatropha 40-60%, palm kernel 46-54%, and *Calophyllum inophyllum* (40-74%), and it does not compete with food interests [39]. In addition, the productivity of *Calophyllum inophyllum* seeds of 20 tons/ha/year is higher than jatropha (5 tons/ha/year), and palm (6 ton/ha/year) [40]. *Calophyllum*

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inophyllum has a very high oil of 75% with an unsaturated fatty acid content of about 71% [41]. It is processed or pressed in the form of yellow-green oil, similar to olive oil, aromatic and tasteless. It usually produces fruit twice a year to 100 kg with the oil content of about 18 kg [42]. *Calophyllum inophyllum* has a higher viscosity, but the capillary ability is lower than kerosene. *Calophyllum inophyllum* oil yields in the process are forged or pressed between 40-70% of the dry seed mass [43], and the degumming process is 62.80 - 65.89% [44].

Generally, biodiesel is processed by thermal or heating system. Biodiesel processing with conventional heating systems is the most widely used method. The conventional biodiesel processes are based on the use of high power heating and magnetic stirring. Biodiesel processing begins with dry seed pressing into *Crude Calophyllum Oil* (CCO). Through the degumming process obtained *Refined Crude Calophyllum Oil* (RCCO), followed by esterification process. The next transesterification process is producing *Crude Biodiesel* and, finally, biodiesel is obtained through washing and drying.

Due to the existence of several stages in the processing of biodiesel causing high cost of biodiesel production, so that the implementation of the production process is operationally inefficient. Such as, a degumming process is heated at a temperature of 80^0 C for 30 minutes, until there is sediment. The next step is esterification process for 1-2 hours at temperature 60^0 C and transesterification process for 1 hour at temperature 30^0-65^0 C. In [45] describes, conventional biodiesel production is generally done at high temperatures with external heat sources. The heat transfer is less effective because it occurs with conduction and convection system. In addition, conventional heating such as hotplate takes a long time and high power.

To address the challenge of high production cost, many efforts have been made on optimizing the biodiesel production process. One of them is microwave technology as an alternative method with several advantages such as quality issues [46, 47], energy efficient [48], and impact on the environment [49, 50]. The other is a more even warming that comes from the material and it is not transferred from the outside. The heating may also be selective, depending on the dielectric properties of the material. Moreover, microwaves can propagate through the liquid by the process of heating more effectively on the production of biodiesel and the time is shorter [51-54].

Regarding the processing biodiesel, we have proposed a new method of electromagnetic induction heating. Induction heating technology has been widely applied to the manufacture of induction cookers and is able to provide faster heat than the microwave. The induction heater (IH), an alternating electrical current from the power unit flows through a coil made of copper. This current will cause an electromagnetic field of varying magnitude. This field will generate an electric current on the metal material inside it. This electric current is known eddy current generates heat which can be used to heat and melt the metal.

2. The basic principle of induction heating

Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction, where eddy current is generated within the metal and resistance leads to Joule heating of the metal. The basic theory of electromagnetic induction, however, is similar to a transformer. The transformer works because of the phenomenon of electromagnetic induction, when there is a current flowing in a closed circuit it will produce various electromagnetic fields. As with transformers, electromagnetic fields (in primary coils) that very affect secondary coils and secondary coils produce induced radiation and AC current flows if the secondary coil is a closed circuit. IH consist of three basic elements: electromagnetic induction, skin effects, and heat transfer [55]. Figure 1 shows the basic principle of induction heating, consisting of inductive heating coils and currents, to explain electromagnetic induction and skin effects. Figure 1 (a) shows the simple form of a transformer, where the secondary current is in direct proportion to the main current in accordance with the turn ratio.

When the secondary coil is turned on for a moment and is short-circuited, there is a substantial heat loss that occurs due to an increase in the secondary current (load current). This is shown in Figure 1 (b). The amount of current in the secondary coil (I_2) is determined from the magnitude of the

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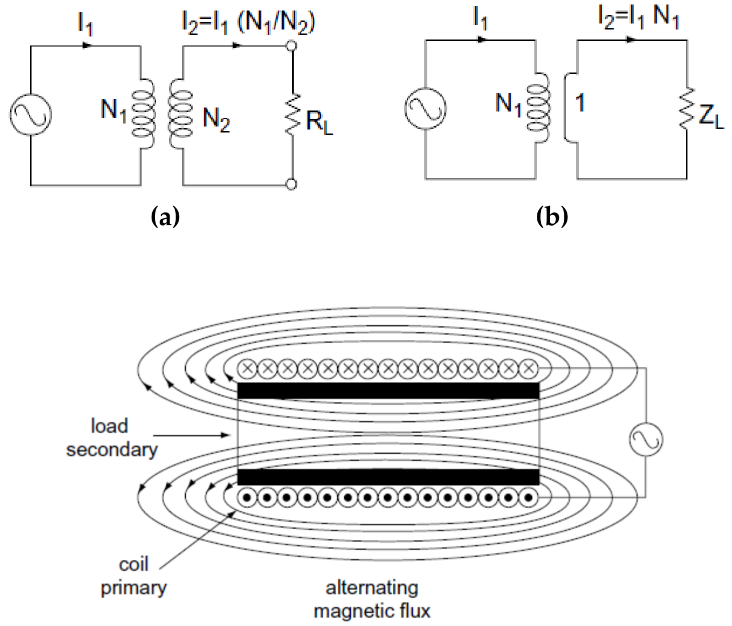
current on the primary coil (I_1) and the ratio of the windings between the primary and secondary coils (N_1/N_2). In this figure, when the secondary coil we replace with 1 wire ($N_2 = 1$) and made into a closed circuit, we will get a large coherent ratio value of the primary and secondary coils and will cause a large secondary current (I2). This will also be followed by a substantial increase in heat due to the increase in the load. Figure 1 (c) shows the concept of induction heating where energy is supplied from the same source from a number of combined primary and secondary losses. The primary inductive coil has many turns, while the secondary is only one and is short-circuited. Because the main purpose of an IH is to maximize the heat energy produced in the secondary, the gap from the inductive heating coil is designed to be as small as possible and secondary is made by displaying low resistance and high permeability. Nonferrous metals weaken energy efficiency because of their high resistance and low permeability.



(c)

Figure 1. Basic induction: (a) equivalent circuit of transformer; (b) secondary short; (c) concept of induction heating

Electromagnetic induction

IH are used to supply an alternating electric current to an electric coil (the induction coil). The induction coil is a source of electricity (heat) that induces an electric current to the metal part to be heated (called a workpiece). There is no contact between the workpiece and the induction coil as a heat source, and heat is restricted to the local area or surface zone adjacent to the coil. This is because the alternating current (ac) in an induction coil has an invisible force field (electromagnetic, or flux) around it. When the induction coil is put next to or around a workpiece, the lines of force concentrate in the air gap between the coil and the workpiece. The induction coil, in fact, functions as a transformer primary, with the workpiece to be heated becoming the transformer secondary. The force field surrounding the induction coil induces a similar and opposing electric current in the workpiece, with the workpiece then heating due to the resistance to the flow of this induced electric current. The rate of heating of the workpiece is influenced by the frequency of the induced current, the intensity of the induced current, the specific heat of the material, the magnetic permeability of the material, and the resistance of the material to the flow of current.

As shown in Figure 1, when an AC current enters a coil, a magnetic field is formed around the coil, calculated according to Ampere's Law as:

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$$\int \boldsymbol{Hdi} = \boldsymbol{Ni} = \boldsymbol{f} \qquad (1)$$
$$\emptyset = \boldsymbol{\mu HA}$$

An object inserted into a magnetic field causes a change in the velocity of the magnetic movement.

The magnetic field density decreases as the object gets closer to the center of the surface. According to Faraday's Law, the current generated on the surface of a conductive object has an inverse relationship to the current on the inductive circuit as described in Equation (2). The current on the surface of the object produces an eddy current, calculated as:

$$E\frac{d\lambda}{dt} = \frac{d\emptyset}{dt} \qquad (2)$$

As a result, electric energy caused by induced currents and eddy currents is converted into heat energy, as shown in Equation (3). Resistance is determined by the resistivity (ρ) and permeability (μ) of the conductive object. Current is determined by the magnetic field intensity.

$$\boldsymbol{P}\frac{\boldsymbol{E}^2}{\boldsymbol{R}} = \boldsymbol{i}^2\boldsymbol{R} \qquad (3)$$

Eddy Current

Induction heating occurs when an electrical current (eddy current) is induced into a workpiece that is a poor conductor of electricity. For the induction heating process to be efficient and practical, certain relationships of the frequency of the electromagnetic field that produces the eddy currents, and the properties of the workpiece, must be satisfied. The basic nature of induction heating is that the eddy currents are produced on the outside of the workpiece in what is often referred to as "skin effect" heating. Because almost all of the heat is produced at the surface, the eddy currents flowing in a cylindrical workpiece will be most intense at the outer surface, while the currents at the center are negligible. The depth of heating depends on the frequency of the ac field, the electrical resistivity, and the relative magnetic permeability of the workpiece.

Eddy Current is the induction of alternating electric current in a conductive material by an alternating magnetic field (generated by alternating electric current). The induced current inside the modified material causes a change in the value of the induced current through the material. The eddy current principle is based on Faraday's law which states that when a conductor is cut out the force lines of the magnetic field or electromotive force (EMF) will be induced into the conductor. The amount of EMF depends: (1) size, strength, and magnetic field density; (2) the speed at which the magnetic force lines are cut; (3) quality of conductors. Because eddy current is the current of electric current in the conductor, it will produce magnetic field too. Lenz's law states that the magnetic field of the induced current has a direction opposite to the cause of the induced current. The magnetic field of eddy current is in opposite direction to the magnetic field of the coil as shown in Figure 2.

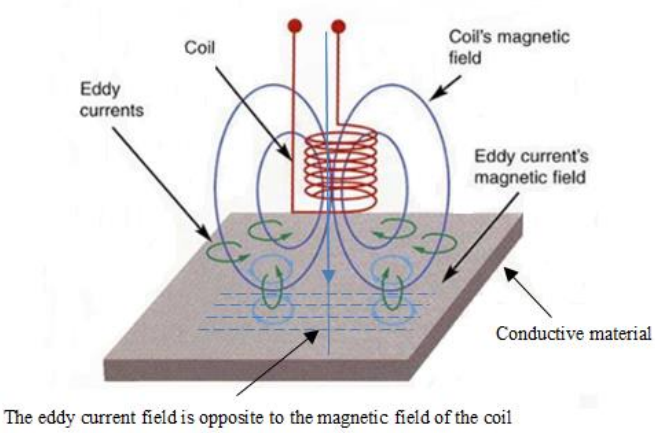

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Figure 2. Direction of magnetic field eddy current opposing to the direction of magnetic field of the coil

3. Topology of IH

Power System of IH

IH technology is nowadays the heating technology of choice in many industrial, domestic, and medical applications due to its advantages regarding efficiency, fast heating, safety, cleanness, and accurate control [56]. The high frequency induction furnace was first applied by Edwin F. Northrup at Princeton in 1916. In the same year, M.G. Ribaud developed high frequency IH technology using spark plug generators and, later, Valentin P. Vologdin developed an IH generator using engine generators and vacuum tubes. There were the beginnings of a modern high frequency induction heating system.

Since the discovery of semiconductor technology, the second major revolution of IH technology is developed. Recent advances of the high-power semiconductor devices technology; the research on high-power solid-state high-frequency power supply has achieved great progress. Power semiconductor technologies, especially thyristors, have been used to implement a very reliable power converter. Later, the expansion of higher frequency power devices, such as the power bipolar junction transistors (BJT) and the power metal-oxide-semiconductor field-effect (MOSFETs), allow higher efficiency power converter designs, making IH technology the option in many applications. The performance and efficiency values achieved in the IH system, along with further advances in semiconductor technology and the introduction of a successful isolated-gate bipolar transistor (IGBT), extend the application of IH technology outside the industrial environment. The IGBT provides low on resistance and need very little gate drive power, it is highly used in generators with frequencies up to 100 kHz, but the frequency about 400 kHz is difficult to achieve for the state-of-the-art IGBT. On the contrary, the SIT has the defects like high conduction loss compared to IGBT, complicated fabrication process, high cost and price that restrict it in its applications. This very high switching frequency can be achieved using MOSFETs.

Currently, new generations of soft-switched converters that integrate the advantages of conventional PWM converters and resonance converters have been developed. This soft-switched converter has a switching waveform that is similar to a conventional PWM converter, except that the edges rise and fall from the waveform 'smoothed' without a temporary surge. Unlike resonant converters, new soft-switched converters generally utilize resonance in a controlled manner. Higher energy conversion efficiency at high-frequency switching can be achieved by manipulating the voltage or current at present of switching to become zero. The concept was to incorporate resonant tanks in the converters to create oscillatory (usually sinusoidal) voltage and/or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. ZVS refers to removing the turn-on switching loss by having the voltage of the switching circuit set to zero right before the circuit is turned on. ZCS avoids the turn-off switching loss by permitting no current to pass through the circuit right before turning it off. The voltage or current administered to the switching circuit can be made zero by using the resonance produced by an L-C resonant circuit. This is a “resonant converter” Topology. Resonance is permissible to occur just before and during the turn-on process and turn-off so that it can create ZVS and ZCS conditions. In addition, they behave like conventional PWM converters.

Half-Bridge Resonance Inverter

According to the number of switching devices, the inverter topologies usually used in IH are the single-switch [57], full-bridge [58], and half-bridge [59], [60] resonant inverters. In this paper a power system using a half bridge resonance series inverter has been applied. The merits of a half-bridge series resonant inverter are stable switching, low cost, and a streamlined design [54]. As the voltage of the circuit is limited to the level of the input voltage, the switching circuit can have low internal pressure, which helps reduce cost. Figure 3 is a block diagram of a power system in a simplified form with reliability and economics. This system consists of AC power supply, main electrical circuit, control circuit, input current detection circuit, resonance current detection circuit, and gate operation circuit. All procedures needed to design and test the system shown in a block diagram. The picture isn't contains heaters and cooling fans. Operation of power the overall system is illustrated in Figure 3.

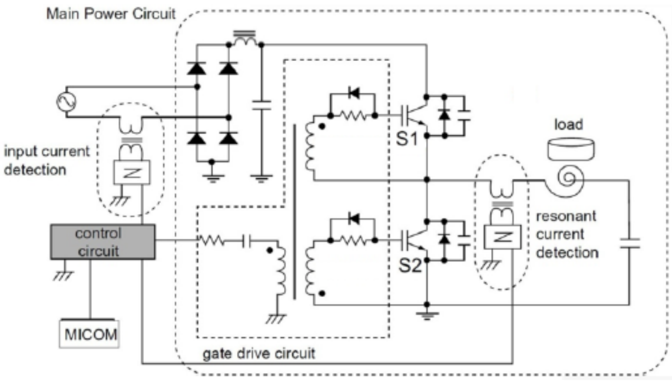

Figure 3. Half-Bridge Series Resonant Inverter

AC power (220 V / 60 Hz) passes through the rectifier to be transmitted to the capacitor. The capacitor in the existing power system is too small in capacity to do leveling work, which leads to the creation of an increased current at 120 Hz, which is not the right level for DC operation. The system for IH, however, does not need large capacitors to produce DC flatter, because the major purpose of this system is to generate heat energy. In contrast, a rough DC form helps increase the system's power factor. In this circuit, the leveling capacitor serves as a filter that prevents high frequency currents from flowing into the inverter and entering the input part. The input current becomes the average current of the inverter and the flow of ripple to the leveling capacitor.

4. Experimental set-up

Biodiesel Processing

Calophyllum inophyllum oil used in the current study was procured from the local market and it is an inedible oil, which belongs to the *Guttiferae* family, commonly termed as ‘‘Nyamplung’’ oil in Indonesia. Normally, the tree grows along the coastal areas and adjacent low land forests, having no incubation in yielding, i.e. the seeds could be obtained throughout the year. Figure 4 shows the crude oil of *Calophyllum inophyllum*. The results of the analysis of the fatty acid fraction of *Calophyllum inophyllum* oil are summarized in Table 1.

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Figure 4. *Calophyllum inophyllum* crude oil

Table 1. Composition of *Calophyllum inophyllum* crude oil

Fatty Acid	Mass content (%)
Palmitic acid	13.92
Stearic acid	13.12
Oleic acid	69.11
Linoleic acid	3.85

There were wide variations in the contents of palmitic, oleic, linoleic, and stearic and acids among the oils studied, leading to differences in saturated and unsaturated fatty acids. The major saturated fatty acids in crude oil were stearic (13.12%) and palmitic (13.92%) acids. This oil samples had high amounts of unsaturated fatty acids, representing 72.96% which consisted mainly of oleic (69.11%) and linoleic (3.85%) acids.

Fig. 5 shows a schematic of the process for making biodiesel. Glycerol is formed and has to be separated from the biodiesel. Both the glycerol and biodiesel need to have alcohol removed and recycled in the process. Water is added to both the biodiesel and glycerol to remove unwanted side products, particularly glycerol, that may remain in the biodiesel. The wash water is separated out similar to solvent extraction (it contains some glycerol), and the trace water is evaporated out of the biodiesel. Acid is added to the glycerol in order to provide neutralized glycerol.

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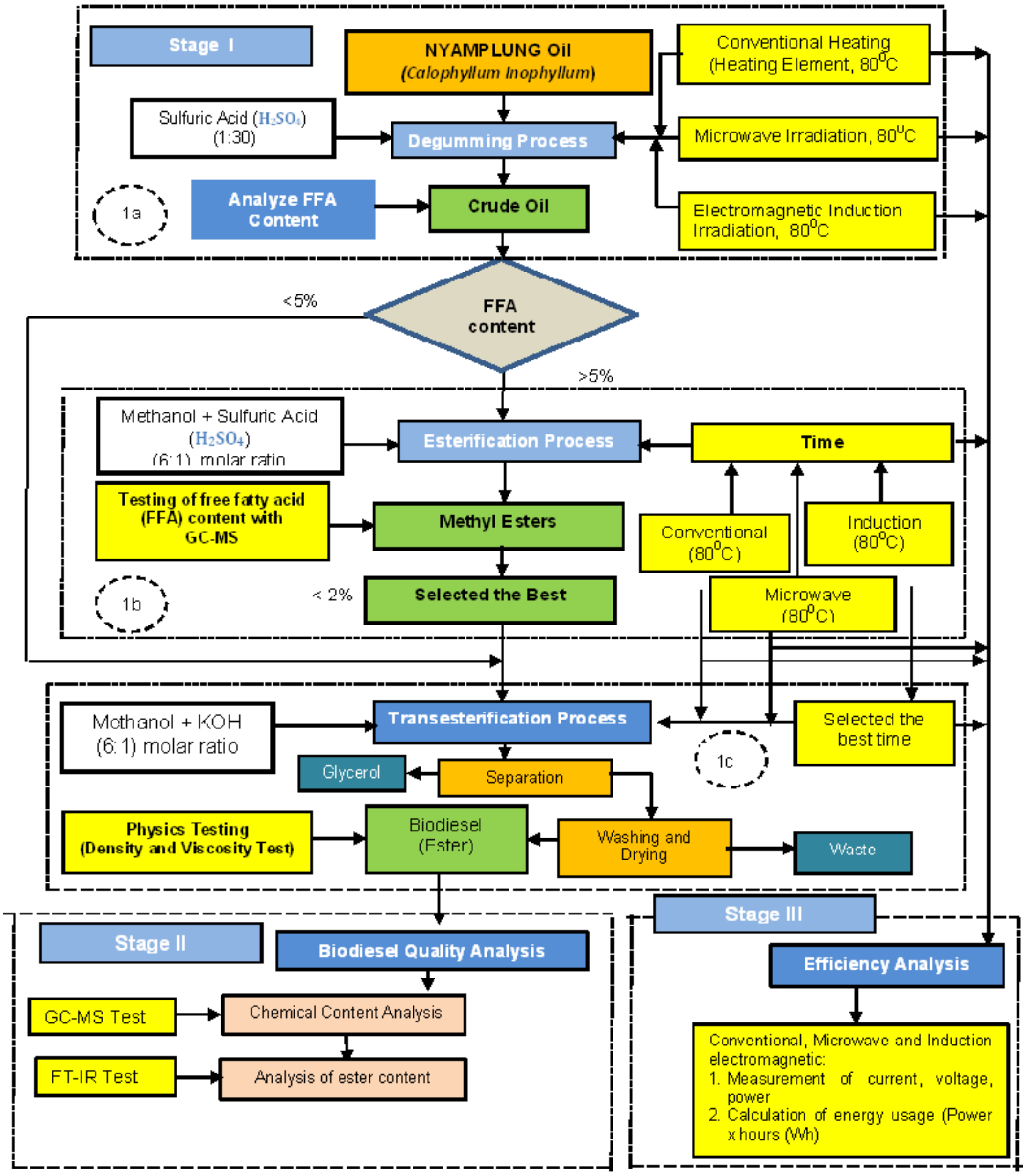

Figure. 5 Schematic of biodiesel process

Induction heating irradiation

In this study, an electromagnetic induction heater has been used in the processing of *Calophyllum inophyllum* biodiesel. The equipment specifications have been detailed in Table 2. The schematic diagram of the experimental set up is given in Figure 6. The electromagnetic induction heat radiation induced by the metal mounted inside the coil is absorbed by the sample oil, which may lead to the appearance of warming in the sample. Heating with induced magnetic field radiation is faster and evenly distributed along the metal mounted inside the coil, it does not transfer heat from the outside. The duration of induction given to metals affects the rise in temperature/heat of the metal which affects the passage of the transesterification reaction. The greater the temperature given, the transesterification reaction runs faster and will result in more biodiesel conversion.

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Table 2. Equipment specification

No.	Name	Specification
1.	Dc Voltage	30 Volts
2.	Power Input	200 watts
3.	Current Output	1.2 Amps
4.	Temperature	0-1000^0 C (adjustable)

Vibrations in molecules induced by induction heat radiation will produce a uniform heat on the molecule, where the resulting induction heat penetrates the molecule and excites the molecules evenly, not just the surface. Induced heating radiation can speed up the reaction by vibrating the reactant molecule quickly. The longer the radiation time is given to the transesterification reaction the heat generated by the reactant molecule's vibration will be greater until reaching its optimum state. The transesterification time at 60^0 C has been controlled automatically by a microcontroller. Output data such as temperature, current, power, and voltage are displayed and stored on a laptop.

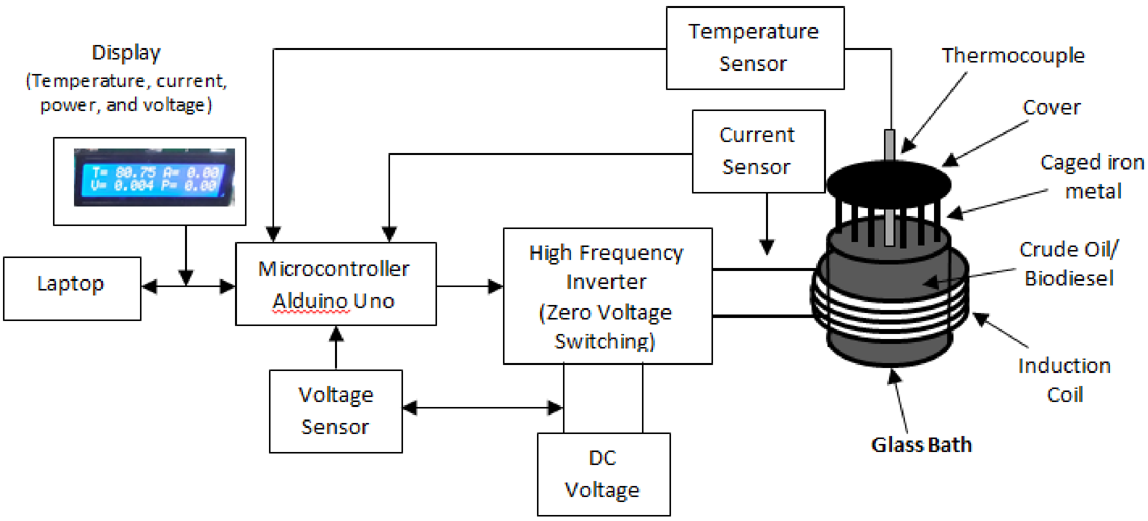

Figure 6. Schematic diagram of electromagnetic induction irradiation

Eddy currents have the most dominant role in induction heating process. The heat generated on the material depends on the amount of eddy current induced by the inductor winding. When the winding is fed by alternating current, a magnetic field will occur around the conductor wire. The magnetic field varies according to the current flowing in the coil. According to [61], if there is conductive material around the changing magnetic field, then the conductive material will flow a current called eddy current. The Eddy Current principle is based on Faraday's law which states that when a conductor is cut out the force lines of the magnetic field or electromotive force (EMF) will be inducted into the conductor. The amount of EMF depends on (1) size, strength, and magnetic field density; (2) the speed at which the magnetic force lines are cut; (3) quality of conductors.

5. Experimental Result

Characteristics of induction heating irradiation

One method of heating to allow the reaction to run faster is to perform a transesterification reaction using electromagnetic induction heat radiation. The electromagnetic induction heat radiation induced by the metal mounted inside the coil is absorbed by the sample, which may lead to the appearance of warming in the sample. Heating with induced magnetic field radiation is faster and evenly distributed along the metal mounted inside the coil, rather than transferring heat from the outside. The duration of induction given to metals affects the rise in temperature / heat of the metal which affects the passage of the transesterification reaction. The greater the temperature given, the transesterification reaction runs faster and will result in more biodiesel conversion.

Vibrations in molecules induced by induction heat radiation will produce a uniform heat on the molecule, where the resulting induction heat penetrates the molecule and excites the molecules evenly, not just the surface. Induced heating radiation can speed up the reaction by vibrating the reactant molecule quickly. The longer the radiation time is given to the transesterification reaction; the heat generated by the reactant molecule's vibration will be greater, so that at any given time the transesterification reaction will reach its optimum state. Eddy current has the most dominant role in the induction heating process. The heat generated in the material depends on the amount of eddy current induced by the inductor winding. When the windings are energized by alternating current, a magnetic field will occur around the conductor wire. Magnetic fields vary according to the current flowing in the coil.

Technically, the induction heater has the following characteristics: able to release heat in a relatively short time. This is because the energy density is high. With induction, it is possible to reach very high temperatures. Heating can be done at a specific location and the system can be made to work automatically. Induction heating, in general, has high energy efficiency, but it depends on the characteristics of the heated material. Heating losses can be minimized. According to [62], several factors determine the number of eddy currents in the metal, including: (1) the magnetic field that induces metal; (2) metal materials used to generate heat. The smaller the resistance of the metal type, the better it is to be the object of heat of the metal; (3) metal surface area, the more surface area of the metal the more eddy currents will be on the metal surface; and (4) the greater the frequency, the greater the frequency the more the magnetic field is generated. In addition, there are several advantages of using induction heater, including: heat is generated directly inside the barrel wall; heat can be applied uniformly across the barrel; cold element operation, so it has no time limit; fast start up time; and energy-efficient

Figure 7 shows a comparison of the results of testing of biodiesel manufacturing processes between conventional, microwave and electromagnetic induction. It is can be seen that electromagnetic induction technology is a great opportunity in the production process in the future. Compared to other methods, the proposed new method has a very short time at every stage of the production process such as degumming, esterification, and transesterification. Another advantage of electromagnetic induction is energy-saving electricity and it can decrease the FFA value of each stage of biodiesel production as shown in Figure 8.

Based on the measurement results, the amount of power used by all heating methods is the multiplication of voltage and output current. Energy consumption is calculated between the time multiplier and the output power. Based on Table 3, it can be seen that electromagnetic induction method using energy more efficient compared to conventional and microwave method, that is, 0.056 kWh. The amount of energy obtained is based on the multiplication of the overall time of the degumming, esterification and transesterification steps by the amount of heating equipment power.

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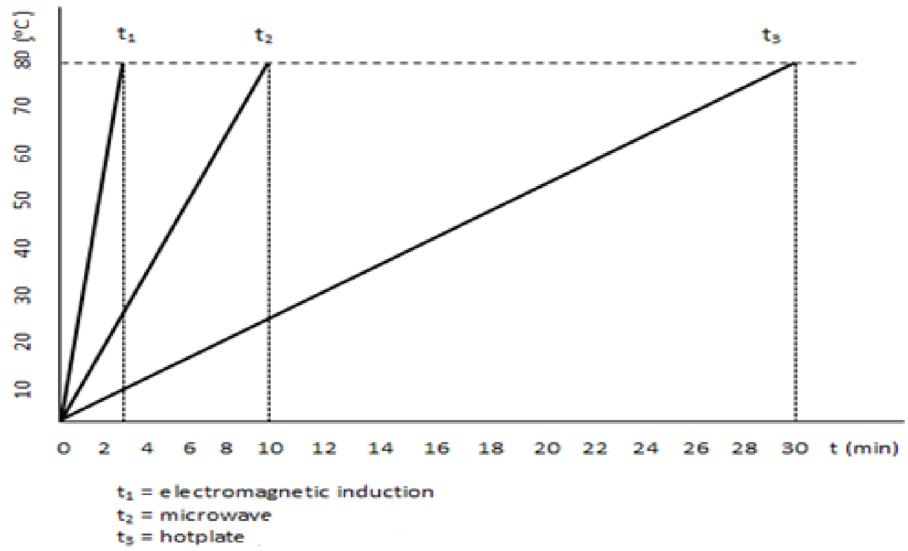
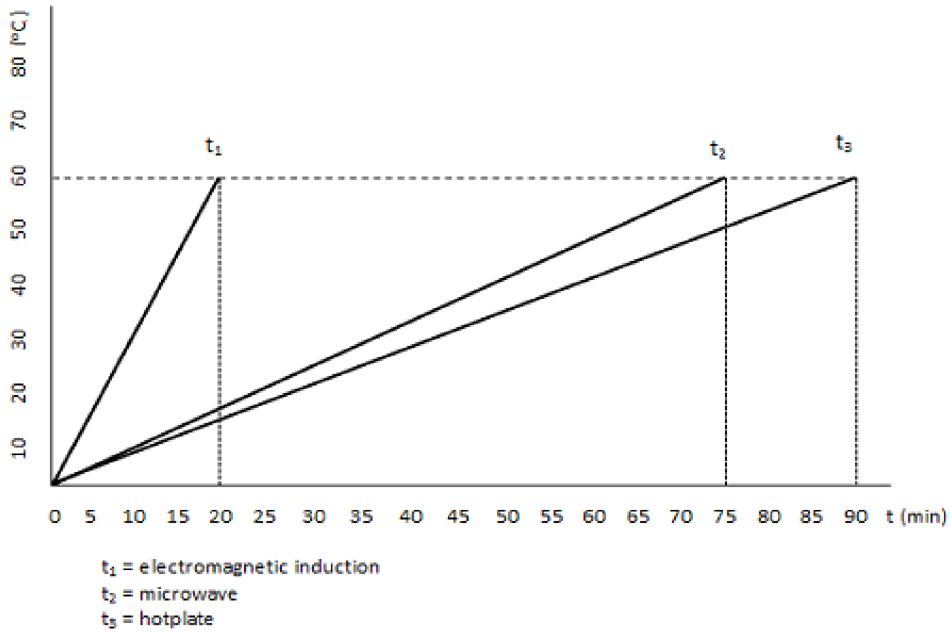


(a)



(b)

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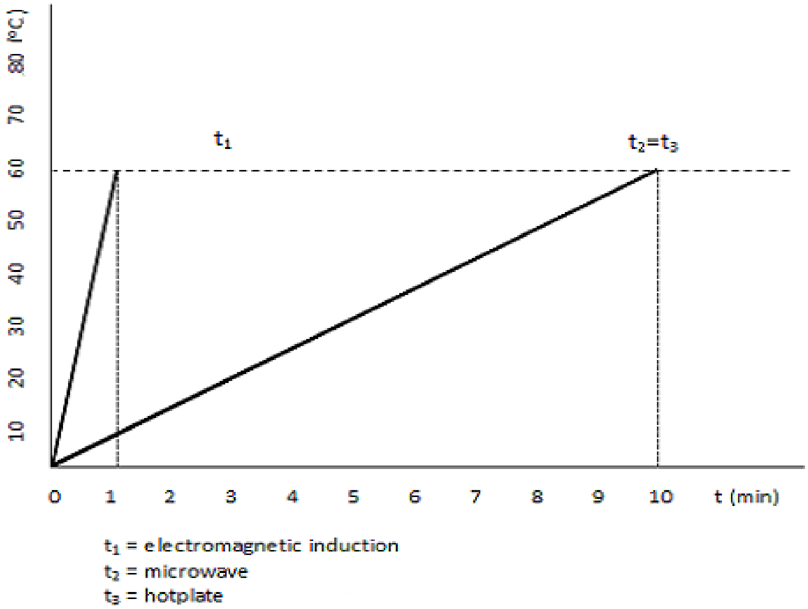

(c)

Figure 7. A Comparison of the time of biodiesel production between conventional, microwave, and induction electromagnetic (a) degumming; (b) transesterification; (c) esterification

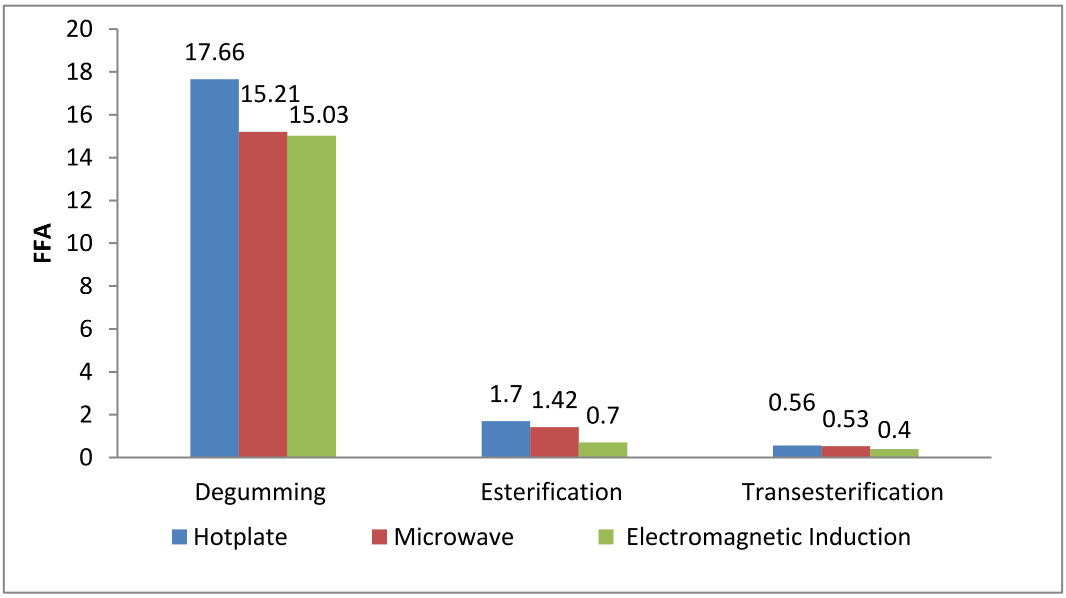

Figure 8. Comparison of FFA measurement values

Table 3. Comparison of energy consumption for *Calophyllum inophyllum* oil (200 ml)

Methods	Energy comsumption (kWh)			Total Energy
	Degumming	Esterification	Transesterification	(kWh)
Hotplate	0.3	0.9	0.1	1.3
Microwave	0.02	0.15	0.02	0.19
Electromagnetic Induction	0.007	0.046	0.003	0.056

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Furthermore, the production of three methyl ester samples obtained was then tested to obtain FAME, viscosity and density values. Table 4 shows the comparison of laboratory testing of FAME, density, and viscosity values for each test sample. Clearly, biodiesel production using electromagnetic induction has a higher FAME value than conventional and microwave. In contrast, the viscosity of the biodiesel is lower than the others, ie, 5.54 Cst. This value is eligible for Indonesian National Standard (SNI) standard in fuel injection process between 2.3 - 6.0 Cst. When the viscosity value is too low it will cause a leak in the fuel injection pump, on the contrary, the high viscosity of the fuel is eliminated to large droplets and has high momentum so that it can collide with the cylinder wall. Figure 9 shows the results of transesterification of Calophyllum biodiesel using electromagnetic induction.

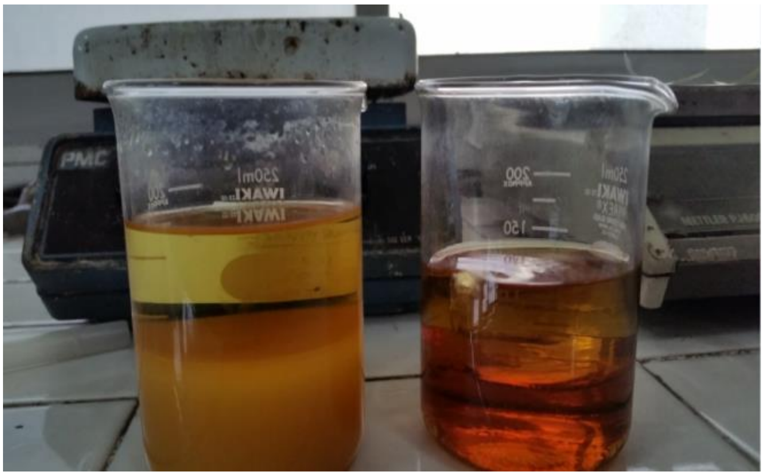

Figure 9. FAME: (a). esterification (b) biodiesel

Table 4. Comparison of testing of FAME, viscosity and density values

Properties	*Calophyllum inophyllum* Oil			Biodiesel				
	Hotplate	Microwave	Electromagnetic Induction	ASTM D6751 (USA)	ASTM PS 121	EN 14214	C1 Biodiesel	SNI
Density (20⁰C) (g/ml)	0.883	0.885	0.882	0.87-0.9	0.7328	No specific	0.877	0,850 - 0,890
Kinematic viscosity, 40⁰C (mm^2/s)	6.353	5.9847	5.54	1.9-6.0	1.9-6.0	3.5-5.0	5.6872	2.3-6.0
FAME (%)	40.06	53.66	65.96					

4. Discussion

Generally, heating coils are used to heat raw materials in biodiesel production processes. This treatment can also be done by microwave method. Alternative heating systems "microwave irradiation" have been used in transesterification reactions in recent years. Microwaves are electromagnetic radiation that represents nonionizing radiation that affects molecular motions such as ion migration or dipole rotation but does not alter the molecular structure [63, 64]. According to [48], when the reaction is carried out under microwaves, transesterification is efficiently accelerated in a short reaction time. As a result, a drastic reduction in the number of byproducts and a short separation time are obtained and high yields of highly pure products are reached within a short time [65]. So, the cost of production also decreases and fewer by-products occur by this method. Therefore, microwave heating compares very favorably over conventional methods, where heating can be relatively slow and inefficient as it transfers energy into the sample depending on the convection currents and the thermal conductivity of the reaction mixture. However, a shorter heating reaction has been achieved through electromagnetic induction than microwave technology.

Experimentally, we have reported a comparison of 3 methods in the production process of Calophyllum biodiesel. In the transesterification process, electromagnetic induction needs only 1.15 minutes, compared with both microwave and conventional methods for 10 minutes. Likewise, other stages such as degumming and esterification, such as Figure 7a, 7b, and 7c show a significant time difference between the three methods. Some characteristics of the electromagnetic induction method show better progress than others, such as the time is shorter, energy saving, the quality of FAME, viscosity, and yield is higher. Therefore, the findings of this method have promising expectations for biodiesel production.

6. **Conclusions**

Using the electromagnetic induction method, the experimental results are rapidly demonstrated at higher reaction rates and conversion results than conventional and microwave methods. Faster heating has been enhanced by electromagnetic induction compared to the microwave is considered the preferred method due to several advantages such as low energy consumption, a substantial reduction in reaction time and solvent requirements, enhanced selectivity, and better conversion with fewer byproducts.

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