Solar-Assisted Biodiesel Production from Used Cooking Oil

Supachai Sampao*, Sukruedee Sukchai, and Prapita Thanarak

School of Renewable Energy Technology, Naresuan University, Phitsanulok 65000, Thailand
***Corresponding author's email:** supachai_s@dede.go.th
Received: 10/10/2017, Accepted: 13/11/2017

Abstract

The moisture in used cooking oil is a significant factor that affects the quality of biodiesel production. This paper presents biodiesel production by using the solar thermal assisted system for moisture removing which can increase the quality of biodiesel. The cross-flow heat exchanger made by copper tube was installed at the header of the evacuated tube heat pipe solar collector of 2.15 m^2. There were two loops of moisture removal in the heat exchanger which one is for used cooking oil, and another one is for biodiesel. The initial moisture content of used cooking oil was 0.08%, and the moisture content after moisture removal was 0%. The biodiesel from 100 liters of used cooking oil flowed into the heat exchanger with a mass flow rate of 0.0076 kg/s. The moisture removing time per cycle was 3.33 hours. The solar irradiation was about 849.4 W/m^{2,} and the heat consumption from solar collector was 1.45 kW that able to increase the temperature of biodiesel from 30ºC to be 135.8ºC. The average temperature in a reaction tank was 60ºC. The yields from 100 liters used cooking oil was 94.37 liters. The final moisture content of biodiesel was 0.005 %Vol. It was found that the properties of biodiesel satisfied with the benchmark of the announcement of the Department of Energy Business. The benefit-cost ratio of this system is about 2.33 while the cost per unit is 25.40 THB/liter.

Keywords:

biodiesel, used cooking oil, eliminate moisture, biodiesel production, solar energy assisted

1. Introduction

From the energy statistics of Thailand presented that the final energy consumption is rising every year, especially in the transportation and industrial sectors [1]. In the year 2015, it showed that Thailand uses renewable energy only 8% of the total domestic energy use. The highest petroleum energy consumption is obtained at 46% from diesel and 18% from gasoline, which is used 66% for transportation and 10 % for the agricultural sectors.

Considering the amount of energy consumption in the transportation and agricultural sectors, it can be seen that oil products, gasoline, and diesel are mainly used. It is found that biodiesel is used at 3.4 million liters per day at present [2]. Moreover, government agencies are now concerned with the policies focusing on boosting renewable energy production. According to the Alternative Energy Development Plan: AEDP 2015-2036 [3] of Thailand, it indicates that the biodiesel production demand increases to be 7 million liters per day. So, the development of research on biodiesel is stimulated to be performed. After that, the government sector has adjusted the operation plan to promote the production and use of biodiesel in 2 phases, aiming to boost the utilization of biodiesel to be 14.0 million liters per day by the year 2036. The proper technology for biodiesel production needs to be investigated and promoted. However, there are many parameters that affect the quality of biodiesel from the production process. Also, energy consumption in the production process is a concern.

Used cooking oil (UCO) can be the feedstock to produce biodiesel. At the same time, it can also decrease the environment problem. From the previous research [4], it was found that the parameter for the suitable condition to achieve the very good quality and yield in biodiesel production should be 60ºC in a reaction tank, 1.5 hours reaction time and 500 rpm stirring speed. Other researches [4,5] also shows that the moisture from used cooking oil is discharged by the heat that is produced from the electric heater or liquid petroleum gas (LPG), which is installed in a reactor. Also, used cooking oil and base catalyst were put in a reactor and mixed using the stirring from the electric motor. So, a new heat exchanger was designed to discharge moisture from the system which was performed by a combination of a solar collector system. The heat was provided from the solar collector to discharge the moisture and to maintain the temperature in a reaction tank. Two nozzles in a reaction tank were also designed and installed in order to increase the chemical reaction area and would improve the system efficiency.

2. Fabrication details

The biodiesel production from used cooking oil with solar-assisted system comprises four main parts (Figure1): heat exchanger, solar collector, a reaction tank, and chemical tank which has details as follows.

Fig. 1 Overview of the biodiesel plant from 100 liters of UCO.

2.1 Heat exchanger

The heat exchanger (H.E.) was designed in cross-flow type as shown in Figure 2. H.E. is made from aluminum combined with the copper tubes and evacuated heat pipes, solar collector. The cross-sectional area of H.E. is 25 cm^2 and 180 cm in length. This H.E. receives the heat from the heat pipes condenser after that; the heat will be transferred to the UCO in circuit No.1 or biodiesel in circuit No.2 in the copper tubes.

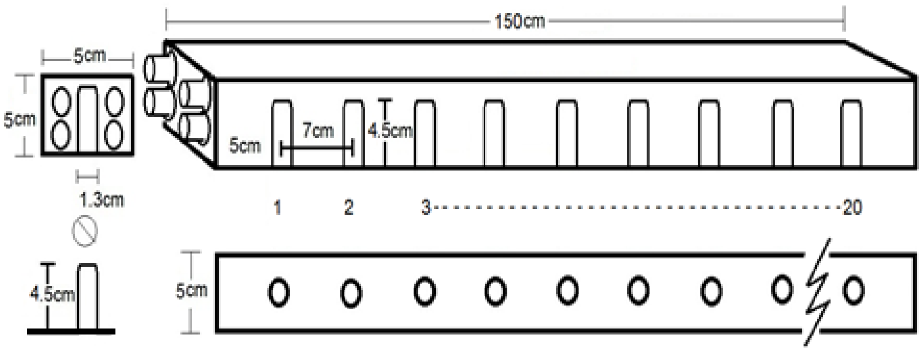

Fig. 2 Heat exchanger.

2.2 Solar collector

The required heat from solar energy can be calculated from the following equation.

$$\dot{Q} = IA$$

If the solar irradiation is 700 W/m^2 [7], the area of the solar collector can be calculated from

$$A = \frac{\dot{Q}_{collector}}{I}$$

While $$\dot{Q} = \dot{m} C_p \Delta T$$

Whereas

$\dot{Q}$	=	Heat transfer rate, kW
$\dot{m}$	=	Mass flow rate, kg/s
C_p	=	Specific heat of oil, kJ/kg °C
ΔT	=	Temperature difference between inlet and outlet, °C

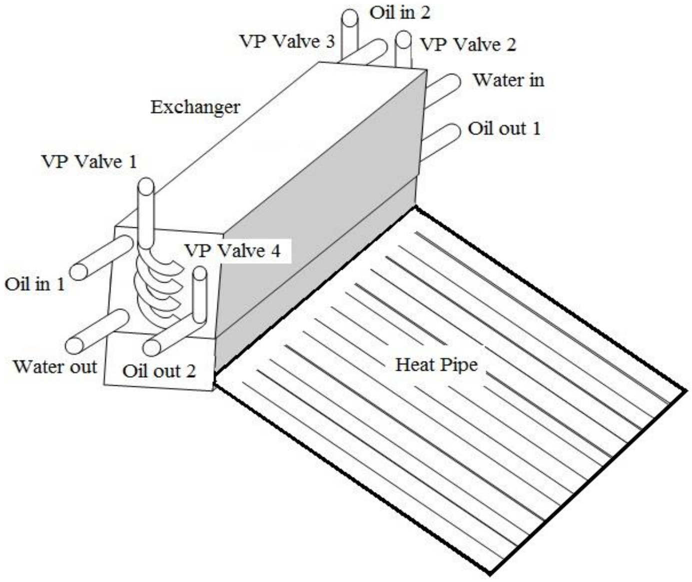

Fig. 3 Heat exchanger combine with evacuated heat pipe solar collector.

The biodiesel flow rate of 0.5 liters per minute was determined when the density of UCO was 910 kg/m^3 and the specific heat of 1.8 kJ/kg. The collector area from calculation was 2.15 m^2. Therefore, the existing evacuated heat pipes solar collector [6] with an area of 2.72 m^2 can be used in this system. It was installed on a high level at 2 m from ground level which is near the UCO tank. In this case, the collector was renovated to combine with aluminum H.E as shown in Fig. 3.

The energy for boiling the UCO 1 liter in every minute from 30°C to be 110°C can be calculated by the following relation. Thus, the total energy for boiling the UCO 100 liters from 30°C to be 110°C will be 13.104 MJ.

2.3 Reaction tank

In the reaction tank, two nozzles were installed for UCO and catalyst ejection as shown in Fig. 4. The type of the nozzle is a flow-adjustable nozzle with a diameter of 2 mm. The UCO flow rate in the copper tube is about 0.0152 kg/s. Moreover, the catalyst flow rate in the copper tube is about 0.0043 kg/s.

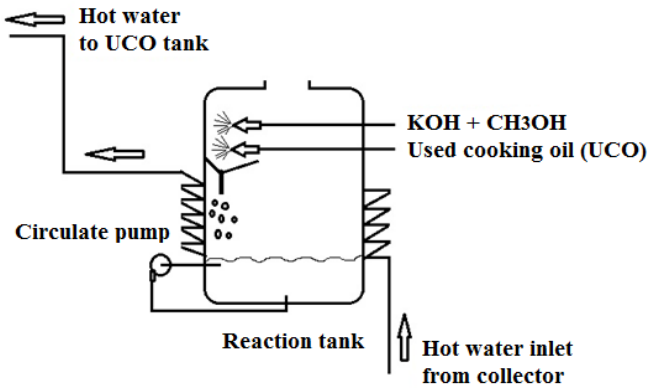

Fig. 4 Reaction tank.

2.4 The chemical tank

The volume of stainless steel chemical tank is 48 liters. It contains 30 liters of substance compound as KOH and CH_3OH. This tank was also designed for air pressure about eight psi to inject the substance compound through the nozzle and mixed with UCO at the inner surface of the reaction tank. Also, the pressure switch was also installed on the top of this chemical tank and UCO tank to check the pressure value for securities. The pressure switch will work to cut on and cut off at 4 / 8 psi.

3. System operation and experiment

The methodology of this research focuses on biodiesel production from used cooking oil with the solar assisted concept. The design of biodiesel production was considered on renewable energy use as much as possible. The solar collectors were used in the system to produce heat.

The biodiesel production was able to produce by two methods that consist of transesterification and esterification [8]. The UCO was titrated and investigated for free fatty acid (FFA). FFA should be less than 20%. From FFA percentage, the ratio of methanol and potassium hydroxide will be known. The production process can be started by feeding UCO to the heat exchanger (H.E.) in a circuit No.1 on the header of the first evacuated heat pipes solar collector. It shows in Figure 1 and Fig. 2. After the evaporated moisture performed in the H.E., the UCO will flow to a storage tank waiting for the temperature reduction to 65^{o}C. The UCO will be injected by a nozzle in a reaction tank besides the catalyst which is methanol and potassium hydroxide will be injected by another nozzle (see Fig. 4). Both UCO and catalyst are mixed at a temperature of about 60°C ± 5 [9-11]. The temperature inside the reaction tank is maintained by the heat from hot water in a 45 m. Length copper coil which is fixed on the outer surface of the tank to avoid the corrosion by chemicals inside the tank. However, all tanks in this system are made of stainless steel. The hot water supply is produced from the second evacuated heat pipe solar collector. The circulating pump will be operated in order to assist in well mixing of UCO and catalyst to get a better reaction. This reaction calls trans-esterification. After that, the mixing liquid will be feed into a washing tank. Then stop the operation and wait until glycerin separates from biodiesel. The valve at the bottom will be opened to let the glycerin flow into the glycerin storage tank waiting for a sale. The biodiesel will be washed by clean water. In each washing time, the water has to be drained to the wastewater tank. pH values have to be checked at this state as pH should be 6-7 then the process for washing will finish. Later, the biodiesel will be pumped up to a tank and flows by gravity to the H.E. After that; biodiesel will be filtered by a sieve. Then B100 biodiesel will be stored in a tank ready to be used.

The experiments of the biodiesel production process were performed in order to investigate all effective parameters as; solar irradiation, ambient temperature, inlet and an outlet temperature of H.E., the temperature inside and outside reactor tank. The properties of biodiesel were analyzed by the laboratory for 5 items as water and sediment, flash point, color, viscosity, and acid number. The yield was also checked.

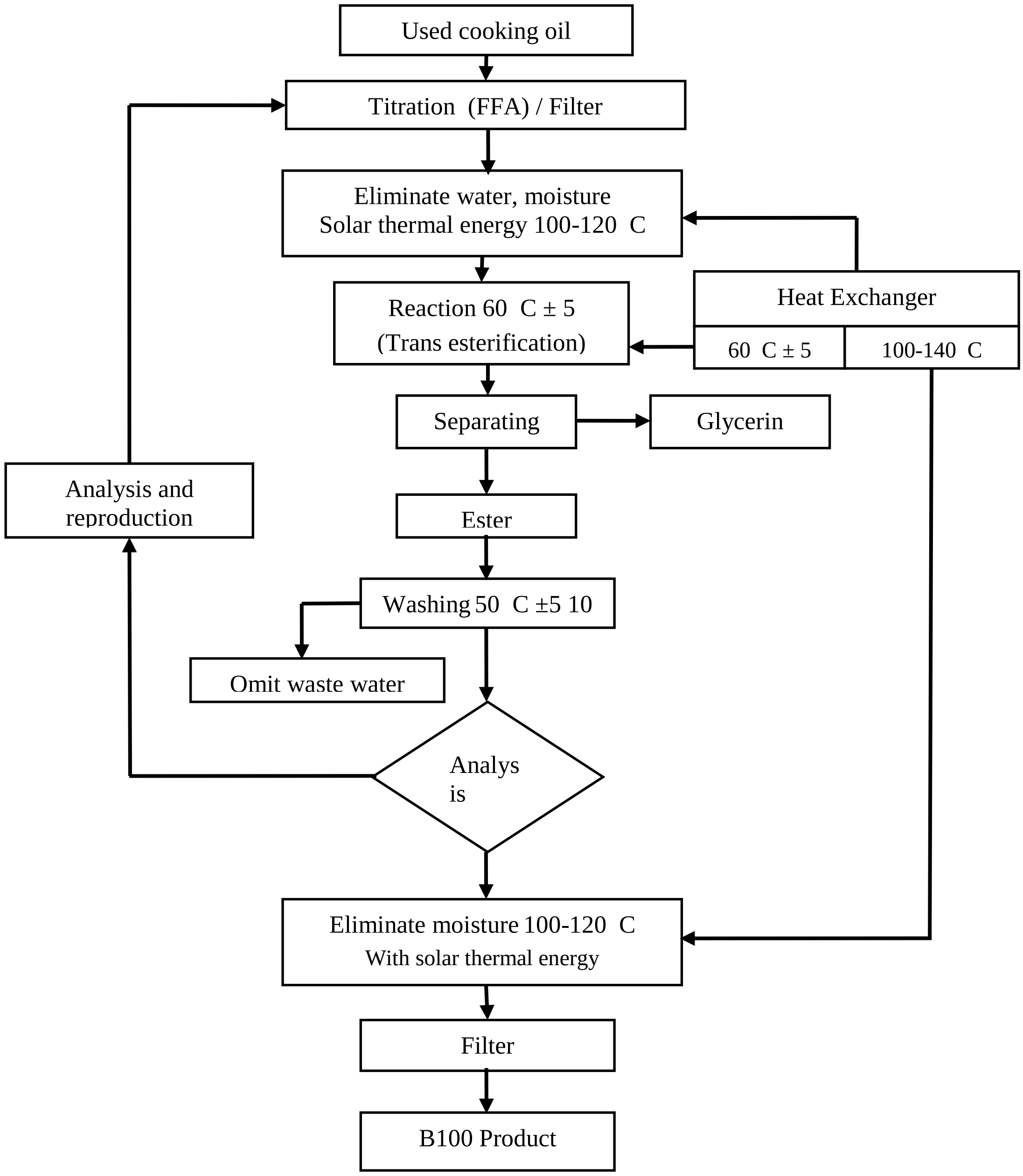

Fig. 5 Schematic design process of biodiesel production.

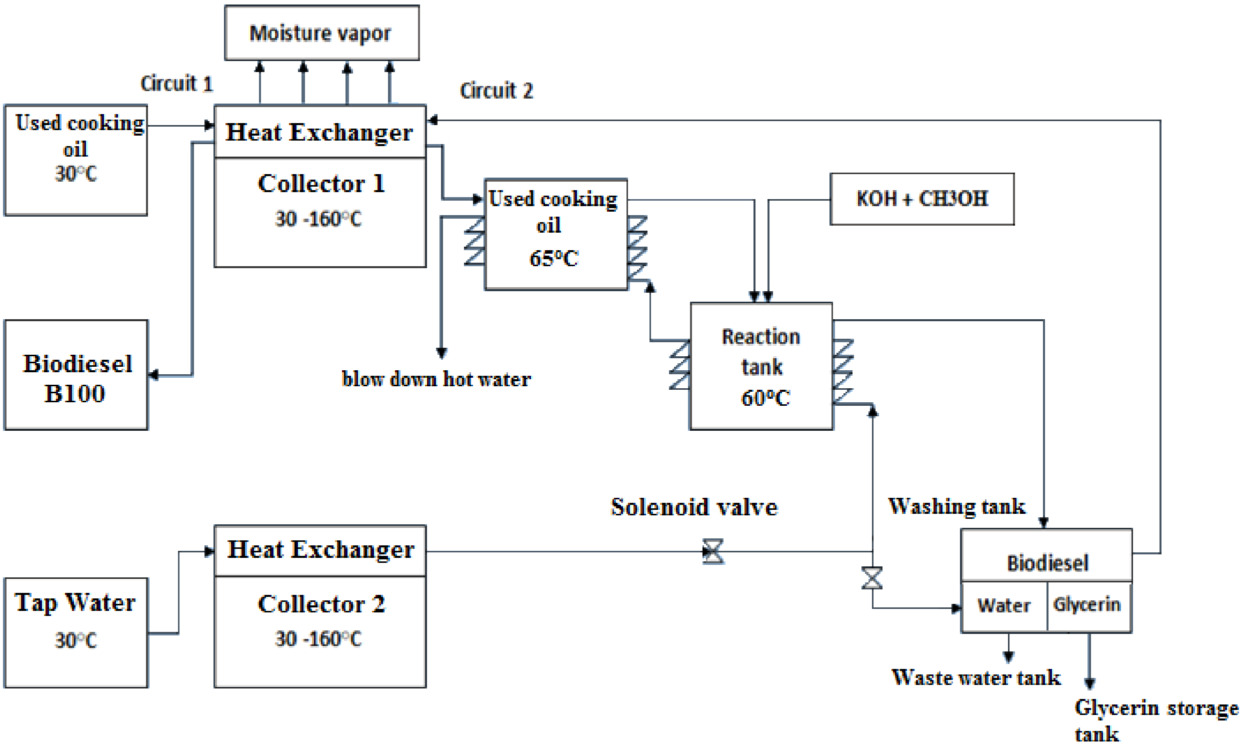

Fig. 6 Diagram of the biodiesel with the solar assisted system operating.

4. Results and discussion

It was found that the biodiesel production system works very well including both moisture elimination process, before and after the reaction. The results and discuss is separated into six parts as follows:

- Solar irradiation and useful heat
- The elimination of moisture and temperature maintain for reaction tank.
- The operating time of biodiesel production
- Yield of biodiesel and glycerin.
- Analysis of biodiesel properties
- Analysis of economic.

4.1 Solar irradiation and useful heat

For the first day operation, the average solar irradiation was about 672.6 W/m^2; the average ambient temperature was 30.7^{O}C. The inlet and outlet temperature of UCO to H.E. was 120.9 °C and 135.5 °C respectively. The reaction tank uses the heat to maintain temperature from the second collector. The average temperature inside the reaction tank was 59.5 °C, and the average temperature on the outer surface of the tank was 91.2 °C as shown in Fig. 7.

After operating, the next step was eliminating the moisture from biodiesel with a heat exchanger at the collector 1. It was found that the average solar radiation was 662.8 W/m^2, the average ambient temperature was 30.7 °C. At the collector 1, the average temperature of biodiesel input to the H.E. was 128.0°C, and the average outlet temperature was 131.3°C as shown in fig. 8. So, the temperature difference is about 3.3 ^{O}C. In the production process, the collector 1 supplies heat to the UCO and the H.E. circuit 2, but the collector 2 supplies heat to the reactor tank as shown in Fig. 8.

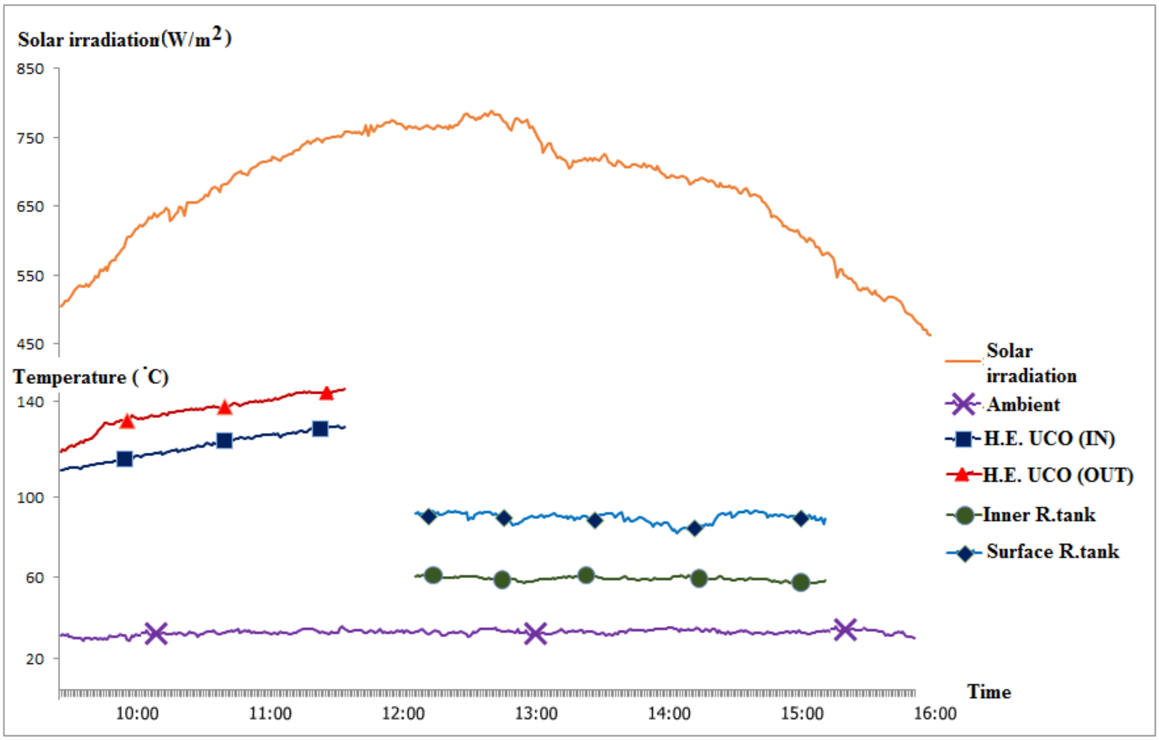

Fig. 7 Inlet and outlet temperature of UCO at the H.E. in circuit No.1.

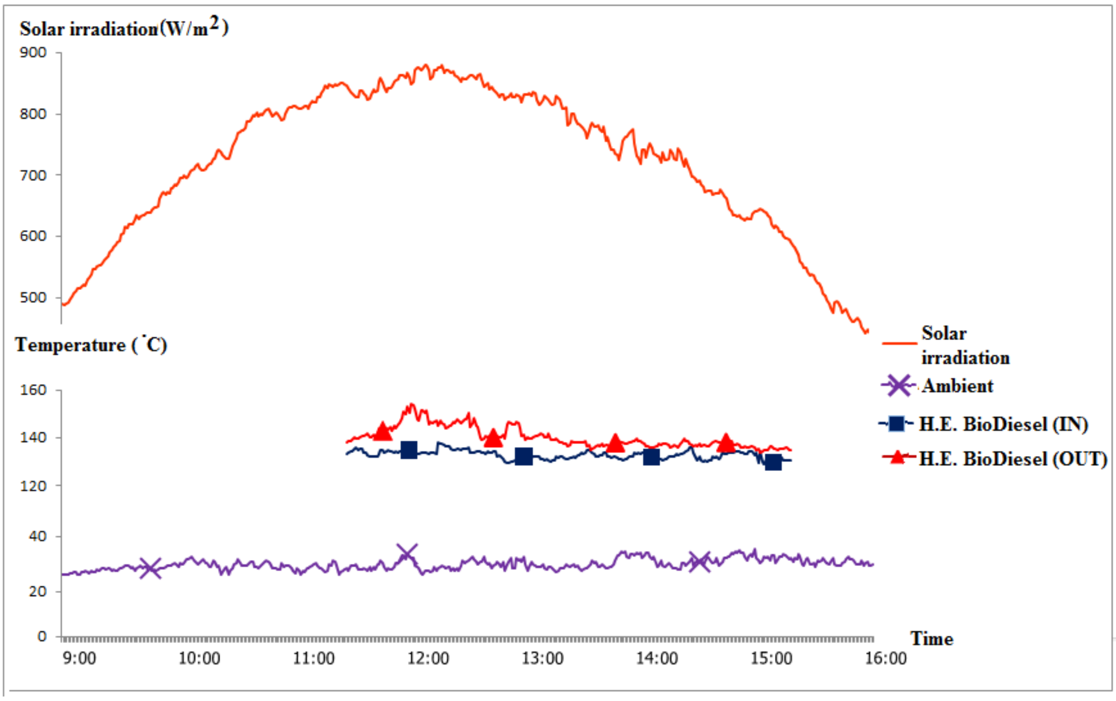

Fig. 8 Inlet and outlet Temperature of biodiesel at the H.E. in circuit No.2.

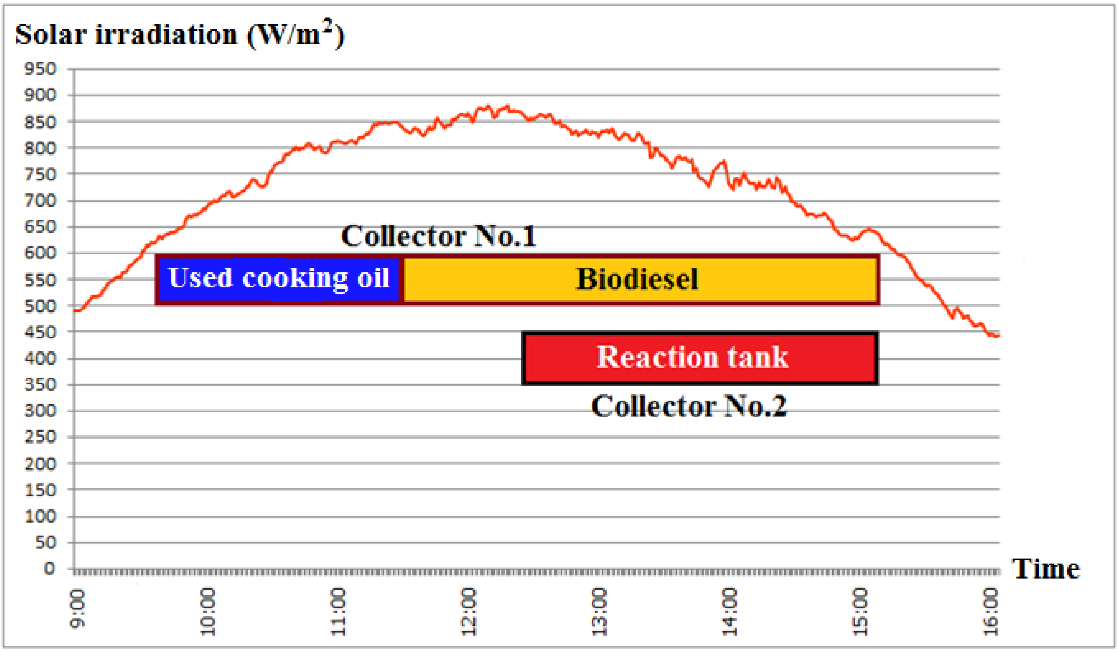

Fig. 9 The operating time to supply the heat to the biodiesel plant.

4.2 The elimination of moisture and temperature maintain for reaction tank.

While biodiesel was operated many parameters; the initial and the final moisture content of UCO, the heat which was used to maintain the temperature in the reaction tank and moisture content of biodiesel after washing tank and after H.E. It was found that from the test to find out the moisture and sediments by weight in UCO based on AOAC 2000 method, the initial moisture content of UCO was 0.08% and the moisture content after moisture removal was 0% which is good for biodiesel production process as if there is high moisture in UCO the process will fail as the product will be soap instead of ester or biodiesel. As can be seen in Figure 9 that the solar collector No.2 is a heat source to maintain the temperature inside the reaction tank to be $60^{O}C \pm 5^{O}C$ which was operated in 12.30 – 15.00. The average temperature on the outer surface of the reaction tank was 91.2 ºC, and the average temperature inside the reaction tank was 59.5 ºC which is suitable for the trans-esterification [10]

From test for water and sediment by %Vol based on ASTMD 2709 of biodiesel after washing, the result shows that the average water and sediment was 0.5 %Vol. After moisture was eliminated by H.E., it was found that Water and Sediment value decreased to be 0.005 %Vol which satisfied with the benchmark that announced by the Department of Energy Business, Ministry of Energy, Thailand (water and sediment %Vol should not greater than 0.2% for community biodiesel).

4.3 The operating time of biodiesel production

The operating time of biodiesel production was 244 hours per month (see Fig. 9) while the operating time of an existing project is 360 hours per month. It can be seen obviously that this system can give more yield than the existing project.

4.4 Yield of biodiesel and glycerin.

Meanwhile transferring the oil in the process from reaction to washing tank, the liquid that is not yet crystallized is separated to the transparent container in order to make sure whether oil in the washing tank will undergo the crystallization process. After about 2 hours for the complete separation, the glycerin is separated into a plastic tank, and biodiesel is washed to eliminate dregs, suspension substances, acid, base, and other remaining substances. From the experiment, the yields shown in Table

2. It was found that the average yield of biodiesel was 94.4 liters/batch while average glycerin was 33.7 liters/ batch. When compare to the Munsell color system, the Color of biodiesel after separated form glycerin was yellow code 7.5Y7/10. [12]

Table 2 Yield of biodiesel production and glycerin.

Experiment	Volume of yield (Liters)		
	Used cooking oil	Biodiesel	Glycerin
1	100	94.65	33.50
2	100	93.90	34.40
3	100	94.55	33.15

4.5 Analysis of biodiesel properties

The 3 samples of B100 biodiesel was sent to PTT laboratory (PTT Public Company Limited, Thailand) to test for some biodiesel standard properties as Kinematic Viscosity(ASTM D445-12), Flash Point (ASTM D93-12), Total Acid Number(ASTM 664-09 and Water and Sediment (ASTM D 2709-96). The results compare to the properties that announced by The Department of Energy Business, show in Table 3. The comparison indicates that the moisture in biodiesel from this experiment is less than the standard value. So this B100 biodiesel can be used for agricultural vehicles.

Table 3 Results of 3 samples from PTT laboratory test compared with the standard announced by The Department of Energy Business.

List	regulations	Low speed Diesel	Community Biodiesel	Experiment result (3Sample) 1 2 3	Method
1	Water and Sediment, % Vol	≤0.30	≤0.20	0.005, 0.005, 0.005	ASTMD 2709
2	Flash Point, ºc	≥52.00	≥120	146, 156.5, 165.5	ASTMD 93
3	Color	Brown	Brown / Yellow	Yellow, Yellow, Yellow	ASTMD 1500 Alternatively, Sigh visible
4	Viscosity, CSt (at 40 ºc)	≤8.00	1.90 – 8.00	4.73, 4.83, 4.78	
5	Acid Number, mg KOH/g	-	≤0.80	0.35, 0.44, 0.36	ASTMD 664

4.6 Economic analysis

From the assumption of 15 years lifetime of biodiesel production with the UCO at 450,000 liters will generate income of 27,046,845.00 THB. The benefit-cost ratio (BCR) of this system and cost per unit (THB/Liter) were 25.40 and 2.54 respectively while the existing project has BCR of 27.75 and cost per unit of 2.33. The biodiesel production with solar-assisted presents energy saving for 202,500 kWh and cost saving of 982,454.00 THB. Also, it can also reduce using crude oil for 17.26 toe and CO_2 emission of 119.41 ton CO_2.

5. Conclusions

To produce a very good grade of biodiesel from the used cooking oil, the percentage of moisture content of used cooking oil and biodiesel from the production process is very important. The 100 liters capacity biodiesel production plant by using solar-assisted with two circuits of moisture elimination at the heat exchanger for used cooking oil and biodiesel was designed and test. It was found that the biodiesel production plant can work very well. While the average solar irradiation was 672.6 W/m^2, the average moisture content of used cooking oil was reduced from 0.08% to be 0%. After washing the moisture and sediment of biodiesel was 0.5% by volume than satisfied with the value of moisture and sediment of community biodiesel from the benchmark announced by the Department of Energy Business, Ministry of Energy, Thailand. And also, the operating time of this plant was 244 hours/month while the existing plant takes 360 hours/month. The average yield of biodiesel was 94.4 liters/batch. The benefit-cost ratio of this system and cost/unit (THB/Liter) was 25.40 and 2.54 respectively.

6. References

[1] Ministry of Energy, Thailand, reported, Department of Alternative Energy Development and Efficiency energy consumption statistical of Thailand 2557, Retrieved from http://www.sasin.edu/ docs/dlm_uploads/2016/03/Twarath_Sasin_Thailand-Policy_-21-August-1.pdf

[2] Energy Statistics & Information, Thailand Energy Balance June 2015, Retrieved from http://www.dede.go.th/ewt_news.php?nid=42079

[3] Department of Alternative Energy Development an Efficiency. A delegation of the European Union to Thailand, Retrieved from http://www.dede.go.th/download/files/Thailand's%20RE%20PV%20Plans.pdf

[4] Muharka, H., Wahjudi, S., Hendrawati, N., Hermien, P., & Irfin, Z. (2013). Comparison of the characteristics of CPO oil and waste cooking oil to the influence of stirring speed, temperature and reaction time in the transesterification., mechanical engineering, chemical engineering department, international journal of engineering and science ISSN: 2278-4721

[5] Kar, R., Gupta, O., & Das, M.K. (2012). Biodiesel Production and Process Optimization., Chemical Engineering Department, Heritage Institute of Technology, Kolkata, India International Journal of Scientific and Research Publications, Volume 2, Issue 6

[6] Nadaf, S.L., & Gangavati, P.B. (2014). Gravity Assisted Heat Pipe (Closed Thermosyphon) As a Biodiesel Preheating Device, Mechanical Engineering Department, Government Engineering College Haveri, India. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181

[7] Visedmanee, J. (2015), Experimental investigation of Solar driven double-stage ejector cooling system, Naresuan University, Thailand., International Journal of Renewable Energy, Vol. 10, No.1, January - June 2015

[8] Ogbu, I.M., & Ajiwe, V.I.E. (2013), Biodiesel Production via Esterification of Free Fatty Acids Cucurbita pepo L. Seed Oil: Kinetic Studies, Department of Pure and Industrial from Chemistry, Nnamdi Azikiwe University, Awka, Anambra State.

[9] Karaj Branch, training document chapter 11, Heat Exchangers, Islamic Azad University, And Jutarat Tasara, Transport Phenomena (part 2 Heat Transfer) 721-283, 2007.

[10] Buaphoom, W., Thepa, S., & Soodprasert, K. The use of solar energy in the production of biodiesel (Solar Energy Assisted in Biodiesel Production), School of Energy, Environment and Materials University of Technology Thonburi.

[11] Hossain, Md A., Chowdhury, S.M., Rekhu, Y., Faraz, K.S., & Islam, M.U. (2012). Biodiesel from Coconut Oil: An Alternative Renewable Fuel for Diesel Engines, World Academy of Science, Engineering, and Technology

[12] Cochrane, S. (2014). The Munsell Color System: A scientific compromise from the world of art. Studies in History and Philosophy of Science 4, 26-41.