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Identification of Direct-Use Geothermal Energy for Extracting Cajuput Oils Used to Reduce Respiratory Disorder Due to COVID-19

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Abstract. The COVID-19 disease causes severe symptoms like fever, cough, and respiratory disorder like streptococcus pneumonia. Essential oil in cajuput is oil is believed to have effect to reduce respiratory disorder due to COVID-19. While the cajuput oil is not proven to prevent or to heal COVID-19 patients, the treatments using cajuput oil are proven helpful to ease the symptoms. Indonesia as a tropical country has large-scale cultivation of cajuput plants, for example in 2017, Sumedang and Majalengka areas produced up to 4 tons raw material or 10 kg in a day. In producing cajuput oil, there are some steps required for oil extraction and distillation including modified steam distillation method used in this study. This method of essential oil extraction process may use a large amount of heat to produce steam. Geothermal residual heat in the form of brine can be an alternative used to extract eucalyptus oil on small scale. This study shows the material balance analysis for the cajuput oil production with 10 kg cajuput leaves per day from Sumedang and Majalengka areas using Wayang Windu geothermal power plant brine at 180.7^{o}C with 0.05 kg/s mass flow rate. Wayang Windu geothermal power plant itself was chosen because the distance is not too far from cajuput source, which is around 99.7 km. In this study the cajuput oil extraction produces around 57.918 x 10^{-3} kg of cajuput oil for daily production time 100 min/day.

1. Introduction

Public health has become a big problem during the pandemics. There were an outbreak of SARS-CoV-1, MERS-CoV, and now Coronavirus 2019 (COVID-19), which continues to mutate to become an extreme threat to human. The World Health Organization (WHO) has categorized COVID-19 as a pandemic. Apart from viruses, bacteria are also one of the main causes of respiratory infections (Streptococcus pneumonia) which is the most common cause of pneumonia cases in many developing countries. *Melaleuca cajuputi* essential oil can inhibit ACE2 protein and reject the protein PDB6LU7 in SARS-CoV-2 [1]. However, this study still needs empirical evidence, but the compound 1.8 cineol is alleged to have antioxidant content that can play a role in the healing process in respiratory diseases [2]. Eucalyptus oil (Cajuput Essential Oil) is a product of the cajuput plant commonly used in the medical world as an herbal remedy for colds, coughs, and even as a laxative. In the course of its content research, it is pointed out that eucalyptus oil can be used to prevent and stop SARS-CoV virus infection in the respiratory tract. Indonesia, as a tropical country, has large-scale cultivation of cajuput plants as illustrated in Figure 1. The current study used the production case in areas of Sumedang and Majalengka (West Java|) where produced raw material up to around 4 tons based 2017 data.

Figure 1. Cajuput leaves**.**

The Wayang Windu geothermal field is located in West Java, Indonesia, about 35 km from the West Java capital, Bandung. The Wayang Windu system is a liquid-dominated field at depth with vapor-dominated two-phase caps, and a single flash power plant has been used to produce electricity. Total installed capacity of Wayang Windu geothermal power plant is 227 MWe [3] connected to the Java-Bali interconnection network. A geological survey began in 1985 and the first well was drilled in 1991. The construction of the unit-1 was completed in 1999 and the commissioning as well as commercial operation were started in 2000. Unit 2 was started to operate in 2009. The unit 1 has a capacity of 110 MW supplied by 13 production wells. The unit 2 has a capacity of 117 MW with 6 production wells. Operations in Wayang Windu geothermal power plant were stopped in early May 2015 because of landslides in the area and reopened in early September 2015 [4]. The location of Wayang Windu geothermal power plant with areas Sumedang is shown in Figure 2.

The main steps in the cajuput oil production process are the extraction and distillation processes. Extraction is the process of separating a substance from a solid or liquid with the help of a solvent. The principle of extraction with evaporated solvents is to dissolve essential oils in volatile organic solvents (organic chemicals containing carbon). The distillation process separates components in the form of liquids or solids from various substances based on their vapor points or evaporation rate differences. The is often used because it produces a much better quality of cajuput oil than air distillation, although steam distillation method requires a higher cost. This distillation system is widely used in the large or modern scale white wood oil refining industry or cajuput oil factory (PMKP), although some are used in small-scale or portable refineries.

Geothermal power plants (GPP) have the potential for waste heat that comes from the brine. The brine is typically re-injected into the reservoir with a temperature that is still relatively high. This study analyzes the potential use of this high temperature brine to produce cajuput oil on a small scale. The production method of cajuput oil by distillation is basically in the form of direct heat contact with the raw material to be extracted using water/steam which is then separated in separator. Geothermal waste in the form of residual heat can be an option that can be used to extract cajuput oil on a small scale during the COVID-19 pandemic.

Figure 2. Distance of cajuput plantation from closest geothermal power plants in west java.

A system for extracting essential oil using high-temperature condensate rejected from the separator is proposed in this study. According to preliminary analysis [5], with a mass flow of 8.69 kg/s condensate for 20 seconds for every 225 seconds, the energy from the condensate is sufficient for the essential oil extraction process. The proposed system can be alternative to the fossil fuels (such as liquid petroleum gas, kerosene) that are normally used for the extraction of the essential oil and hence would help in reducing CO_2 emission. The process of refining Vetiver oil for example using geothermal waste can reduce CO_2 gas emissions produced by GPP by 213.5 tons/year [6]. The reported average oil production is 0.579 liters in a day within a production cycle of 8.33 hours [7]. Although the average total extraction time was 100 minutes, it was observed that up to 67% of the oil was already collected within first 40 minutes, and 95.90% was collected within 80 minutes [7]. Many research works have been published on extracting essential oil from leaves, mostly at a laboratory scale, without the economics of its production [8][9].

2. Cajuput Oil Extraction Process

Essential oil is defined as odorant products with complex compositions with many advantages, from cosmetics, pharmacy, and food sectors [10]. Each species of aromatherapy plant has different characteristics and compositions. The characteristics and compositions are considered to determine the suitable extraction process for the plant. The method selection of the Essential oil extraction process can determine the quality of the oil produced. Choosing incorrect oil extraction method could lead to reduced pharmacological content, off-flavor, physical change, and stain effect on essential oils [11].

In general, the method of Essential oil extraction is divided into conventional and innovative methods. The examples of conventional methods are hydro distillation, steam distillation, hydro diffusion, and solvent extraction. The examples of the innovative methods are supercritical fluid extraction, subcritical extraction liquid, and solvent-free microwave extraction [10]. Cajuput oil is obtained from the extraction process of the cajuput plant using the conventional extraction method. According to SNI, the standard temperature for the cajuput extraction process is 95-100 °C [12]. In comparison, the standard pressure is known from the steam temperature; to get steam at that temperature, the pressure is set at 1 atm. The conventional method commonly used in cajuput plant extraction is steam distillation. The diagram of the cajuput oil extraction process can be seen in Figure 3.

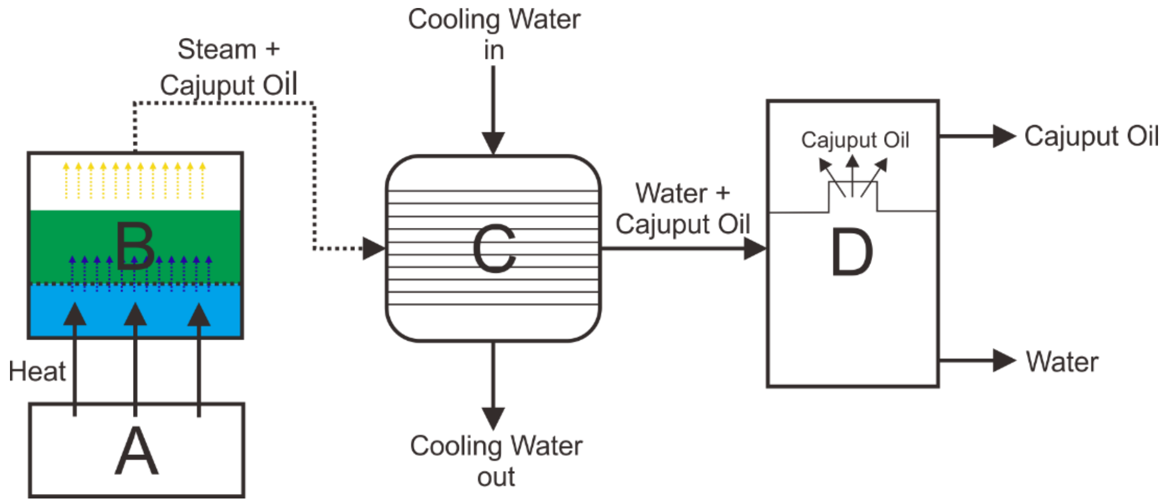

Figure 3. Existing extraction process diagram.

The main components of the cajuput oil extraction process are furnace (A), extractor (B), condenser (C), and separator (D). The other components are pipe, pump, water tank, and valve. The furnace can used wood, twig, and other organic material as fuels. The heat produced by the furnace is supplied to the extractor. In the extractor there are water and cajuput leaves, water and leaves are separated by a perforated plate. The heated water would be vaporized then the steam flows to the top through the cajuput leaves. The cajuput oil is then extracted from the leaves with heated steam. The steam and cajuput oil are mixed, then the mixture is condensed using a shell and tube condenser. The condensate then flows to the separator. The separator is utilize using the density difference between water and cajuput oil. Cajuput oil has a lower density than water so that the cajuput oil will be at the top of the separator and water at the bottom of the separator. In the end, water and cajuput oil is accommodated to separate containers.

3. Geothermal Power Plant Brine

In a geothermal power plant, a separator is located after geothermal wellhead to separate steam and hot temperature liquid called brine. High-pressure steam then flows into turbine, while brine usually injected to subsurface using injection wells. Sometimes brine is treated as waste from geothermal plant because it is not included in producing electricity. Although treated as waste, brine injection is one of reservoir management strategy to provide sustainability of the geothermal field. In general, brine injection objective is to balance reservoir fluid, and also a common procedure to prevent temperature and pressure drop in geothermal reservoir. Brine injection needs to be done correctly to manage its temperature and fluid characteristic in order to prevent the field from problems related with scaling and temperature drop.

The brine waste characteristics of the Wayang Windu geothermal field separator have a temperature of 180.7 ºC and a flow rate of 48 kg/s [13]. The minimum temperature is using to prevent fouling of the heat exchanger. According to [13] the minimum temperature for using a brine in Wayang Windu is 113 C. Wayang Windu produced almost dry steam with the quality above 97%. While treating the brine as a waste by directly injected it into the injection wells is safer and simpler for geothermal companies, but it is wasting the heat energy potential that is contained in the brine. The current study provides calculation for cajuput oil extraction using geothermal brine as thermal energy source.

4. The Proposed of Cajuput Oil Extraction Process

Section 2 explained the extraction of cajuput oil using a conventional method. The production of cajuput leaves could reach 4 tons/year or average in a day is 10 kg [5]. This production capacity is used as a design reference in this paper, namely 10 kg of cajuput leaves in one batch.

Before the extraction begins, the leaves need to have pretreated to remove impurities and reduce water content on the leaves in order to have lower extraction time and higher amount of oil produced. After the leaves are cleaned from impurities, then it will put into the extractor. On the extractor, fresh water in form steam being used as solvent because it does not contain hazardous chemicals. The better the substances contained in the solvent, the better the quality of cajuput oil. The brine contains sulfur and other chemicals that can contaminate cajuput oil so that it cannot be flashed, and the vapor is fed into the extractor. Thus, a solvent that being used is water. On the other side, this brine is only used to evaporate the water into steam. The thermal device used to transfer the brine heat to the water is a heat exchanger. A boiler is no longer used in this design because a heat exchanger has replaced its function.

The evaporator type used is shell and tube type. Shell and tube heat exchanger was chosen because the design is simple and easy to maintain. The hot side (brine) is placed on the tube side while the annulus is filled with water. The purpose of the brine is to pass down the tube for easy maintenance due to more impurities than water, therefore that the channel through which the brine is passed will experience more frequent blockages. The straight tube will be easier to clean. The cleaning process only opens the side of the evaporator and then inserts the cleaning rod into the tube channel. The annulus is difficult to clean because the shell and baffles are permanently welded.

Furthermore, the oil extractor has a slight change in the water reservoir. The water reservoir is replaced by a smaller hot well. Hot well serves to accommodate the condensate. The size of the hot well is not as large as a reservoir. On top of the hot well, a hole is made for the steam inlet. There was no change in the perforated plate that separated the bottom with the leaf storage, as did the steam and cajuput oil outlet holes located at the top. The downstream component after the extractor does not change from the existing design. Condenser used is a shell and tube type heat exchanger, the oil separator separates oil and water by density differences. It means that there is a bit difference with the previous design by [7], this proposed design is easy to be implemented because the majority of the extraction component surely available. The previous design can be upgraded to proposed design which means that it can be done with small scale industry like home industry.

This steam distillation system consists of an evaporator, oil extractor, condenser, two pumps, a reservoir, and an oil separator. These components are connected by hoses and pipes. It can be seen in the Figure 4.

5. Energy and Material Balance

Using basic principles of heat transfer and thermodynamics, energy and material balances were calculated based on energy and material requirements to produce eucalyptus oil from 10 kg of cajuput leaves. The extraction time used was 100 minutes using 7.5 kg (7.5 liters) of water. Water was assumed to be fully evaporated into a saturated vapor phase. The calculations were carried out using the assumption that the entire process is in a steady state with no chemical reactions. Complete formula calculation was explained by [7].

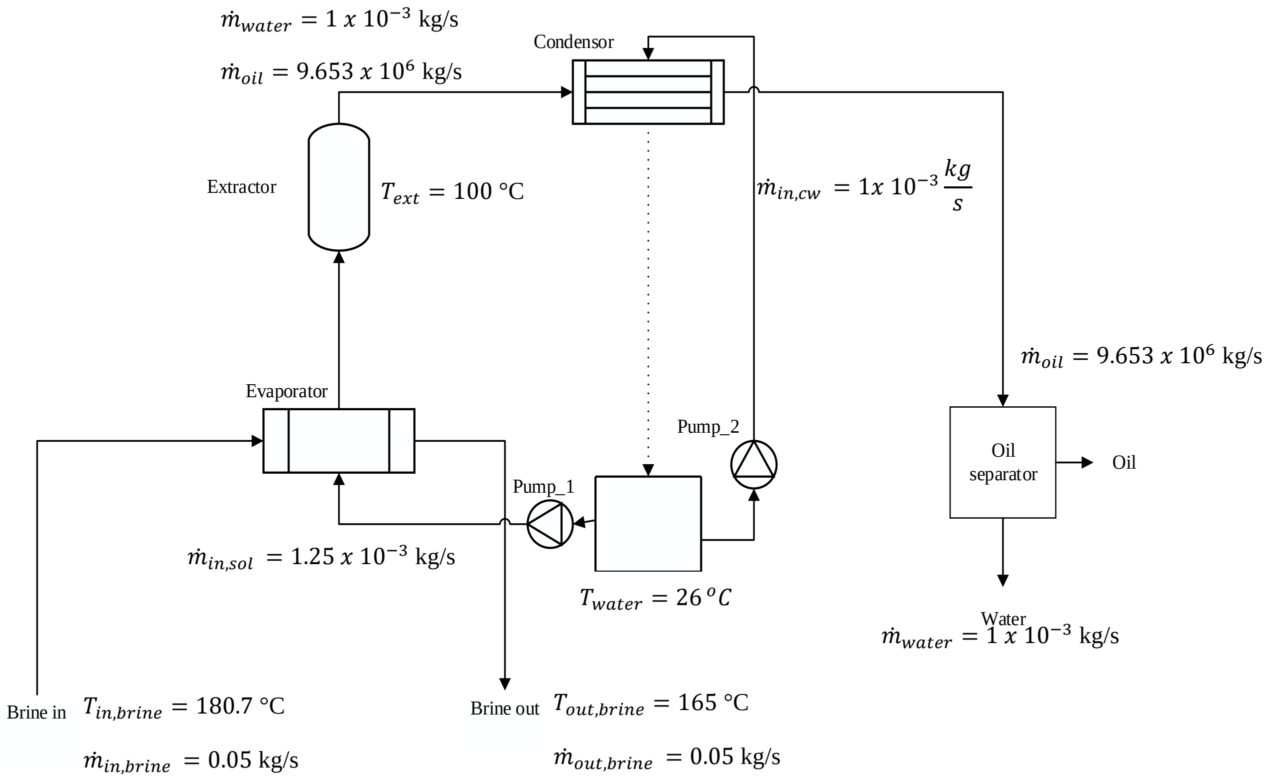

Figure 4. Extraction system of cajuput oil.

5.1 Evaporator

In evaporator, heat exchanges between the water and brine. Brine enters as the hot fluid and water as the cold fluid. The water then gets evaporated, as the brine temperature decreases assuming no heat loss to the environment and no pressure drops. Figure 5 shows the heat exchanger diagram.

The heat received by the water was calculated from liquid phase to saturated vapor at constant pressure of 1 atm using Equation. (1) to (3). Energy balance Equation (1),(2) and (3)

$$\dot{Q}_{water} = \dot{Q}_{brine} = \dot{Q}_{supplied} \tag{1}$$

$$\dot{Q}_{water} = \dot{m}_w\left[c_p(100 - T_i) + h_{fg}\right] \tag{2}$$

$$\dot{Q}_{brine} = \dot{m}_b c_p \Delta T \tag{3}$$

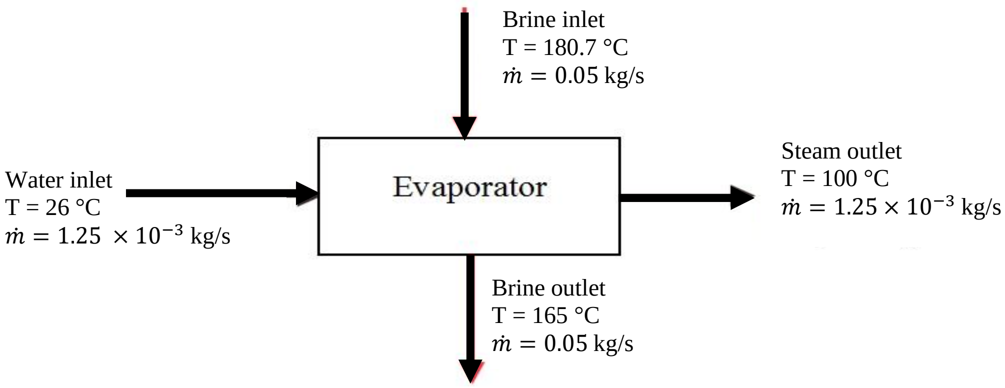

Figure 5. Evaporator material balance.

From the calculation, the heat transferred from the brine to water was 3210 W. Mass flow rate output on the heat exchanger was not change, the brine output is 0.05 kg/s and the steam output is 1.25x10^{-3} kg/s. From Figure 4, steam produced in the evaporator was then supplied to the extractor.

5.2 Extractor

The steam in extractor was used to extract eucalyptus oil from eucalyptus leaves. The extractor outputs were eucalyptus oil and steam, but some of the steam is already condensed. Figure 6 shows a diagram of the extractor that explains the energy and material balance.

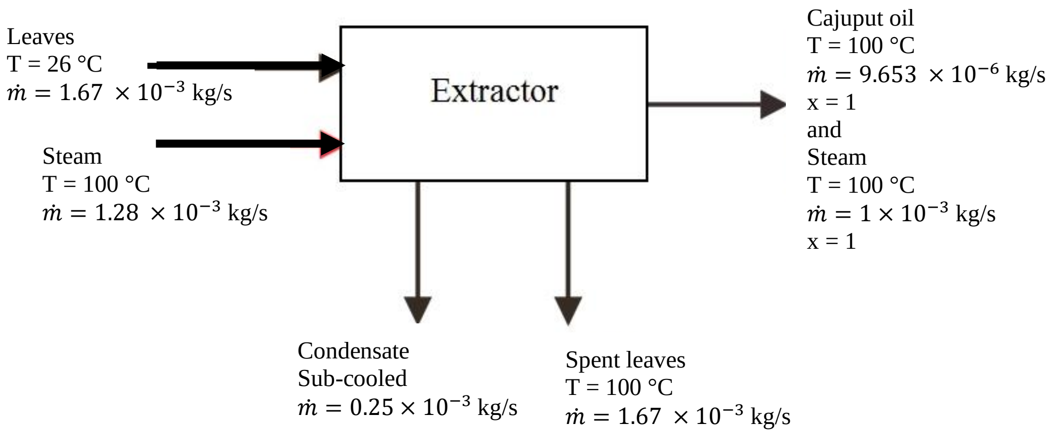

Figure 6. Extractor material balance.

Equations (4) and (5) are used to calculate the heat required by the oil and the leaves. The specific heat of eucalyptus leaves used in calculation was assumed as half of the specific heat of eucalyptus wood, which 470.7 J/kgK. The steam at the extractor outlet was assumed as at saturated vapor, so that the required heat by the steam calculation was used saturated enthalpy (h_{fg}). The formula to calculate the heat for steam that came out from the extractor can be seen in Equation (6).

Energy balance calculation in extractor is show in Equation (4), (5), (6), (7), and (8) :

$$\dot{Q}_{oil} = \dot{m}_o c_{p_o} \Delta T_o \tag{4}$$

$$\dot{Q}_{leaves} = \dot{m}_l c_{p_l} \Delta T_l \tag{5}$$

$$\dot{Q}_{steam,out} = \dot{m}_{so} h_{fg} \tag{6}$$

$$\dot{Q}_{condensate} = \dot{Q}_{steam,in} - \dot{Q}_{steam,out} - \dot{Q}_{leaves} - \dot{Q}_{oil} - \dot{Q}_{loss} \tag{7}$$

$$\dot{Q}_{condensate} = \dot{m}_c h_c \tag{8}$$

In the extractor, the heat loss to the environment was assumed as 25% from the steam input heat or about 802.5 W. The condensate phase must be between sub-cooled. Equations (7) and (8) can be used to check the phase of the condensate.

The energy needed to extract oil of cajuput leaves in the extractor was 58.17 W with unused energy of 92.33 W. The steam energy processed in the extractor is 2257 J/s. That show there is still much energy left that can be used/optimized for the extraction of eucalyptus oil in greater quantities. The energy balance calculation in the extractor can be seen in Appendix 1.

5.3 Condenser

In the condenser, the cajuput oil and remaining steam were condensed using cooling water to become saturated liquid. Cajuput oil and water were condensed to ease the process of refining oil in the oil separator. The heat of the oil is neglected because the amount is much less than the heat of the steam. The condenser process diagram can be seen in Figure 7.

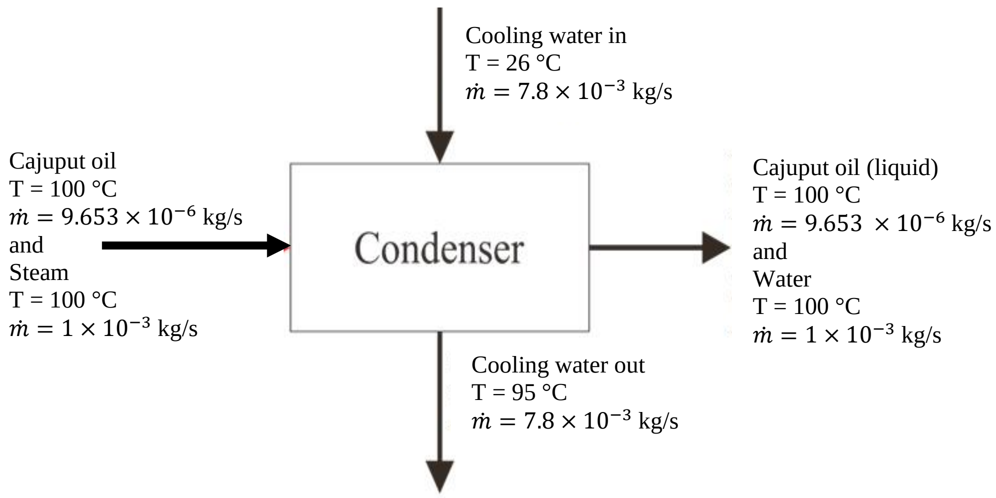

Figure 7. Material balance over condenser.

The formula to enargy balance calculation in condenser is shown in Equation (9) to (11).

$$\dot{Q}_{cw} = \dot{Q}_{steam} + \dot{Q}_{oil} \tag{9}$$

$$\dot{Q}_{steam\ out} = \dot{m}_{cw} \Delta h_{cw} \tag{10}$$

$$m_{cw} = Q_{steam\ out} / \Delta h_{cw} \tag{11}$$

Table 1. Energy balance calculation in condenser.

	Label	Equation	Value	Unit
Condenser	$\dot{Q}_{cw}$	$\dot{Q}_{steam} + \dot{Q}_{oil}$	2257	J/s
	$\dot{Q}_{steam\ out}$	$\dot{m}_{cw}\Delta h_{cw}$	2257	J/s
	m_{cw}	$Q_{steam\ out}/\Delta h_{cw}$	7.81×10^{-3}	kg/s

Table 1 shows the energy balance calculation in condenser. The mass flow rate of eucalyptus oil that has been processed is 9,653x10^{-6} kg/s. The condensation used cooling water with mass flow rate of 7.81x10^{-3} kg/s. The calculation was assumed to use cooling water that enter the condenser at 26 °C. From the calculation, the outlet temperature of the cooling water was 95 °C.

5.4 Oil Separator

The function of oil separator is to purify cajuput oil from water by utilizing the difference in density of the two fluids, and cajuput oil will be above the water. The refined oil is then streamed and collected. In the separator, it is assumed that there are no losses, so that no cajuput oil is wasted. Figure 8 shows a process diagram on the separator. The amount of cajuput oil produce from the extraction can be seen in Equation (12). Energy balance calculation in oil separator

$$m_{oil} = \dot{m}_o t \tag{12}$$

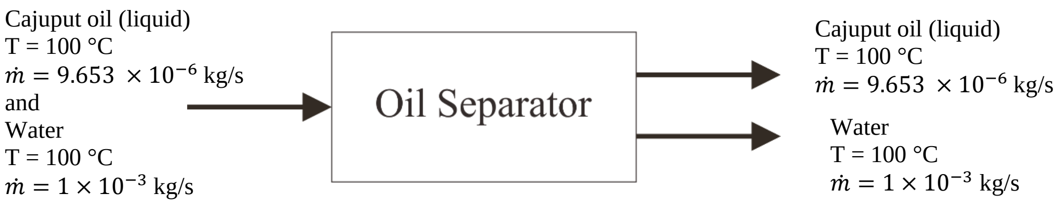

Figure 8. Material balance over oil separator.

In the final process, the processed cajuput oil has become a ready-to-use product. The mass flow rate has not changed from the previous process, so the amount of cajuput oil produce from the extraction process was 57.918 x 10^{-3} kg.

6. Analysis

A scheme for utilizing geothermal waste from GPP for cajuput oil extraction has been made. The remaining brine from GPP Wayang Windu with the temperature of 180.7 °C and a flow rate of 0.05 kg/s can produce cajuput oil up to 0.058 kg/batch for 100 minutes of system operation. Calculations done at steady state, assumed that the cajuput oil produced from the first second of the system starts to operate. The condition could be different from the original in the field. Therefore, it cannot reduce the extraction time because it will take effect on produced oil significantly. However, the raw material from the area around the GPP location is more than sufficient to be used in the designed scheme. The selection of source raw material's location becomes an advantage due to the relatively closest distance, so the distribution is easy. The heat from brine is used primarily for cajuput oil extracting, which is flowed through the evaporator. Although the brine output temperature from the evaporator is higher than SNI for the cajuput extraction process (165 °C). Silica scaling also considered on the brine re-injection line. This study assumed that the evaporator outlet distance from the injection well is far enough. The distance could be very far and a significant drop in brine temperature. Thus it needs to be developed further according to the piping conditions in the field. Therefore, re-use of geothermal waste in this case requires brine/heat source with a higher temperature and further observations on heat loss in the system.

This analysis has provided an overview of the mechanism for utilizing geothermal waste from a GPP. The geothermal waste of PLTP Wayang Windu is more than enough to extract cajuput oil for small-scale or home industries. The existing scheme has provided a complete picture of the material needs and energy balance in producing cajuput oil for one batch and can provide an overview for investors to do business in utilizing geothermal waste. The large potential of brine is an open opportunity to develop a business of cajuput plantation and cajuput oil extraction on a larger scale. Furthermore, cajuput oil will be quite a demand in the future because of its properties in warding off COVID-19. On the other hand, the proposed design could be done by a small-scale industry. To approach a more precise result, some more accurate data and assumptions are needed to enhance the current design.

7. Conclusions

Geothermal waste has been studied for cajuput oil extraction. The difference between the proposed and the existing design is the heat source. Brine from geothermal waste could replace conventional heater as a hot fluid in the evaporator. The obtained oil from proposed design is 0.058 kg/batch. The oil has same quality as the fresh water that used for extraction. Furthermore, the proposed design used brine which will has an impact to carbon pollution reduction. Brine of GPP Wayang Windu field usually is reinjected into the earth and sometime perceived as a waste. By being used as an evaporator heater, brine is more economically valuable. This paper provided a complete illustration of direct use geothermal for investors who have interest to open a cajuput oil extraction company. The proposed design can be modified for other existing GPP schemes, as well as many aspects that need to be taken into consideration.

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APPENDIX 1 Energy and Material Balance Calculation

Component 1 : Evaporator

$$\dot{Q}_{water} = \dot{Q}_{brine} = \dot{Q}_{supplied}$$

$$\dot{Q}_{water} = \dot{m}_w\left[c_p(100 - T_i) + h_{fg}\right]$$

$$\dot{Q}_{water} = 1.25 \times 10^{-3}[4.2(100 - 26) + 2257]$$

$$\dot{Q}_{water} = 3.3\ kJ/s = 3297.12\ J/s$$

$$\dot{Q}_{brine} = \dot{m}_b c_p \Delta T$$

$$\dot{Q}_{brine} = 0.05 \times 4.2(180.7 - 165)$$

$$\dot{Q}_{brine} = 3.3\ kJ/s = 3297.12\ J/s$$

Component 2 : Extractor

$$Q_{oil} = m_o {c_p}_o \Delta T_o$$
$$Q_{oil} = (9.653 \times 10^{-6})(2.6 \times 10^{-3})(100 - 26)$$
$$Q_{oil} = 1.86 \times 10^{-6}\ J/s$$

$$Q_{leaves} = m_l {c_p}_l \Delta T_l$$

$Q_{leaves} = (1.67 \times 10^{-3})(941.4)(100 - 26)$; Assumptions ${c_p}_l = \frac{{c_p}_{wood}}{2} = \frac{1883.4}{2} = 941.4\ J/kg°\mathrm{C}$

$$Q_{leaves} = 116.34\ J/s$$

$$Q_{steam,out} = m_{so} h_{fg}$$
$$Q_{steam,out} = 1 \times 10^{-3} \times 2257$$
$$Q_{steam,out} = 2.257\ kJ/s$$
$$Q_{steam,out} = 2257\ J/s$$

$$Q_{loss} = 0.25 \times 3695.2 = 824.28\ J/s$$

$$Q_{condensate} = Q_{steam,in} - Q_{steam,out} - Q_{leaves} - Q_{oil} - Q_{loss}$$
$$Q_{condensate} = m_c h_c = 99.5\ J/s$$
$$h_c = 398.03\ kJ/kg \rightarrow \textit{Subcooled Phase}$$

Component 3 : Condenser

$$Q_{cw} = Q_{steam\ out} + Q_{oil}$$
$$m_{cw}\Delta h_{cw} = Q_{steam\ out}$$
$$m_{cw}(398 - 109.11) = 2257\ J/s$$
$$m_{cw} = 7.81 \times 10^{-3}\ kg/s$$

Component 4 : Separator

$$m_{oil} = m_o t$$
$$m_{oil} = 9.6 \times 10^{-6} kg/s \times 100\ min$$
$$m_{oil} = 57.918 \times 10^{-3}\ kg$$