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Original research article

Experimental Study of Citronella Oil Extraction by Solar Distillation Using Bubble Pump Technique

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ABSTRACT

Citronella oil is a popular essential oil widely used to repel mosquitoes because it's safe, residue-free, and environmentally friendly. Therefore, this research aims to study the feasibility of extracting citronella oil by solar distillation using a bubble pump technique. The results of the study included the amount of essential oils and the cost of production. The experiment was conducted for 10 days during April and May 2018 in Nakhon Pathom province, Thailand. In the distillation process, the 40 liters of chopped lemongrass juice contained 80% lemongrass by weight. The solution flows through the solar collector. The area is 2.2 m^2 with a 14-degree inclination angle. The results showed that the amount of radiation arriving from the sun was not constant. The average value of solar intensity was 884.98 W/m2 at 81.3°C. Under this condition the maximum was 73.80 ml/day (average was 59.084 ml/day), and the amount of essential oil was 590.84 ml. For economic analysis, it was shown that the production cost of citronella essential oil was 60.43 THB/liter or 1.86 USD/liter (1 THB = 0.0308 USD). In addition, the total amount of essential oils distilled from solar energy using bubble pump techniques increased compared to conventional distillation by 36.95%.

Keywords: Bubble pump technique; Citronella, Essential oil; Lemongrass; Solar energy

1. Introduction

Mosquito borne illness causes high fever, rash and debilitating joint pain, and it can develop into a more severe and lethal form [1]. Therefore, we try to prevent mosquito bites by using chemicals such as mosquito repellent, pesticides, etc., which, despite their functioning, are harmful to other organisms, including our bodies [2, 3]. For the safety of life, there is an idea to use natural extracts as protection against mosquitoes, which is an excellent solution to

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this problem [4-8]. The first use of citronella oil as an insecticide was recorded around 1882, making it one of the first botanical insecticides. It was primarily used as a mosquito repellent for camping, along with cedar oil and camphor spirits, early in the 20th century. The use of essential oil extracted from the citronella is not harmful to the body and without residue as well [7-12].

Citronella is sometimes called lemongrass. For Thailand, citronella is an easy-to-grow and inexpensive plant. It takes about 7-9 months from planting to first harvest. Lemongrass essential oil may be extracted by many different methods, such as solvent extraction, steam distillation, hydro-distillation (HD), microwave energy. The water distillation has been popular and has been involved in the extraction of essential oil for a very long time [13-16]. Steam and hot water are used as extraction and transport mediums to release bioactive elements from plant resources and take them along as a mixture. The equipment consists of a condenser that provides indirect cooling of the mixture for separating water from the oil. This process is carried out at high temperatures (above the boiling point of water). This causes excessive heat, which may dry out the material and some of the volatile and heat-sensitive elements of the oil may be lost during the process, causing combustion that leads to the production of low-quality oil. Therefore, it is necessary to find new techniques for helping the production process of high quality and large quantity as required. The essential oil distillation typically uses heat sources from fossil fuels, natural gas, and biomass [17] which are expensive and release carbon dioxide. Carbon dioxide is a pollutant and a cause of global warming [18, 19].

As mentioned above, it is necessary to find other sources of energy to use as renewable energy. Solar-powered technologies have provided us a way to sustainable development in the extraction sector. It can be considered clean energy without energy costs [15, 20]. Especially, distillation with a bubble pump technique makes slurry formation easy and can be done quickly. However, previous studies have shown that there is very little research that combines bubble pump techniques with sun ray collectors to distill the essential oils.

The main objective of this work is to evaluate the performance of the solar energy and bubble pump technique for the distillation process of citronella oil. The study presents the experimental results of amount of essential oils and the cost of production.

2. Materials and Methods

2.1 Feed preparation

Citronella was purchased from the market, washed, and cut into small pieces. Then the chopped citronella was mixed with clean water (ratio of 1 liter water to 1 kg of lemongrass) and the lemongrass juice squeezed, as seen in Fig.1.

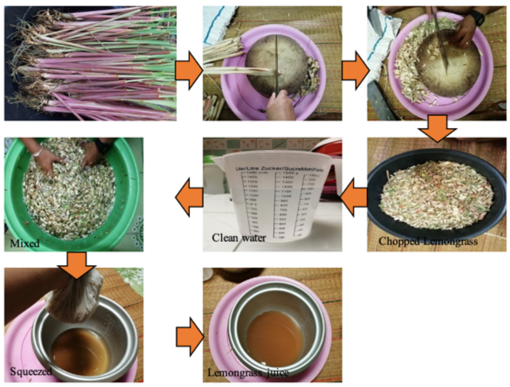

Fig. 1. Lemongrass juice preparation.

2.2 Experimental setup

The solar essential oil distiller using bubble pump techniques shown in Fig. 2 was designed according to engineering principles based on reference [21, 22]. Fig. 3 shows a diagram of the experiment and location of temperature measurement sensor. The equipment was tested to distill the essential oils by maintaining the citronella juice at 80% of the solar panel. The solar panel was at an inclined angle with a 14-degree orientation. The solution flow rate was 0.0035 kg/s. It was controlled by a rotameter. The condenser size was 0.751 m-tall and 0.025 m-inner diameter.

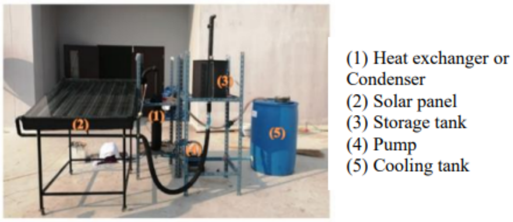

Fig. 2. Solar energy distillation system of citronella oil using bubble pump technique.

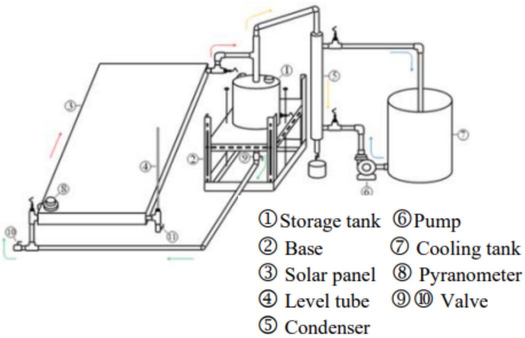

Fig. 3. Experimental procedure and location of temperature measurement.

The experiment was conducted on a clear and cloudless day. The distillation process ran from 8:30 AM to 4:00 PM. The solar radiation was measured with an on-level pyranometer (Kipp and Zonenn c220), the value was recorded every 30 minutes in unit watts per square meter (W/m^2). Type K thermocouples were installed at the designated points for measuring the temperature (^oC). All physical properties were measured, such as solar radiation intensity; volume of essential oil; temperature distribution, during the process. The results obtained from the experiment were graphed to show the performance of citronella oil extraction by solar distillation using the bubble pump technique.

From Fig. 3, the steps in the experiment and temperature measurement can be described as follows:

1. To prepare citronella juice at a volume of 40 liters, which will be distilled for 10 times.
2. To turn on the coolant water pump ⑥ for performing heat exchange between the water and the essential oil vapor.
3. To fill the citronella juice into a storage tank □□amount of 40 liters.
4. To open the valve □. The citronella juice flow into the solar panel □.
5. To adjust the level of citronella juice at 80% of the solar panel by adjusting the height of the base □□and observing with the solution level tube □.
6. The solution was boiled, if the solar panel □□ has reached the boiling point of the solution. The vapor flowed to the top of the solar panel and condensing in the condenser □. During that time, the vapor that condensed before entering the condenser will flow back into the storage tank for distillation again.
7. To record temperature at 8 points in degrees Celsius. The values were kept every 30 minutes, where T1-T4 (solution temperature in solar panel), T5 (inlet coolant temperature), T6 (outlet coolant temperature), T7 (ambient temperature in solar panel), T8 (surrounding temperature).
8. To measure the volume of distilled citronella oil every 60 minutes after starting the distillation process.

3. Results and Discussion

Figs. 4-6 show the measurement values of the relationship between light intensity and yield, density, and volume of essential oils, respectively. The results were obtained at different times of the day.

3.1 Solar radiation intensity

The experiment was performed for 10 days. This result was selected from some day to display the profile of solar radiation intensity and initial concentration solution and profile of solar radiation intensity and temperature at different times during the distillation process in Figs. 4-5, respectively. From Fig. 4, it can be seen that the peak intensity period occurred between 0:00 to 2:00 PM. The concentration of the initial solution was decreasing day by day and the average exposure and temperature inside the sun collector was 884.98 W/m^2 at 81.3°C (as seen in Fig.5).

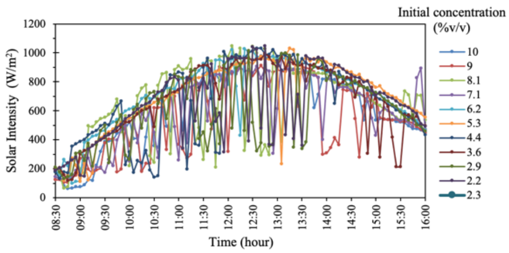

Fig. 4. Profiles of solar radiation intensity and concentration of essential oils at different time in one day.

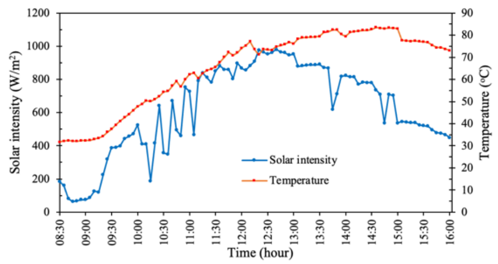

Fig. 5. Profiles of solar radiation intensity and temperature at different time in one day.

3.2 Density and the volume of essential oils distilled

Fig. 6 shows the density and volume obtained by distillation of citronella juice using solar energy with a bubble pump technique for 10 days. It shows that the density of citronella oil started at 980.5 kg/m^3 (Day 1) and then increased steadily, resulting in the highest density at 989.8 kg/m^3 (Day 10). By the way, the volume of essential oils obtained from the citronella distillation that tends to be in the opposite direction. In the case of distillation of 40 liters of citronella solution, the highest distillation was 73.80 ml on the first day (Day 1) and the lowest distillation was 38.57 ml on the last day (Day 10). In addition, it was found that the amount of distilled essential oils was according to the amount of light intensity and temperature inside the solar collector.

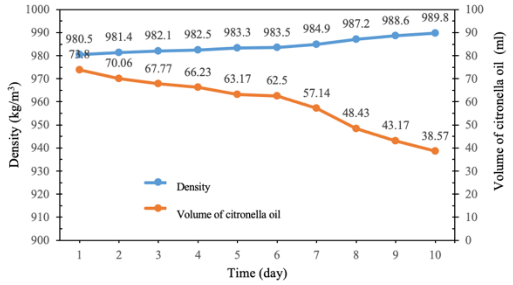

Fig. 6. The density and volume of citronella oils distilled from Day 1 to Day 10.

3.3 Efficiency of solar energy with bubble pump technique for citronella oils distillation

Fig. 7 shows the total volume of the essential oils obtained by conventional method and solar distillation with the bubble pump technique. It was found that the total volume of essential oils obtained was 372.52 ml and 590.84 ml by conventional distillation and solar distillation with bubble pump technique, respectively. This study found that the total volume of citronella oil increased with increasing the heat of the distillation process. The main factor resulting in the total volume of citronella oil was type of heat exchanger. This is because the conventional distillation did not use a split heat exchanger for the coolant and essential oil system. The water was mixed with an essential oil. It was passed through the process of separating water and essential oils again, which this process may not separate the water and essential oil. For the solar essential oil distillation using the bubble pump technique, the coolant and essential oil were separated as a result of increasing volume of essential oil. In addition, the performance of solar essential oil distillation using bubble pump techniques increased compared to the convention distillation by 36.95%.

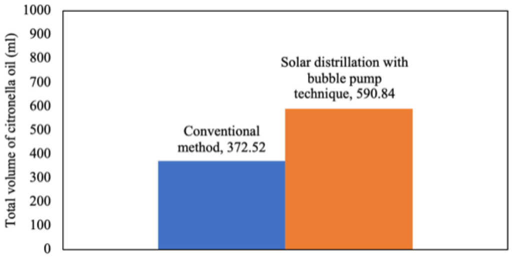

Fig. 7. Comparison of the total volume of the essential oils obtained by conventional method and solar distillation with bubble pump technique.

3.4 Economic analysis

The important part of engineer work was economic analysis because the results will be the information and criteria for making an investment decision. In this work, the cost per unit of essential oil distillation will be assessed using the annual cost method. The annual cost was sum of annual investment (C_I), operating and maintenance $(C_{O\&M})$, and energy cost (C_E). The calculation was based on a year, as:

$$\text{Total annual cost} = C_I + C_{O\&M} + C_E \quad (3.1)$$

The assumptions used for calculation were as follows:

1. Capital cost or equipment cost with details are shown in Table 1.
2. Operating and maintenance $(C_{O\&M})$ cost was set to be 10% of the initial investment.
3. The device service life was 10 years.
4. The interest rate was equal to 7.125% per year
5. Electric energy cost was calculated according to the electricity tariff category 2.1 (for small businesses).
6. The working day was 300 days per year and working hours were 7.30 hours per day.

Table 1. Essential oil distillation equipment cost.

List	Price (THB)	Price (USD)
Solar collector size 2.2 m^2	16,000	492.8
Heat exchanger	4,000	123.2
Coolant pump	400	12.32
Citronella solution tank	3,000	92.4
Stainless steel, pipe, leveling stand, valve fitting, and insulation.	1,000	30.8
Total	24,400	751.52

****Note:*** 1 THB = 0.0308 USD

3.4.1 Investment cost (C_I)

The annual investment of the distillation system was 24,400 THB (751.52 USD), the interest rate (*i*) was 7.125% per year, and the service life (*N*) of 10 years. Therefore, the annual investment for the solar distillation system using the bubble pump technique was equal to 3,494.11 THB/year (107.62 USD/year); it was calculated from the following equation:

$$C_I = P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right], \quad (3.2)$$

where P = Initial investment (THB or USD), N = service life (year), and i = the interest rate (per year)

3.4.2 Energy cost (C_E)

For electrical energy, it used the Mirano water pump (370 Watts) The electric power price will be based on electricity tariff Category 2.1 for small business. The working hour of the machine was 7.30 hours each day. The working days were 300 for 1 year. Thus, Electricity consumption for one month:

$$= 7.30\frac{hr}{day} \times 30\frac{days}{month} \times 370\frac{W}{hr},$$

$$= 81.03\frac{kW}{month}.$$

According to the tariff category 2.1 for a small business,

Part 1: base electricity cost

- Energy cost (0 - 150 units) = 2.7268 THB/unit

$= 81.03 \text{ units} \times 2.7268 \dfrac{\text{THB}}{\text{unit}},$

$= 233.87 \text{ THB or } 8.62 \text{ USD}.$

Service charge = 46.16 THB

Total Electric cost

= 233.87 THB + 46.16 THB,

= 280.03 THB or 8.62 USD.

Part 2: Variable Electric Charge (F_t)

- Variable electricity rate = 0.9581 THB/ unit

$= 81.03 \text{ units} \times 0.9581 \dfrac{\text{THB}}{\text{unit}},$

$= 77.63 \text{ THB or } 2.39 \text{ USD}.$

Part 3: VAT 7%

(Base electricity cost + Variable electricity cost) × (0.07)

$= (280.03 + 77.63) \text{ THB } \times (0.07)$

$= 25.0362.$

Finally,

- Total monthly electricity cost

= base electricity cost + variable electricity cost + VAT.

$= (280.03 + 77.63 + 5.0362) \text{ THB}$

$= 382.70 \text{ THB or } 11.79 \text{ USD}.$

- Total yearly electricity cost

= Total monthly electricity cost × working months

$= 382.70 \dfrac{\text{THB}}{\text{month}} \times 9.87 \text{months},$

$= 3{,}777.25 \dfrac{\text{THB}}{\text{year}} \text{ or } 116.34 \dfrac{\text{USD}}{\text{year}}.$

3.4.3 Operating and maintenance $(C_{O\&M})$

In this study, the operating and maintenance cost of the solar citronella essential oil distillation system using the bubble pump technique was set to 10% per year. Thus, operating and maintenance cost was equal to

$= \left(0.1 \dfrac{1}{\text{year}}\right) \times 24{,}400 \text{ THB},$

$= 2{,}440 \dfrac{\text{THB}}{\text{year}} \text{ or } 75.15 \dfrac{\text{USD}}{\text{year}}.$

3.4.4 Production cost of essential oil from citronella

In this study, the cost of production of essential oil from citronella

$$= \frac{\text{Total Annual cost + citronella cost per year}}{\text{The volumn of essential oils that can be distilled per year}}.$$

- the total annual cost

$= (3{,}494.11 + 3{,}777.25 + 2{,}440) \dfrac{\text{THB}}{\text{year}},$

$= 9{,}711.36 \dfrac{\text{THB}}{\text{year}} \text{ or } 299.11 \dfrac{\text{USD}}{\text{year}}.$

The cost of citronella was shown in Table 2.

Table 2. Citronella cost.

List	Mass (kg)	Price / unit (THB)	Price / year (THB)
Citronella	20	50	1,000

- the volume of distillation per year = 177.252 liters.

Thus,

$$= \frac{9{,}711.36 \dfrac{\text{THB}}{\text{year}} + 1{,}000 \dfrac{\text{THB}}{\text{year}}}{177.252 \dfrac{\text{liters}}{\text{year}}},$$

$= 60.43 \dfrac{\text{THB}}{\text{liter}} \text{ or } 299.11 \dfrac{\text{USD}}{\text{liter}}.$

3.4.5 The payback period of production of citronella essential oil

- Total cost per year

$= C_I + C_E + \text{Citronella cost},$

$= (3,494.11 + 3,777.25 + 1,000)\ \dfrac{\text{THB}}{\text{year}},$

$= 8,271.335\ \dfrac{\text{THB}}{\text{year}} \text{ or } 254.76\ \dfrac{\text{USD}}{\text{year}}.$

- Selling price of citronella essential oil

$= 60.43\ \dfrac{\text{THB}}{\text{liter}} \text{ or } 1.86\ \dfrac{\text{USD}}{\text{liter}}.$

- Essential oil yield from citronella

$= 177.252\ \dfrac{\text{liters}}{\text{year}}.$

- Revenue from citronella essential oil

$= 177.252\ \dfrac{\text{liters}}{\text{year}} \times 60.43\ \dfrac{\text{THB}}{\text{liter}},$

$= 10,711.34 \dfrac{\text{THB}}{\text{year}}.$

- The profit from selling of essential oils

$= (10,711.34 - 8,271.335)\dfrac{\text{THB}}{\text{year}},$

$= 2,440.005 \dfrac{\text{THB}}{\text{year}}.$

Finally, payback period

$= \dfrac{\text{Total cost per year}}{\text{The profit from sellong}} = \dfrac{8,271.335}{2,440.005},$

$= 3.40 \text{ years}.$

4. Conclusion

This study was the distillation of essential oils from citronella using solar energy with the bubble pump technique. The results show that the high quality of the distillation process occurred on the first day (Day 1) because it was low density and low boiling point. The distillation volume was 73.80 ml; it tended to decrease with higher density and increasing boiling point. The lowest distillation volume was 38.57 ml on the last day (Day 10). In addition, the volume of essential oils obtained by conventional distillation was 372.52 ml, and the volume of essential oils obtained from solar distillation with the bubble pump technique was about 590.84 ml with 36.95% increasing. Finally, in the economic analysis, the cost of citronella essential oils was 60.43 THB/liter (or 1.86 USD/liter) and the payback period was equal to 3.40 years.

The interesting issues were chosen to study for the future work: (1) Adjusting the inclination angle of the solar panel over time (2) Design the solution tank for easy cleaning for industrial scale.

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References

[1] Guarner, J. and Hale, G.L., 2019, May. Four human diseases with significant public health impact caused by mosquito-borne flaviviruses: West Nile, Zika, dengue and yellow fever. In Seminars in diagnostic pathology Vol.36, No.3, pp. 170-6.

[2] Fradin, M.S. and Day, J.F., 2002. Comparative efficacy of insect repellents against mosquito bites. New England. *Journal of Medicine*, 347(1), pp.13-8.

[3] Clem, J.R., Havemann, D.F. and Raebel, M.A., 1993. Insect repellent (N, N-diethyl-m-toluamide) cardiovascular toxicity in an adult. *Annals of Pharmacotherapy*, 27(3), pp. 289-93.

[4] Chattopadhyay, P., Dhiman, S., Borah, S., Rabha, B., Chaurasia, A.K. and Veer, V., 2015. Essential oil based polymeric patch development and evaluating its repellent activity against mosquitoes. *Acta tropica*, 147, pp. 45-53.

[5] de Paula, J.P., Gomes-Carneiro, M.R. and Paumgartten, F.J., 2003. Chemical composition, toxicity and mosquito repellency of Ocimum selloi oil. *Journal of Ethnopharmacology*, 88(2-3), pp. 253-60.

[6] Azeem, M., Zaman, T., Tahir, M., Haris, A., Iqbal, Z., Binyameen, M., Nazir, A., Shad, S.A., Majeed, S. and Mozūraitis, R., 2019. Chemical composition and repellent activity of native plants essential oils against dengue mosquito, Aedes aegypti. *Industrial Crops and Products*, 140, p.111609.

[7] Soonwera, M. and Phasomkusolsil, S., 2015. Efficacy of Thai herbal essential oils as green repellent against mosquito vectors. *Acta tropica*, 142, pp. 127-30.

[8] Sakulku, U., Nuchuchua, O., Uawongyart, N., Puttipipatkhachorn, S., Soottitantawat, A. and Ruktanonchai, U., 2009. Characterization and mosquito repellent activity of citronella oil nanoemulsion. *International journal of pharmaceutics*, 372(1-2), pp. 105-11.

[9] Novak, R.J. and GERBERG, E.J., 2005. Natural-based repellent products: efficacy for military and general public uses. *Journal of the American Mosquito Control Association*, 21(sp1), pp. 7-11.

[10] da Silva, M.R.M. and Ricci-Júnior, E., 2020. An approach to natural insect repellent formulations: From basic research to technological development. *Acta Tropica*, p.105419.

[11] Kumar, N., Kumar, S., Singh, S.P. and Rao, R., 2021. Enhanced protective potential of novel citronella essential oil microsponge hydrogel against Anopheles stephensi mosquito. *Journal of Asia-Pacific Entomology*, 24(1), pp. 61-9.

[12] Specos, M.M., García, J.J., Tornesello, J., Marino, P., Vecchia, M.D., Tesoriero, M.D. and Hermida, L.G., 2010. Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 104(10), pp. 653-8.

[13] Timung, R., Barik, C.R., Purohit, S. and Goud, V.V., 2016. Composition and anti-bacterial activity analysis of citronella oil obtained by hydrodistillation: Process optimization study. *Industrial Crops and Products*, 94, pp. 178-88.

[14] Gavahian, M. and Chu, Y.H., 2018. Ohmic accelerated steam distillation of essential oil from lavender in comparison with conventional steam distillation. *Innovative Food Science & Emerging Technologies*, 50, pp. 34-41.

[15] Radwan, M.N., Morad, M.M., Ali, M.M. and Wasfy, K.I., 2020. A solar steam distillation system for extracting lavender volatile oil. *Energy Reports,* 6, pp. 3080-7.

[16] Yingngam, B., Kacha, W., Rungseevijitprapa, W., Sudta, P., Prasitpuriprecha, C. and Brantner, A., 2019. Response surface optimization of spray-dried citronella oil microcapsules with reduced volatility and irritation for cosmetic textile uses. *Powder Technology*, 355, pp. 372-85.

[17] Cao, Y., Mihardjo, L.W., Dahari, M. and Tlili, I., 2021. Waste heat from a biomass fueled gas turbine for power generation via an ORC or compressor inlet cooling via an absorption refrigeration cycle: A thermoeconomic comparison. *Applied Thermal Engineering*, 182, pp. 116-7.

[18] Alexiadis, A., 2007. Global warming and human activity: A model for studying the potential instability of the carbon dioxide/temperature feedback mechanism. *Ecological modelling*, 203(3-4), pp. 243-56.

[19] Pelletier, C., Rogaume, Y., Dieckhoff, L., Bardeau, G., Pons, M.N. and Dufour, A., 2019. Effect of combustion technology and biogenic CO2 impact factor on global

warming potential of wood-to-heat chains. *Applied Energy*, 235, pp. 1381-8.

[20] Afzal, A., Munir, A., Ghafoor, A. and Alvarado, J.L., 2017. Development of hybrid solar distillation system for essential oil extraction. *Renewable Energy*, 113, pp. 22-9.

[21] Robert W. Fox, Alan T. McDonald, Philip J. Pritchard, 2010. *Introduction to Fluid Mechanics*. John Wiley & Sons (Asia) Pte Ltd

[22] Yunus A.Cengel & Afshin J.Ghajar, 2015. *Heat and Mass Transfer Fundamentals & Applications*. New York:MaGraw-Hill Education.