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Efficiency and performance evaluation of eucalyptus oil extractor

Danjuma, M. N., Lamido, S. I. and Baba, M. B.

Department of Chemical Engineering, Kaduna polytechnic

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Correspondence author:

e-mail:

Phone :

+2348096363587.

ABSTRACT

The Success of any design and construction of equipment lies on smooth test running of the equipment. This work was aimed at test running of an eucalyptus oil extractor which was design and constructed. The efficiency of the equipment was computed to be 89% and Heat exchanger duty Q to be $5.22 \times 10^2 \text{ kW}$ at average steam rate of $2.3 \times 10^{-4} \text{ kg/s}$. The optimal operating period of 70minutes for a small size of leave below 4cm was recommended for use.

Introduction

There are different procedures available for extraction of oil or volatile oil from plant cells containing oil, such as eucalyptus. The majority of essential oils are obtained by steam distillation or hydro-distillation. Three types of hydro distillation are employed in the essential oil industry: Water distillation, water and steam distillation and direct steam distillation. In order to isolate an essential oil from an aromatic plant, the plant material is packed into a still. Sufficient quantity of water is added and the mass is brought to a boil, or live steam is injected into the plant charge. Due to the action of hot water and steam, the essential oil will be freed from the oil glands in the plant tissue (Padma, 2004). Steam distillation has been the best method for optimum conditions. Steam distillation has also its own ranges of technology sophistications (Kebede and Hayelom, 2008). Steam

distillation is a special type of a separation process for temperature sensitive materials like oils, resins, hydrocarbons, etc. which are insoluble in water and may decompose at their boiling point. The temperature of the steam must be high enough to vaporize the oil present. Essential oils contain substances with boiling points up to 200°C or higher temperatures; in the presence of steam or boiling water, these substances are volatilized at a temperature close to 100°C , at atmospheric pressure. A number of factors determine the final quality of a steam distilled essential oil. Apart from the plant material, most important are time, temperature and pressure, and the quality of the distillation equipment (Satishkumar, 2010).

Considerable effort has been made by researchers to find efficient extraction methods in order to get high efficiency and efficacy.

Efficiency refers to the yield of extraction, whereas efficacy refers to the potency (magnitude of bioactivity / the capacity to produce an effect) of the extract. For isolation of biological components, extraction from plant is one of the more sustainable approaches (Gupta *et al.*, 2012). Performance of heat exchanger is done more easily by a method based on effectiveness (efficiency) of the heat exchanger in transferring a given amount of heat. The effectiveness offers many advantages for analysis of problem in which a comparison between various types of heat exchangers must be made for purposes of selecting the type best suited to accomplish a particular heat-transfer objective. (Holman, 2002.; Coulson and Richardson, 1997).

Equipment used to extract the oil, or design for such purposes is based on specific properties of the oil and chosen parameters. Success of design and construction of any equipment lies on smooth test running and evaluation of the efficiency of the design equipment as well as compliance with the set down objectives. In most cases during test running and evaluation of equipment performance arises, the need for modification in order to eliminate some unforeseen problems which may arise in design stage

The Eucalyptus oil extractor under study consists of stripping chamber, heat exchanger unit and the separating unit. Stripping chamber being a unit where the oil containing plant part is to be stocked and oil extracted at the designated temperature and pressure. Heat exchanger is a device built for efficient heat transfer from one medium to another where the medium are separated by a solid wall to prevent mixing or direct contact of the medium (Backhust and Harker, 1983.; Sinnott, 1999). Oil extracted are cooled and condensed in heat exchanger. Extraction of oil out of adipose cell by a solvent is

affected by factors among others are particle size, nature of solvent, temperature, Agitation etc. (McCabe *et al.*, 1985.; Trebal, 1980)

Heat exchanger effectiveness is used to predict the performance of heat exchanger designed is define as the ratio of the actual rate of heat transfer Q to the maximum rate Q_{max} that is thermodynamically possible.

$$\text{Efficiency } (\eta) = \frac{Q}{Q_{max}} \dots\dots\dots 1$$
$$= \frac{\Delta T(\text{Minimum fluid})}{\Delta T(\text{Maximum temperature difference in heat exchanger})} \dots\dots\dots 2$$

Q_{max} is the heat transfer rate which would be achieved if it were possible to bring the outlet temperature of the steam with the lower heat capacity to the inlet temperature of the other stream. The minimum fluid is always the one experiencing the larger temperature difference in the heat exchanger, and the maximum temperature difference in the heat exchanger is always the difference in inlet temperatures of the hot and cold fluid (Holman, 2002.; Coulson and Richardson, 1997).

This work therefore is to test run a designed eucalyptus oil extractor as well as to evaluate its performance in an attempt to asses compliance or deviation from the set out design aim of the equipment. It should be understand that this work is a follow up to the design of eucalyptus oil extractor.

Materials and Methods

The following procedures set out below were adopted to conduct the study.

1. Experimental set - up

The designed and constructed equipment consist of a cylindrically shaped stripping chamber, with a conically shape top cover which was fitted with a pressure gauge, through which the steam from boiler passes into the stripping chamber.

The stripping chamber is then connected at its lower part to a shell and tube heat exchanger, which condensed the stripped vapors that contained essential oil. The condensate is collected in a separating funnel which separated oil layer out of the water (condensate).

2. Experimental runs

A 2kg of pretreated leaves sized to 4 cm was charged into stripping chamber and the top cover coupled. Steam generated in a boiler at a pressure of 1.5 bar was admitted through the stripping chamber. The steam stripped out the essential oil and it was condensed to 36°C in heat exchanger of which cooling water was allowed to circulate through the external shell of the exchanger. Mixture of condensed steam and extracted essential oil emerged from the heat exchanger outlet. It was collected in a separating funnel, where oil separated out of water.

3. Determination of optimum extraction time and rate

The experimental set-up was run as described above and variation in oil yield with time was monitored with aim to determine the optimum extraction time. Quantity of oil extracted at every ten minutes interval was measured. The procedure was stopped when no

significant quantity of oil extract come out of the leave.

4. Variation of oil extracted with leave sizes

A fully matured eucalyptus leave average 15cm long in size was obtained from parent tree. The leaves obtained were reduced into various size, 4cm, 8cm and 15cm sizes were experimented on. In an attempt to determine the optimal average leave size to give the best oil yield.

5. Heat exchanger performance (effectiveness)

One of the most useful methods of evaluating the performance of an existing heat exchanger or to asses a proposed design was to determine its effectiveness. The inlets as well as the outlets temperatures of steam and cooling water were measured by thermocouple and these values were used to compute efficiency using equation 2.

Other parameters, Cooling water flow rate and steam flow rate were measured using appropriate flow meter.

Results and Discussion

The results obtained during the study were presented graphically and into tabular form, as shown below;

Table1: Measured Operating Temperatures

<i>Fluid</i>	<i>Inlet Temperature, °C.</i>	<i>Outlet Temperature, °C</i>
Cooling Water	28	35.5
Steam	100	36

Table 2: Measured Heat Exchanger Operating Parameters.

<i>Parameters</i>	<i>Values</i>
Cooling water flow rate G1	11.64 x 10 ⁻² kg/s
Average steam rate G2	2.3 x 10 ⁻⁴ kg/s
Steam pressure	1.5 bar

G1 and G2 are the average value of cooling water and steam flow rate respectively.

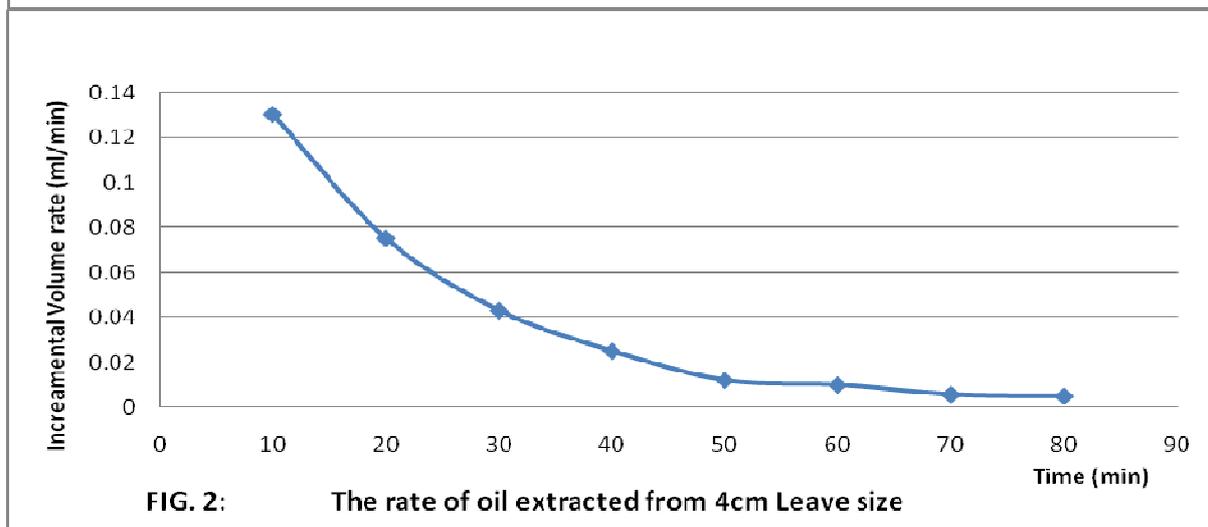
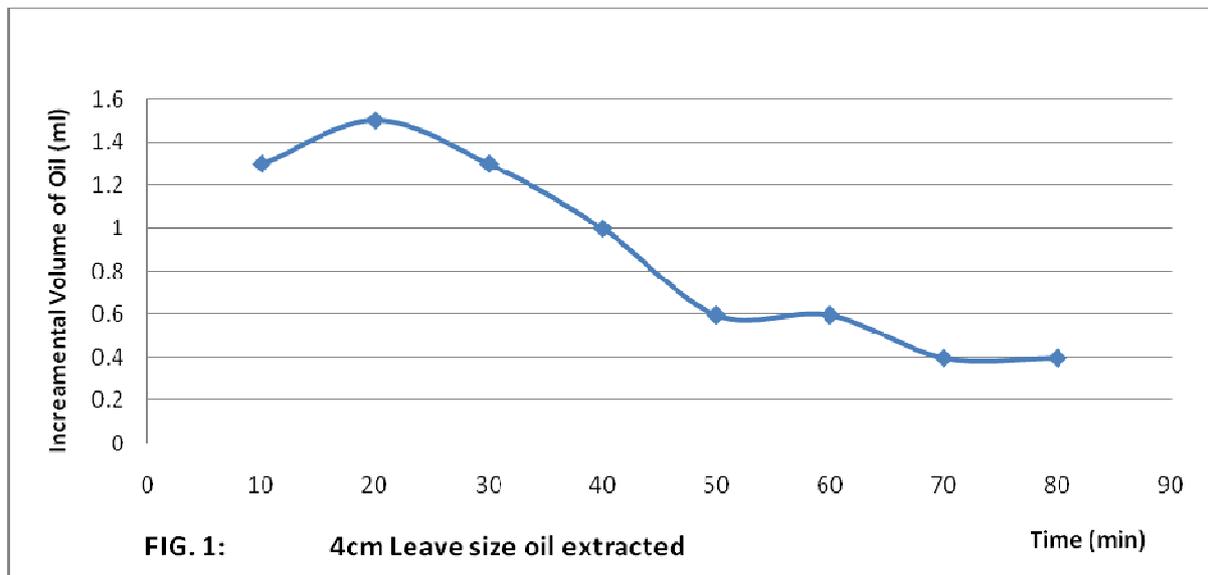
Table3: Evaluated Heat Exchanger Performance Parameters.

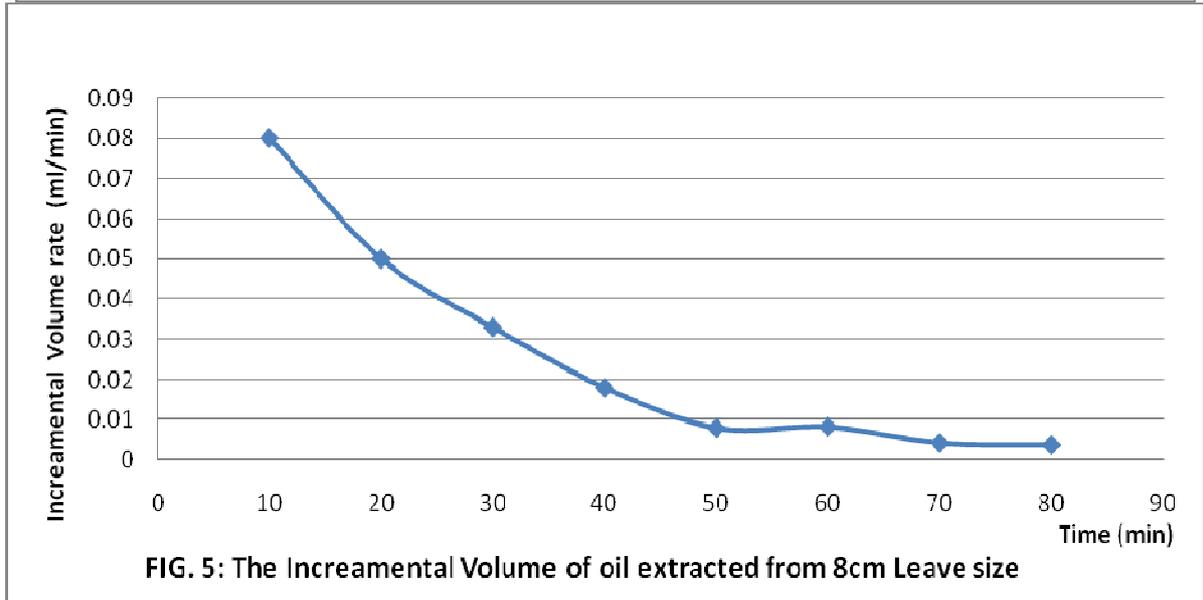
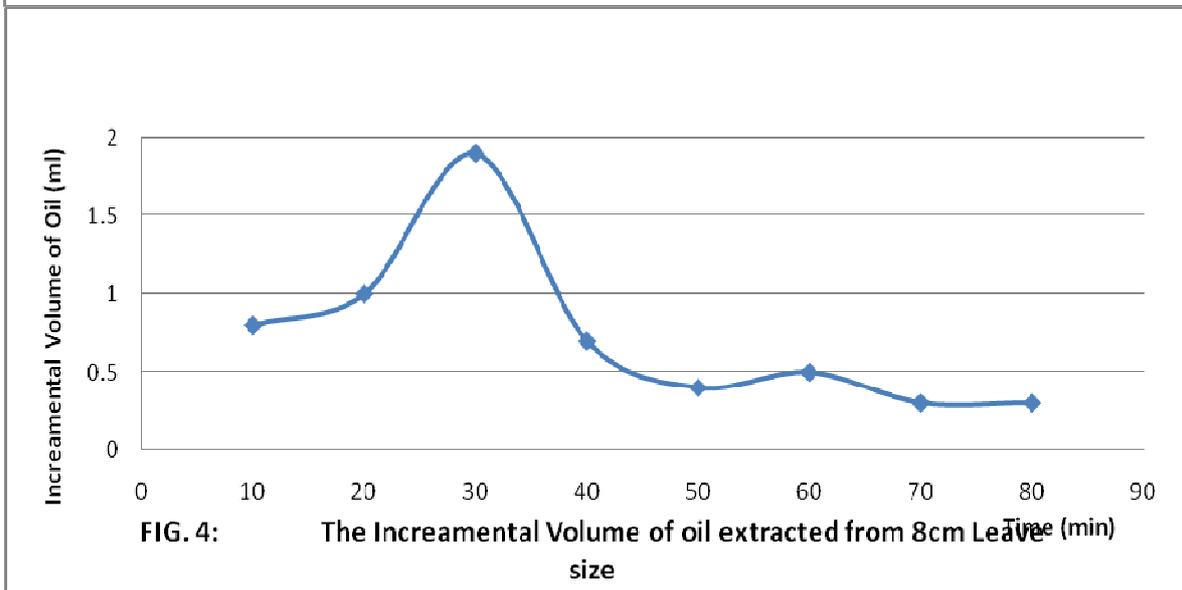
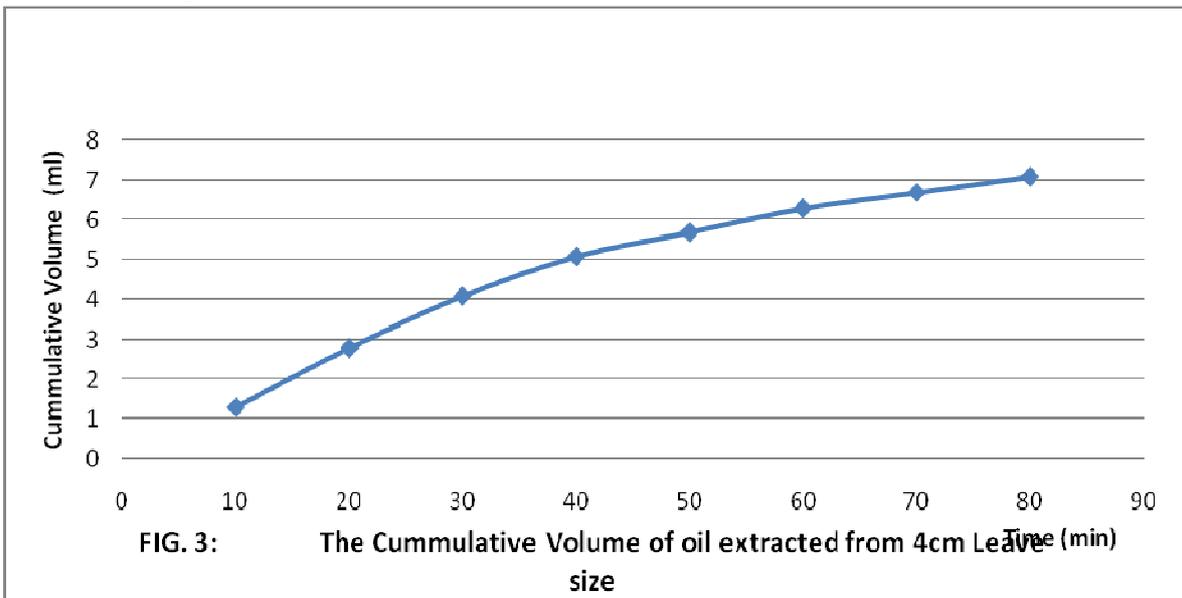
Parameters	Computed Values
Heat exchanger duty Q	5.22 x 10 ⁻¹ kw 89%
Efficiency η	
Percentage oil yield	0.36 wt/wt

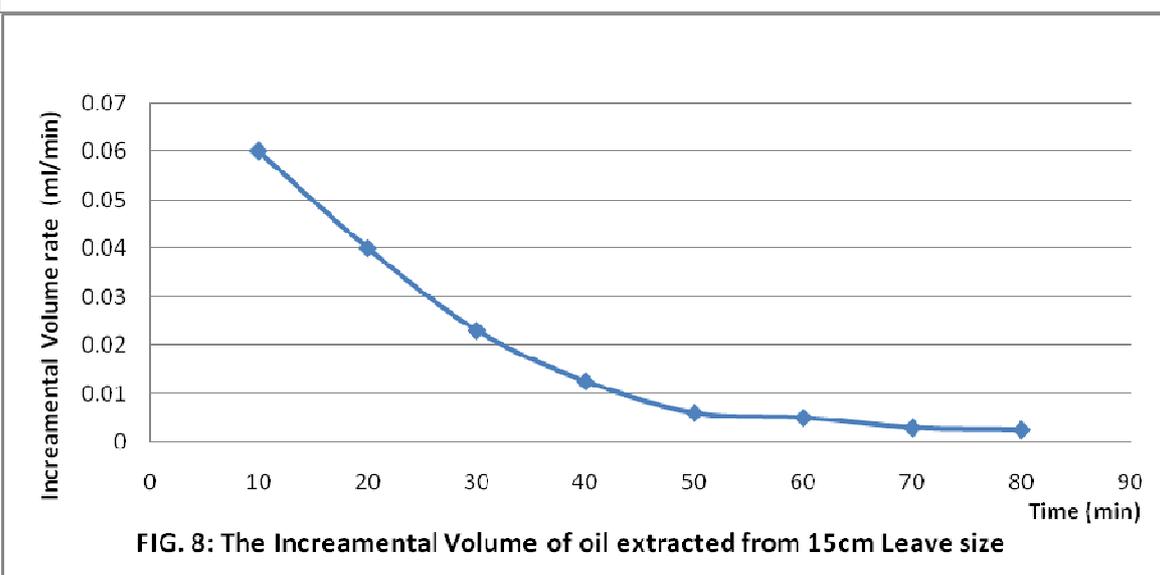
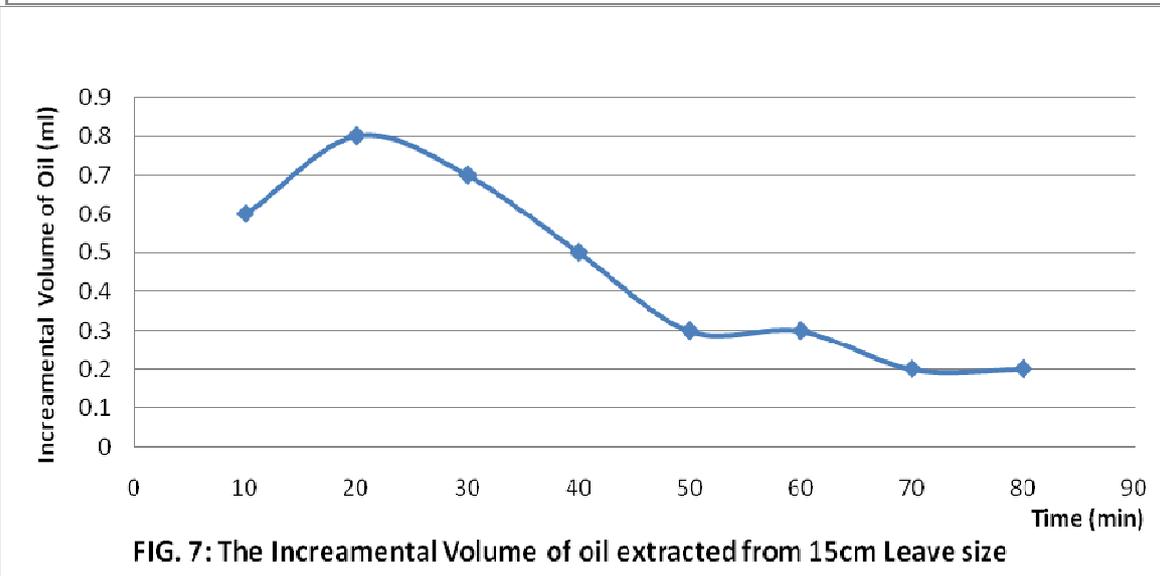
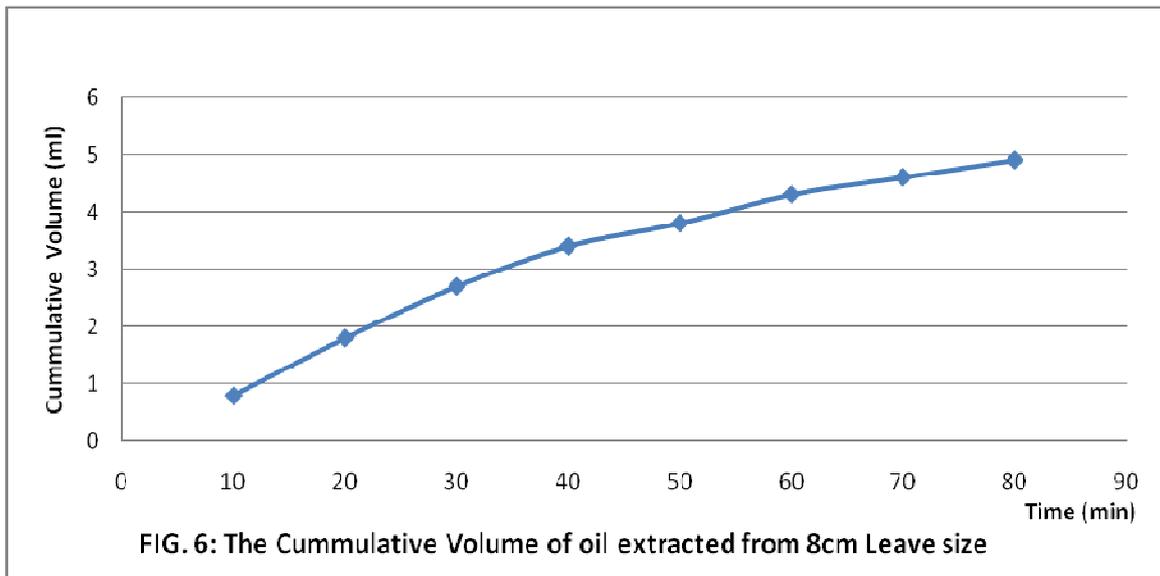
Table 4: Variation of Cumulative Volume of Oil and Oil Rate for Various Leave Sizes.

Time (min)	Leave Sizes (cm)	Cumulative Volume of Oil (ml)	Rate of Oil (ml/min)
80	4	7.1	8.9 x 10 ⁻²
80	8	4.9	6.1 x 10 ⁻²
80	15	3.6	4.5 x 10 ⁻²

Figures 1 to 9 were the graphical presentation of the result of extraction rate studied.







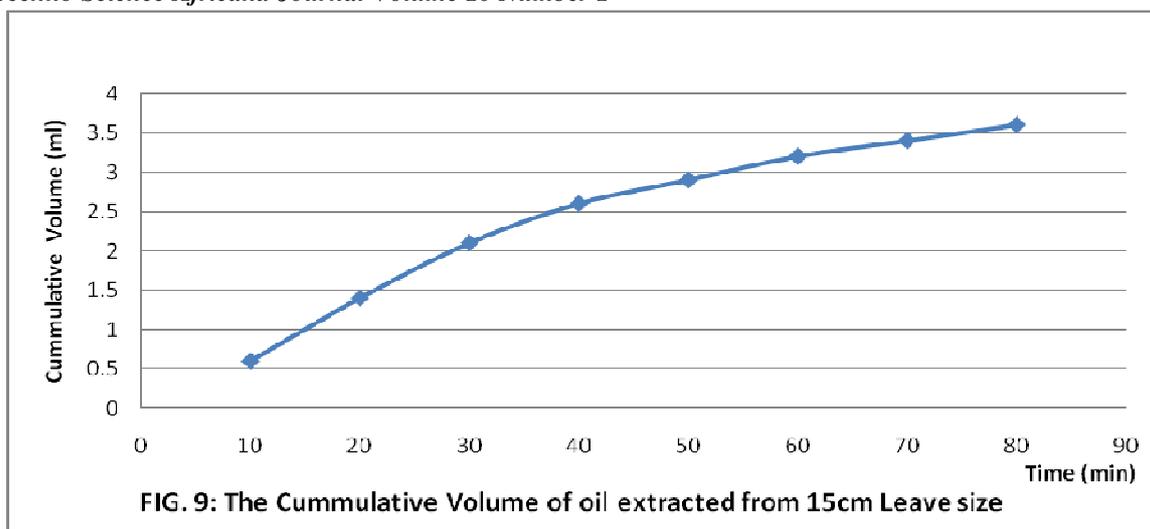


FIG. 9: The Cumulative Volume of oil extracted from 15cm Leaf size

Discussion

The result of measured operating temperatures as presented in table 1 shows that the cooling water was admitted into the heat exchanger at 28 °C and it was discharged at 35.5 °C, while the steam containing extract oil was admitted at 100 °C and was cooled to 36 °C. The trend of result indicated that significant amount of heat has been removed by the cooling water as to allow a drop in the steam line outlet temperature.

The results of measured heat exchanger operating parameters as presented in table , shows that the heat exchanger was operated at cooling water flow rate of 11.64×10^{-2} kg/s, average steam flow rate of 2.3×10^{-4} kg/s and steam pressure of 1.5 bar. The high values of cooling water flow rate above that of steam flow rate, justify the reason why the outlet temperature of cooling water did not raised so much; because the water served as heat sink.

Table 3. Shows evaluated heat exchanger performance parameters. Heat exchanger duty was computed to be 5.22×10^{-1} kw, this is the heat load obtained during the analysis. Effectiveness which shows how effective a given heat exchanger is in transferring heat across it boundary also useful information in

selecting heat exchanger for specific purposes. Was obtained to be 89% for the test run equipment, the value obtained implied that the equipment is efficient in heat transfer operation and suitable for the design purposed. The percentage oil yield was obtained as 0.36 wt/wt.

The result of variation of cumulative volume of oil and oil rate for various leave sizes as presented in table 2. These result for cumulative volume of oil obtained during eighty minutes of extraction and the rate of oil obtained from various leave sizes tested; shows that cumulative volume of oil decreases from 7.1ml to 3.6 ml and the rate of oil extracted decreases from 8.9×10^{-2} ml/min to 4.5×10^{-2} ml/min, as the leaves sizes increases from 4cm to 15cm. This implies that the smaller the leave size the better the rate of oil extracted and the greater the volume of oil collected because a greater surface area is presented for extraction of oil out of smaller leaves sizes.

The result of increment in volume of oil collected (extracted) from 4cm leave size was plotted against time, as presented in figure 1. It shows that the volume of oil collected increases gradually, it reached peak value in 20 minutes after which the incremental volume started to decline gradually until it reached 70 minutes.

Then it remain asymptote (constant).The same observation was made in figure7 for 15cm leave size.; While 8cm leave size reached its peak value in 30 min as shown in figure 4. This could be as a result of fluctuation in steam supply from boiler. These results implied that within the first 70 minutes of extraction highest percentage of oil was extracted out. After 70 minutes the amount of oil extracted out of the leaves remain constant to end of the extraction process.

Incremental volume rate (ml/min) versus time (min) as shown in figure2.The shape revealed that the rate of extraction of oil out of 4cm leave sizes reduces with increased or passage in time until it reached 70 minutes. During this period 89% of the oil has being extracted. After 70 minutes the rate of extraction remains constant. Based on this result of rate of extraction, it suggests that optimal extraction period was obtained to be 70 minutes after that the quantity of oil extracted becomes insignificant. The same observation was made in figure5 for 8cm leave sizes and figure 8 for 15cm leave sizes.

Figure 3: shows the plot of cumulative volume of oil extracted from 4cm leave sizes versus time. The shape of the curve indicated that the volume of oil extracted out of the leaves increases steadily for the first 40 minutes. After that the increase is gradual to the end of extraction. The same observation was made in figure 6 for 8cm leave sizes and figure 9 for 15cm leave sizes. This result is showing quantitatively how volume of oil accumulated during extraction, significant recovery of volume of extracted oil is achieved within the first 40 minutes, this may be as a result that most of oil cell rupture to release oil during this periods.

Based on the shapes of Figure: 1, 4 and 7; oil extraction is thought of to

involves three stages; the first stage is extraction of oil out of adipose tissue of the leaves is control be surface dissolution and/ or leaching of the oil from surface of oil cell capillaries during the first 30minutes in which rate of oil extraction is in the increased. While after that involves the second stage, the interface between the steam and residual oil in the cell capillary becomes receded just below the surface of capillary and oil has to diffused out to meet the steam at near the surface of capillary this occurred between 30-70 minutes of extraction it is characterized with decreased in oil extracted. The last stage is after 70minutes in which the interface of steam to oil receded deep down into the oil cell capillary the steam has to diffuse into the capillary to extract or leached the oil and then diffused out of capillary to the surface. This stage occurred after 70minutes of extraction, it is characterized by small constant volume of oil collected up to the end of extraction. The same phenomena apply to the observation of the entire figure presented.

Conclusion

In conclusion, the designed eucalyptus oil extractor was successfully test run. It was found to be efficient with 89% efficiency. The heat exchanger duty was found to be 5.22×10^{-1} kW. The optimal extraction period of 70minutes was established during this period 89% of the oil was recovered. The analysis reveals the smaller the sizes of the leaves the higher the quantity of oil extracted due to increase in surface area presented for extraction.

Recommendation

Optimal period of 70 minutes and 4cm leaves sizes was recommended for used in this equipment.

References

- Backhust, J.R and Harker, J.H (1983) "Process plant design." Heinemann chemical engineering series. Heinemann education books London. Pg 65-85.
- Coulson, J. M and Richardson, J. F (1998) "Chemical Engineering Series". Butterworth – Heinemann, 4th edition, vol. 2, pg. 395, 401.
- Gupta. A, Naraniwal, M and Kothari, V (2012). "Modern Extraction Method for Preparation of Bioactive Plant Extract." *International Journal of Applied and Natural Science (IJANS)*. Vol.1, Issue,1. Pg 8-26.
- Holman, J.P (2002). "Heat Transfer." Ninth edition, Tata McGraw-Hill publishing company, New Delhi. Pg 518-537.
- Kebede, A and Hayelom, M (2008). "The Design and Manufacturing of Essential Oil Distillation Plant for Rural Poverty Alleviation in Ethiopia." *Ethiopia Journal of Environmental Studies and Management*. Vol.1, No.1: Pg 84-91.
- McCabe W. L., Smith C. J. and Hariott, P (1985) "Unit Operation of Chemical Engineering" Mc Graw – Hill, New York, 4th edition, Pg.529-536.
- Padma, S.V (2004). "Essential Oil and Fragrances from Natural Sources." Resonance. Pg 30-41.
- Satishkumar, K (2010). "Extraction of Essential Oil using Steam Distillation." Unpublished work. A thesis submitted for Bachelor of Technology in Chemical Engineering at National Institute of Technology, Rourkela. Pg 1-33.
- Sinnott, R. K. (1999). "Chemical Engineering Series." Butterworth – Heinemann. 3rd edition. Vol.6, Pg. 445, 670 – 671.
- Trebal, E.R (1980). Mass transfer Operation. 3rd Edition. Mc Graw – Hill Book Co, Singapore. 3rd edition, Pg 717-724 and 739-748.