ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE December 2019. Vol. 15(4):958-972
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

PRODUCTION AND ECONOMICS EVALUATION OF PILOT SCALE ESSENTIAL OIL EXTRACT FROM EUCALYPTUS CITRIODORA LEAVES

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ARTICLE INFORMATION

Submitted 15 November, 2018
Revised 15 June, 2019
Accepted 20 June, 2019

Keywords:
Eucalyptus citriodora leaves
essential oil
steam distillation
economic analysis and
oil yield .

ABSTRACT

In this study, essential oil was extracted from eucalyptus citriodora leaves plant species (lemon-scented gum) in a pilot plant using steam distillation technology. The extraction pattern of the oil was monitored over time and economic analysis of the production was carried out. Five batches were carried out in a day and the results revealed that the daily production of the oil was 0.579 liters in a loading capacity of 100kg of leaves. It was also observed that the total production cycle per batch was 1.96 hours out of which 80 minutes were the actual extraction time with lag period of 37 minutes. The results further revealed that 66.7% of the oil was extracted in 40 minutes while 95.6% in 80 minutes. Liquefied petroleum gas (LPG) was used as source of energy with daily consumption of 7.5 kg at a cost of N2,400.00K. The economic analysis on annual basis revealed that the operating cost was N1,742,400.00K. The production output of the oil was estimated at 138.96 litres with expected selling price of N4,863,600.00K at the rate of N35,000.00K per litre and expected profit after tax of N2,115,871.00K. From this economic analysis carried out based on the practical data generated in the pilot plant, this project is highly profitable and is strongly recommended to potential investors and entrepreneurs. This will help in providing jobs for our teaming unemployed youths mostly in rural areas where these raw materials are in abundant thereby increasing nation's foreign earning due to its export potential.

1.0 Introduction

Essential oils are volatile, natural base products, which are found in spices, aromatic and medicinal plants. The Extraction of essential oils is well known from old ages when pure essential oil and crude extract of essential oil bearing plants, herbs and grasses were in use for various medicinal and fragrances, flavors, preservatives and insect repellants purposes (Weiss, 1997; Panda, 2000).

Eucalyptus plant is mainly grown in tropical and sub-tropical regions because of its resistance to many pest and adaptability to various climatic conditions. These include South Africa, China, Congo Republic, Angola, India and West Africa. The plant has up to 700 species and can grow as high as 40 m tall in an altitude of 600m. The principal component of the essential oil extracted from eucalyptus citriodora leave is cineola which is up to 70 - 80%. The oil is mainly used in medicinal, industrial and perfumery applications. The yield of essential oil is naturally constrained (usually less than 2%) but with high market value. (UNIDO, 1983).

Many research works have been published on extraction of essential oil from eucalyptus citriodora leave mostly at laboratory stage without economics of its production (Seid et al., 2014; Deepak et al., 2013; Manika, et al., 2012). Mu'azu et al. (2009) reported economics of essential oil production using eucalyptus citriodora leaves at pilot plant. However, data used in the study were not optimized and kerosene was used as fuel.

Scanty information is available in the literature regarding the detailed economic study on the production of essential oil from eucalyptus citriodora leaves at pilot scale level using steam distillation technology and liquefied petroleum gas (LPG) as source of energy. It must be noted that energy cost accounts for about 70% of the production cost. Against this background, a study was therefore planned from practical approach to determine the actual daily production of the essential oil, production costs and profit margin in a pilot plant. This information can serve as an important resource in attracting investors to the essential oil industry and exploring its commercial utilization.

2. Materials and Methods

The block diagram and flow sheet for the extraction process of essential oil from eucalyptus leaves using steam distillation method were developed and shown in Figures 1 and 2 respectively.

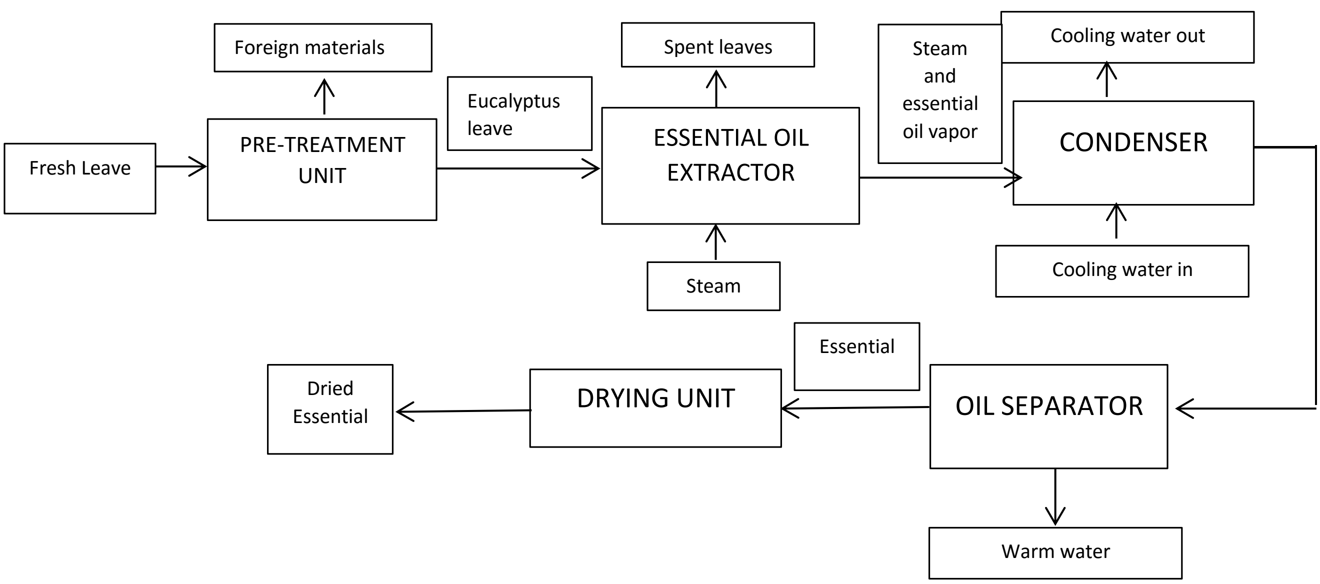

Figure 1: Block diagram for the steam extraction of essential oil from Eucalyptus leaves

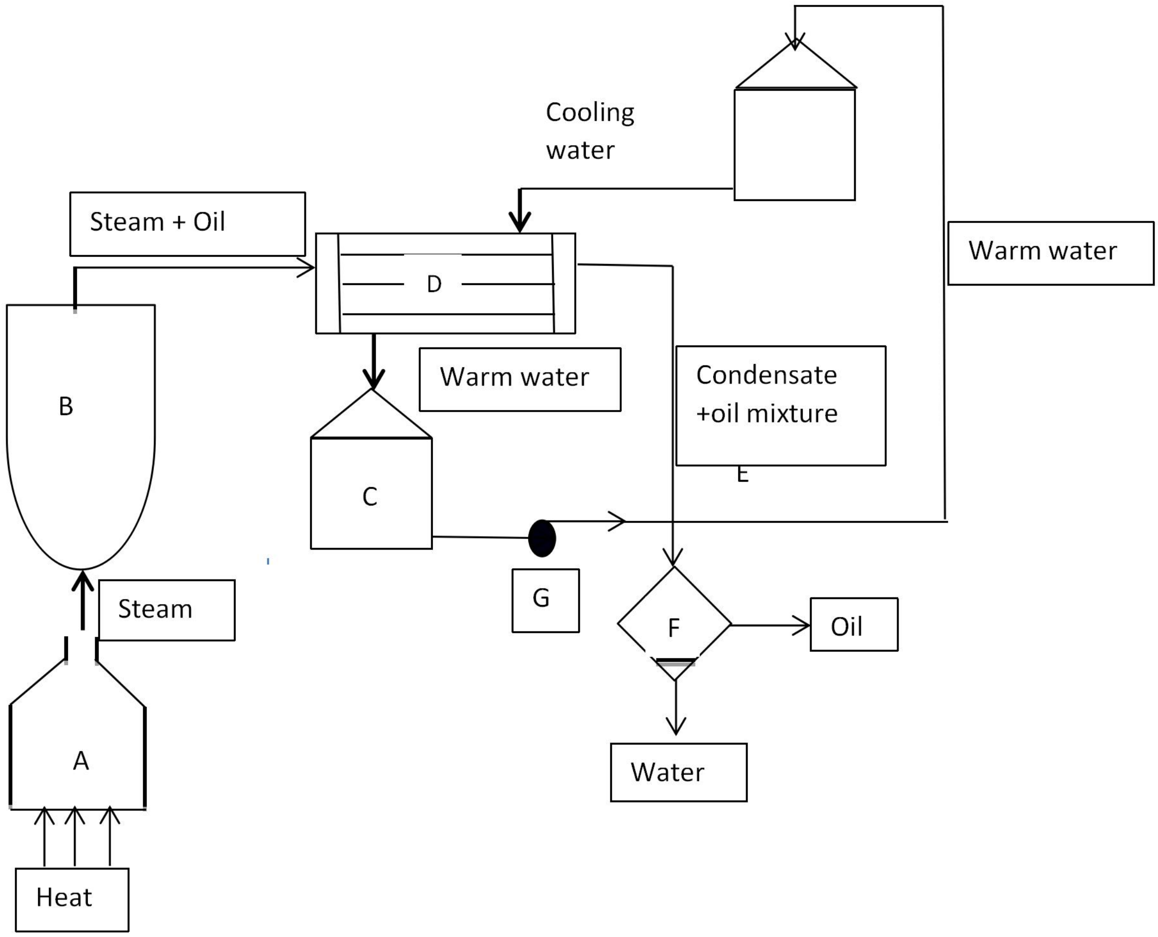

Figure 2: Flow sheet for the steam extraction of essential oil from Eucalyptus leaves

Key: A-Boiler B-Extractor C-Storage water tank D-Condenser E-Storage water tank F-Oil separator G-Water pump

2.1 Material Procurement and Preparation

Fresh Eucalyptus leaves shown in Figure 3 were obtained from National Research Institute for Chemical Technology (NARICT) plantation in Zaria, Nigeria. Prior to commencement of the extraction process the unwanted materials found in the leaves were removed and 20kg of the leaves were weighed for a batch operation.

Figure 3: Eucalyptus citriodora leaves

2.2 Description of the Essential Oil Extraction Plant

The extraction of essential oil was done using water as solvent in the form of steam in a steam distillation pilot plant. The pilot plant consists mainly of oil extractor, steam boiler, condenser, gas-fired burner and oil separator as shown in Figure 4.

KEY

A=Essential oil extractor

B=Boiler

C=Condenser

D=Cooling water tank

E=Oil collector

F=Steam and oil line

G=Cooling water line

Figure 4: Steam distillation pilot plant for extracting essential oil from eucalyptus leaves

The oil extractor and condenser were fabricated using grade 304 stainless steel while the oil separator was transparent glass. The boiler section is located at the bottom of the oil extraction chamber and separated by a stainless steel weir mesh. The gas-fired burner was connected to a 12.5 kg gas cylinder with a rubber hose and placed directly under the oil extractor. The connections were adequately checked to avoid gas leakages. The cooling water at 25°C from the overhead tank was allowed to run into the condenser at the rate of $1.67x10^{-3}$ m^3/min and discharged at 40 °C. This was done to aid easy condensation of the steam and oil mixture vapour at 100 °C to liquid. A detail of these equipment specifications is shown in Table 1.

Table 1: Summary of process unit specifications

Process unit	Specification
Extractor	
Material of construction	Stainless steel
Height	1.65 m
Diameter	0.45 m
Thickness	0.003 m
Boiler	
Capacity	0.0075 m^3/hour

Condenser	
Type of condenser	shell and tube
Material of construction of shell	mild steel
Material of construction of tube	stainless steel
Number of passes in the tube	2
Number of pass in the shell	1
Tube length	1.2 m
Tube outside diameter	0.02 m
Tube inside diameter	0.016 m
Number of tubes	16
Number of tubes per pass	8
Shell internal diameter	0.385 m
Number of baffles	3
Baffles spacing	0.3 m
Baffles cut	15%
Baffle pitch	Square
Tube side fluid	Steam and oil
Shell side fluid	Cooling water
Oil separator	
Capacity	0.0005 m^3
Shape	Conical
Flow rate	0.00025 m^3/min

2.3 Methods

Twenty five (25) litres of water and 20kg (W_1) of fresh eucalyptus leaves were charged into the essential oil extractor (A) shown in Figure 4. The gas line was opened and the burner was ignited and time of ignition was recorded. The burner fuel- to- air ratio was adjusted until blue flame was obtained implying steady energy supply. After 24 minutes of burner ignition (Induction period), steam and oil mixture began to drop in the oil separator (E) at 40°C as condensate. The oil was then separated from the warm water using separating flask and measured in a cylinder after every 10 minutes for a period of 100 minutes. The cumulative oil collected was dried using 150g of anhydrous Sodium Sulphate (Na_2SO_4) and allowed to stand for overnight (12 hours) followed by filtration to remove moisture and suspended impurities associated with the oil as shown in Figure 5. The same procedures were repeated for subsequent batches with addition of 10 litres of the warm water collected into the boiler as make-up water to maintain minimum of 20 litres at any time. In each case the weight of the dried oil was recorded (W_2) and oil yield was calculated using Equation (1).

$$\text{Oil Yield} = \frac{W_2}{W_1} \text{ x } 100 \qquad (1)$$

Figure 5: Essential oil extracted

2.3.1 Material Balance

The material balance was carried out on the process units based on the plant throughput of 115.84ml (1.1584×10^{-1} kg) of essential oil per batch, leaves input of 20 kg, extraction time of 100 minutes, water requirement of 15 liters (15kg) and steam production of 8.894 kg. Thus, for a steady state batch process without chemical reaction, the material balance is given by Equation (2) and was applied to all the process units starting with oil extractor as shown in Figure 6.

$$Material\ Input = Material\ Output \qquad (2)$$

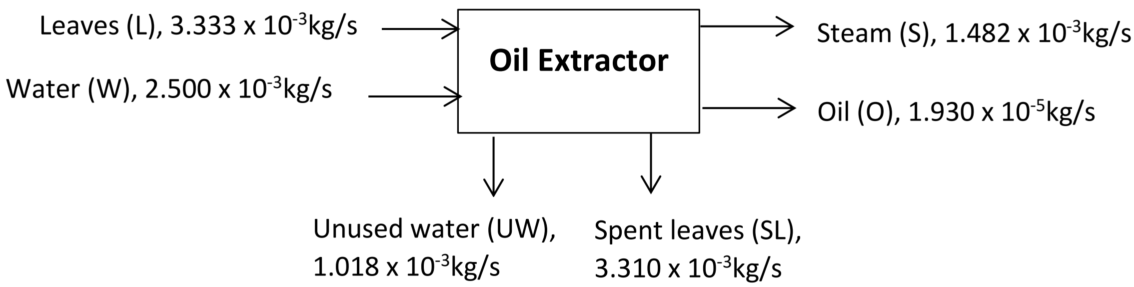

Figure 6: Material balance over oil extractor

In the condenser unit steam oil mixture passes through the tube side while cooling water in the shell and the material balance is presented in Figure 7.

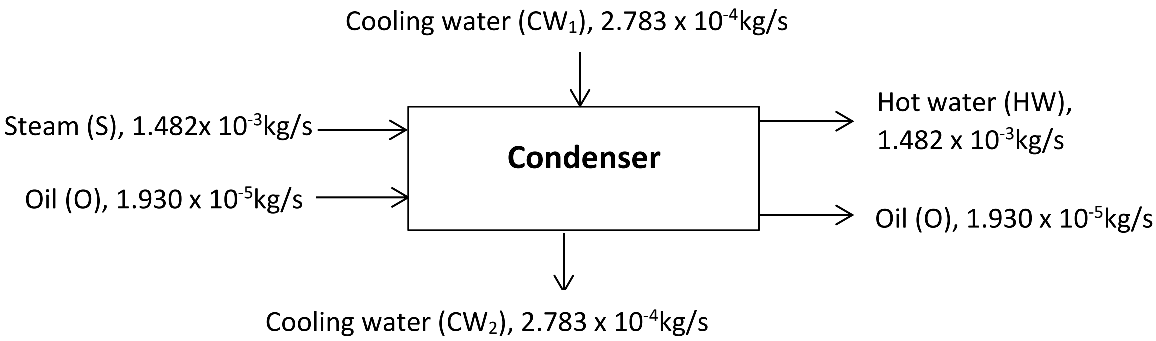

Figure 7: Material balance over oil condenser

Mixture of hot water and essential oil from the condenser were fed into the oil separator and the material balance is presented in Figure 8

Figure 8: Material balance over oil separator

The material balance on the drying unit is presented in Figure 9.

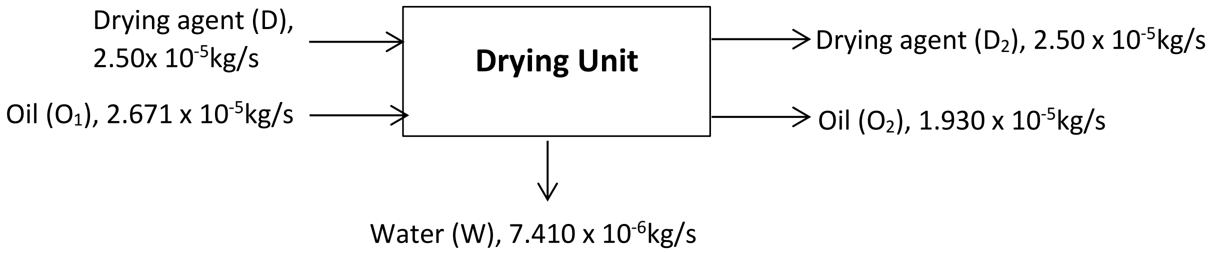

Figure 9: Material balance over drying unit

2.4 Energy Utilization

The quantity of gas (G) utilized in kg for every batch operation was calculated by taking the respective difference between the initial weight of gas cylinder (W3) and its final weight (W4) after each production cycle as given in Equation (3).

$$G = W_3 - W_4 \qquad (3)$$

The energy utilization, Q (in MJ) per batch was thereafter obtained from Equation (4).

$$Q_{supplied} = G * C_v \qquad (4)$$

where G is the quantity of gas consumed (kg) and C_V is the calorific value of gas in MJ/kg and has the value of 46.1 MJ/kg for LPG.

2.4.1 Energy Balance over Oil Extractor

In Figure 6, for a batch process without chemical reaction, the energy balance is given as

$$Q_{supplied} = Q_{water} + Q_{evap} + Q_{oil} + Q_{leave} + Q_{tank} + Q_{lost} \qquad (5)$$

$Q_{supplied}$ = 11,525J/s as given in Equation (4).

Heat gained by water in the boiler

$(Q_{water}) = M_W C_W \Delta T_W$,

$M_W = 2.500 \times 10^{-3}$ kg/s,

$C_W = 4.200 \times 10^3$ J/kg°C,

$\Delta T_W = 75$°C, implying that $Q_{water} = 787.5$ J/s.

Heat needed to evaporate water in the boiler $(Q_{evap}) = M_s L$, $M_s = 1.482 \times 10^{-3}$kg/s, $L = 2.260 \times 10^6$ J/kg, implying that $Q_{evap} = 3350.1$ J/s.

Heat gained by oil in the leaves $(Q_{oil}) = M_{oil} C_{oil} \Delta T_{oil}$, $M_{oil} = 1.930 \times 10^{-5}$kg/s, $C_{oil} = 2.6 \times 10^{-3}$ J/kg°C, $\Delta T_{oil} = 75$°C, implying that $Q_{oil} = 3.765 \times 10^{-6}$ J/s.

Heat gained by the leaves $(Q_{leave}) = M_L C_L \Delta T_L$, $M_L = 3.310 \times 10^{-3}$ kg/s,

C_L= 0.5 x C_{wood} = 9.414 x 10^2 J/kg°C, ΔT_L = 75°C, implying that Q_L = 233.987 J/s.

Heat lost to the surrounding (Q_{lost}) = 20% of $Q_{supplied}$ = 2,305 J/s

From Equation (5), heat gained by oil extractor
(Q_{tank}) = $Q_{supplied}$ - Q_{water} - Q_{evap} - Q_{oil} - Q_{leave} - Q_{lost}, implying that Q_{tank} = 4,848.41 J/s

2.4.2 Energy Balance over Condenser

In the condenser unit shown in Figure 7 and assuming steady state energy supply, the heat released by the steam oil mixture equals to heat absorbed by the cooling water.

Thus, $Q_{steam\ oil\ mixture}$ = $Q_{cooling\ water}$.

$Q_{steam\ oil\ mixture}$ = 3,350.1 J/s= M_{cw} x C_{cw} x (T_2 –T_1),

where M_w =mass flow rate of cooling water = 2.783 x 10^{-4} kg/s,

C_{cw} = specific heat capacity of water = 4,200 kJ/kg°C, T_1= inlet water temperature = 25°C. Solving for T_2 = 28°C.

2.4.3 Energy Balance over Separator

The energy balance in the oil separation unit shown in Figure 8 was carried out based on the fact that the separation of water oil mixture was based on density difference and occurred at room temperature (25°C) implying that there was no temperature gradient.

Thus, M_{w1} H_{w1} + M_{o1} H_{o1} = M_{w2} H_{w2} +M_{o2} H_{o2} and M_{w1}= M_{w2}=1.482 x 10^{-3} kg/s, H_{w1}=H_{w2}= 419.1 kJ/kg (enthalpy of water at 25°C), M_{o1}=M_{o2} = 1.93 x 10^{-5} kg/s and H_{o1} = H_{o2} = 0.65 kJ/kg.

2.5 Determination of Extraction Time

The extraction time was determined using stop clock by recording the time for loading the leaves and sealing the tank cover (T_1), time the first drop of steam oil mixture was collected (T_2) and the time between first drop of steam oil mixture and its last drop (T_3) and time the spent leaves were off-loaded (T_4).

2.6 Determination of Steam Requirement

The steam needed to extract the essential oil from unit kilogram of the leaves was determined from the cumulative condensate collected at the end of batch operation. The ratio of steam collected to the quantity of leaves loaded gives steam to leave ratio.

2.7 Economic Analysis

The analytical tools employed for calculating the economic indices of the plant such as total investment cost, direct and indirect production costs, annual operating cost, profit after tax, return on investment, break-even point and payback period were obtained from a related works (Mu'azu et al., 2009 and Galidama, 2004).

3. Results and Discussion

This section discussed both the material and energy balance carried out in the plant. Similarly, total extraction time per batch including loading and off- loading of leaves, induction period and actual extraction time were also presented and discussed. These results will help an investor to know the number of batches to run on daily basis, time for stoppage of the extraction, actual steam and energy requirements in a batch operation and economics for the production has also been discussed.

3.1 Material Balance

The summary of material balance carried out in the plant is presented in Table 2. It is evident that in every 3.333 x 10^{-3} kg/s of eucalyptus leaves charged into the extractor, the output of essential oil was 1.980 x 10^{-5} kg/s and required 1.482 x 10^{-3} kg/s of steam. This implies that steam to leaves mass ratio per second was 1.482 x 10^{-3} : 3.33 x 10^{-3} or 1 : 25 and oil to leaves mass ratio per second was 1.980 x 10^{-5} : 3.333 x 10^{-3} or 1 : 1.68

Table 2: Summary of material balance for the process units

Oil extractor		
Material	**Input, kg/s**	**Output, kg/s**
Eucalyptus Leaves	3.333 x 10^{-3}	3.333 x 10^{-3}
Water	2.500 x 10^{-3}	3.333 x 10^{-3}
Steam		1.482 x 10^{-3}
Essential oil		1.930x 10^{-5}
Spent Leaves		3.310 x 10^{-3}
Unused water		1.018 x 10^{-3}
Total	**5.833 x 10^{-3}**	**5.830 x 10^{-3}**
Condenser		
Steam	1.482 x 10^{-3}	
Cooling water	2.783 x 10^{-4}	
Essential oil	1.930 x 10^{-5}	1.930 x 10^{-5}
Hot water		1.482 x 10^{-3}
Warm water		2.783 x 10^{-4}
Total	**1.780 x 10^{-3}**	**1.780 x 10^{-3}**
Oil separator		
Hot water	1.482 x 10^{-3}	1.475 x 10^{-3}
Essential oil	1.930 x 10^{-5}	2.671 x 10^{-5}
Total	**1.501 x 10^{-3}**	**1.501 x 10^{-3}**
Drying unit		
Essential oil	2.671 x 10^{-5}	1.930 x 10^{-5}
Sodium sulphate	2.500 x 10^{-5}	2.500 x 10^{-5}
Water		7.41 x 10^{-6}
Total	**5.17 x 10^{-5}**	**5.17 x 10^{-5}**

3.2 Energy Balance

The summary of energy balance carried out in the plant is presented in Table 3. At a steady state, the energy supply by the steam (11,525 J/s) equals to energy gained by the leaves, oil, water, extraction tank and lost to surrounding and due evaporation. However, the energy gained by the oil (3.765 x 10^{-6} J/s) was negligible compared to water (787 J/s) and leaves (233.99

J/s). In the oil separation unit, there was not temperature gradient (25°C) and therefore the energy remained constant.

Table 3: Summary of energy balance for the process units

Item	Input, J/s	Output, J/s
Oil extractor		
Energy supplied	11,525.00	
Heat gained by water		787.50
Heat of evaporation		3350.10
Heat gained by oil		3.765×10^{-6}
Heat gained by leaves		233.99
Heat lost to surrounding		2305.00
Heat gained by extraction tank		4848.41
Total	**11,525.00**	**11,525.00**
Condenser		
Heat released by steam	3350.10	
Heat released by oil	3.765×10^{-6}	
Heat gained by cooling water		3350.10
Total	**3350.10**	**3350.10**
Oil separator		
Warm water	621.00	621.00
Essential oil	1.25	1.25
Total	**622.25**	**622.25**

3.3 Extraction Time

The total extraction time per batch consists of time for loading of eucalyptus leaves into the oil extractor, induction time, actual extraction time and time for off-loading the spent leaves as shown in Table 4.

Table 4: Sequential production time for each activity in a production cycle

Batch	Loading of fresh leave, T_1 (minutes)	Induction period, T_2 (minutes)	Extraction time, T_3 (minutes)	Off-loading of spent leave, T_4 (minutes)
1	5	32	100	10
2	4	20	100	8
3	5	28	100	9
4	5	25	100	9
5	4	15	100	10
Average	4.6	24	100	9.2

It can be seen from Table 4 that the average time required for loading was 4.6 minutes and 9.2 minutes for off-loading the spent leave and these times were considered as the lag time in the production cycle. The induction period is the time between ignition of the burner and the first drop of the steam plus oil mixture. This period is generally dependent on the energy supply, volume of the water in the boiler and loading density of the leave. In this study, the period was higher for the 1st batch (32 minutes) compared to other four batches and was due to the addition of both sensible heat and latent heat to the fresh water in the boiler whereas in the other four batches only latent heat was added. However, the average induction period was 24 minutes and is in agreement with the values obtained by Okonkwo et al (2010) and Mu'azu et al (2012).

Although, the average extraction time was 100 minutes, it was observed that up to 67% of the oil was collected between 0- 40 minutes and 95.90% was collected within 80 minutes. This implies that extraction beyond 80 minutes is uneconomical relative to energy input which was considered as the major production cost. Therefore, the effective production time per batch is the summation of time of loading, induction, extraction and off-loading and was found to be 117.8 minutes (1.96 hours)

3.4 Effect of Extraction Time on Oil Yield

The effect of extraction time on yield of the essential oil extracted is presented in Figure 10. The oil yield increases with increase in extraction time for all the batches until it reached 30 minutes for the 2nd batch and 20 minutes for the other batches before declining. The difference in the extraction pattern between 2nd batch and other batches could be due to loading pattern of the leaves.

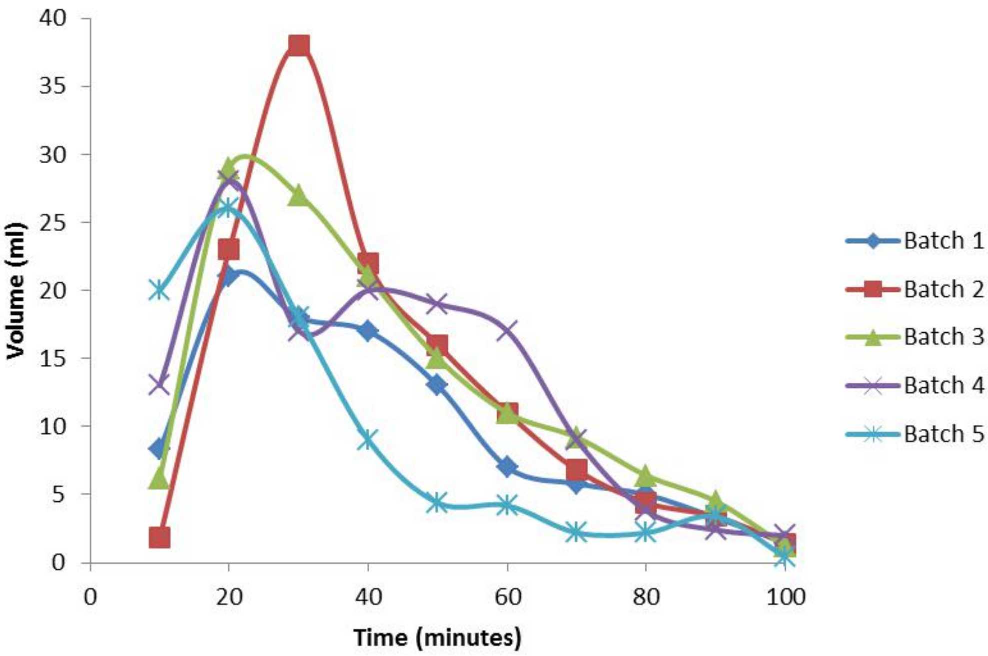

Figure 10: Extraction pattern of essential oil as a function of time

It was also observed that about 67.7% of the oil was extracted between 0-40 minutes while 95.90% was extracted in 80 minutes for all the batches (Figure 11). The cumulative volume of the oil extracted ranged from 99.9-131.2 ml with an average yield of 115.84 ml (0.1158 litres) per batch. This implies that for 5 batches operation in a day the average oil yield was 579.2 ml (0.579 litres).

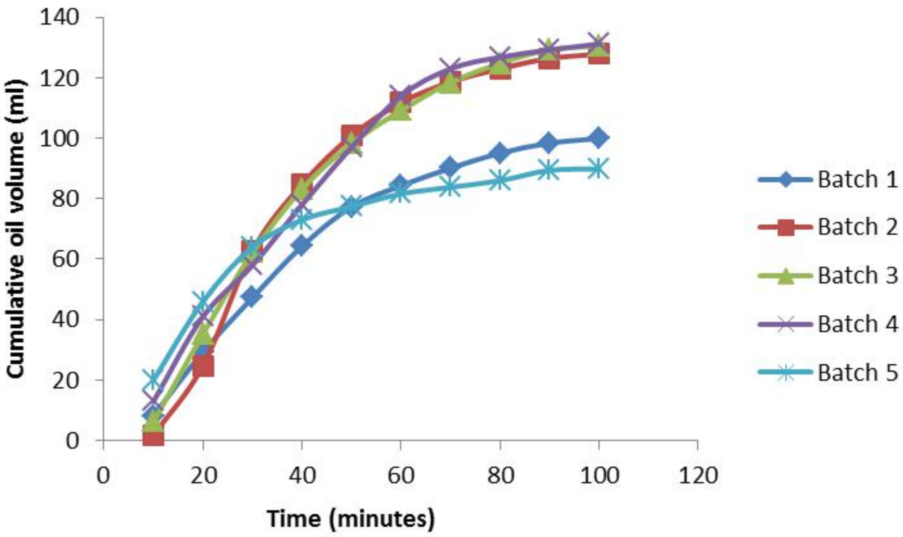

Figure 11: Cumulative volume of essential oil as a function of time

3.5 Steam Requirement for Extraction

The quantity of steam needed to rupture the leaves for the oil to be released from the cell matrix and transported to the condenser is presented in Table 5.

Table 5: Cumulative condensate collected in each batch

Time (Minutes)	Batch 1 (ml)	Batch 2 (ml)	Batch 3 (ml)	Batch 4 (ml)	Batch 5 (ml)
10	521.7	425	550	510	1200
20	1540.7	1565	1490	1290	2880
30	2450.7	2965	2430	1910	4440
40	3540.7	4015	3330	2530	5760
50	4510.7	5135	4220	3190	6970
60	5460.7	6275	5100	3830	8190
70	6450.7	7335	5920	4620	9350
80	7435.7	8355	6710	5120	10470
90	8325.7	9415	7440	5560	11710
100	8625.7	9725	7760	5920	12440

It is evident in Table 5 that the cumulative volume of water required for daily operation of 5 batches was 44470.7 ml (44.47 litres) with average batch consumption of 8894.14 ml (8.894 litres). However, 15 litres of water is recommended per batch to compensate for losses during production. The steam to oil volumetric ratio per batch was 77:1 (8894.14 ml/115.84 ml) and steam to leave ratio was 445:1 (8894.14 ml/20 kg).

3.6 Energy Requirement

Energy consumption plays a significant role in the extraction of essential oil from aromatic plant using steam distillation method. As seen in Table 6 the first batch consumed more energy as a result of addition of both sensible and latent heats when compared with the other batches where only latent heat was applied. It was observed that the average gas utilization per batch was 1.5 kg with corresponding energy input of 69.15MJ.

Table 6: Energy utilization for each batch operation

Batch	Quantity of gas consumed (kg)	Energy utilized (MJ)
1	1.8	82.98
2	1.4	64.54
3	1.4	64.54
4	1.4	64.54
5	1.5	69.14

3.7 Economic Analysis

Table 7 presents economic analysis of the plant based on daily throughput of 0.579 litres of essential oil per batch and 20 working days in a month. The estimated cost of the plant is N3,500,000.00K with an assumed lifespan of 35 years.

The profit after tax (PAT) of N2,115,871.00 obtained in this study was higher than N981,600.00 and N1,818,806.00 obtained in a separate studies using kerosene as fuel (Mu'azu, et al., 2009; Galadima, 2004). The difference in the net profit is mainly due to type of fuel used and cost of raw materials.

Table 7: Economic analysis for production of eucalyptus essential oil on annual basis

S/N	Item	Equation	Value	Amount (N)	Total(N)
1a	Fixed capital cost (Fc)			3,500,000.00	
1b	Land & Non depreciable costs (Lc)			50,000.00	
1c	Capital for test-run (Wc)			20,000.00	
1d	Total Investment Cost (Tc)	Fc + Lc +Wc			3,570,000.0
2a	Raw materials (Rm)			240,000.00	
2b	Utilities (U)			605,400.00	
3a	Maintenance (Mc), 1% of Fc			35,000.00	
3b	Labour cost (Lc)			720,000.00	
3c	Plant overhead (PO), 10% of Fc			72,000.00	
3d	Local taxes (Lt), 1% of Fc			35,000.00	
3e	Insurance (I), 1% of Fc			35,000.00	
3f	Direct Production Cost (DPC)	Mc+Lc+PO+ Lt+I			897,000.00
4	Sales expenses (4% of DPC)			35,880.00	
5	General Overhead (4% of DPC)			35,800.00	
6	Research & Development (8% of DPC)			71,760.00	
7	Annual Operating Cost (AOC)	Rm+U+DPC			1,742,400.0
8a	Annual production138.96 liters				

8b	Annual selling price (ASP) @ N35,000/L			4,863,600.00	
8c	Operating profit (OP)	ASP-AOC			3,121,200.0
8d	Lifespan of the plant (Ls), years		35		
8e	Salvage value (Sv)	0.35 x Tc		124,950.00	
8f	Depreciation (D)	(Tc-Sv)/Ls			98,430.00
8g	Profit Before Tax (PBT)	OP-D		3,022,700.00	
8h	Tax (T), 30%	0.3x PBT		906,831.00	
8i	Profit After Tax (PAT)	PBT-T		2,115,871.00	
8j	Return on Investment (ROI),%	(PAT/Tc) x100	59.27		
8h	Profit Margin (PM),%	(PAT/ASP) x 100	43.50		
9a	Equity (E), @20%	0.2xT_C		714,000.00	
9b	Return on Equity (ROE),%	(PAT/E)x100	296.34		
9c	Annual Cash Flow (ACF)	PAT+D			2,214,301.0
9d	Break Even Point (BEP)	[Fc/(ASP-OC)]			1.12
9e	Pay Back Period (PBP)	Tc/ACF			1.61 years

4. Conclusion

The study revealed an average oil production of 0.579 litres in a day within a production cycle of 8.33 hours. The study further revealed that with an initial investment of N3,570,000:00K, the expected annual profit after tax was N2,115,871:00K and project payback period of 1.61 years. These promising economic indices suggest that extraction of essential oil using LPG has higher returns than kerosene and is strongly recommended to any potential investor in the sector.

Acknowledgements

The authors express their sincere appreciation to the Director-General/CEO of National Research Institute for Chemical Technology (NARICT), Zaria for his moral and financial supports towards this project. The friendly corporation and support by members of staff of Pilot Plants & Fabrication Technology, NARICT, Zaria is also highly appreciated.

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