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Design and Analysis of Small-Scale Essential Oil Steam Distillery for Better Energy Utilization

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Abstract
The essential oil industry, an agro-based sector, involves cultivation and distillation activities and can manufacture products using various methods. Steam distillation accounts for 93% of essential oil extraction, while the remaining 7% is extracted using other methods that employ thermal energy. In Ethiopia, the abundance of aromatic plant leaves has made essential oils a primary raw material for industries.

Steam distillation, a well-established technology, utilizes thermal energy in the extraction process. In this method, steam is produced in a satellite station (boiler) and fed to a still where the biomass is boiled to extract the oil. The extracted oil is then cooled in a condenser. The density difference method is used to separate the liquid mixture (water and oil) in a separator. The current steam distillation equipment experiences significant energy loss in the steam generator and waste water after oil separation.

This study aimed to design and manufacture a prototype of steam distillation equipment. The developed essential oil extraction plant was tested using eucalyptus leaves. The results showed that steam distillation yielded 0.188 kg or 15.5 mL of essential oil per batch from 10 kg of eucalyptus leaves with a total water volume of 20 liters. Additionally, the results indicated that the volume of essential oil increases with temperature while maintaining a constant heating time. Reducing pressure allowed for the extraction of essential oils at relatively lower temperatures and shorter heating times. Energy losses were minimized by recycling hot waste water back to the boiler and using improved biomass stoves.

Keywords: Essential Oil, Steam Distillatory, Energy, Waste and Aromatic Plants

Introduction
Essential oils are distilled volatile oils of plants materials that have strong aromatic components. These aromatic substances are made up of different chemical compounds that occur naturally in the plant. For example, alcohol, hydrocarbons, phenols, aldehydes, esters and ketones are some of the major components. Among all types of plants in the world, only about 700 plants are considered aromatic, and therefore, they are all significant for the production of essential oils. Besides the limited source of supply, the small amount of essential oils that are contained in each aromatic plant makes it even more valuable [1].

Essential oils and plant extracts are the basis for the natural flavor and fragrance industry worldwide. They are extensively used globally for food flavoring, fragrances, aromatherapy and pharmaceuticals. The worldwide market for essential oils has been estimated at US$2.6 billion, with an annual growth rate of 7.5% [2]. In order to get the best quality and quantity of essential oils, extraction procedure seems the key-controlling step. Factors such as types of plants, chemical make-up of oil, and location of oil within the plant are to be considered prior to the extraction. Choosing a proper extraction method is also important as well.

Essential oil industry is an agro-based industry, which involves cultivation and distillation activities and can be manufacture using different methods. Distillation (steam distillation, hydro-distillation, and water distillation), carbon dioxide extraction, cold pressing and solvent extraction are the methods used in the production of essential oils. These different methodologies have different impact on the quality of oil produced. Taking a matrix of the above technology characterizations and experiences, steam distillation has been the best method for optimum conditions.

Steam distillation uses thermal energy in the extraction process and is a well-known technology method. It is also the best way for energy efficiency which is one of the main costly inputs in the essential oil industry for mass production [3]. Proportion of different essential oils extracted by steam distillation is 93% and the remaining 7% is extracted by the other methods. A steam distillation system is relatively uncomplicated. A source of energy, different materials like fuel wood or fuel oil could be used for different type of aroma plants as the same time in this paper use Eucalyptus leaves to extract essential oil [3].

Essential Oils

Essential oils are distilled volatile oils of plants materials that have strong aromatic components. These aromatic substances are made up of different chemical compounds that occur naturally in the plant. For example, alcohol, hydrocarbons, phenols, aldehydes, esters and ketones are some of the major components. Among all types of plants in the world, only about 700 plants are considered aromatic, and therefore, they are all significant for the production of essential oils [4].

For instance, essential oil of Eucalyptus occurs in the leaves and the stems; for cymbopogon sp. (tejsar), mentha spp. (nana), Cymbopogoncitratus (lomisar), Spearmint occur in the leaves, for Clove in the bud, for Lemon and Orange in the peel while for Rose merry and Jasmine, odoriferous substances occur in the flowers. There are major and minor constituents in essential oils, but the different percentages of each constituent give each oil its own uniquecharacteristic [5].Most essential oils are only slightly soluble in water, but completely soluble in organic solvents such as benzene and alcohol. They have characteristic odors and are flammable. However, the only type of essential oil of interest to this paper is the Eucalyptus oil.

Eucalyptus Trees

Eucalyptus is increasing in importance globally, because many species of eucalypts have the ability to improve conditions in treeless areas. In Ethiopia, its divergence had increased in 1980s and then slows down. In many places, eucalypts have helped to raise people's livings standard by providing several ends uses. Eucalyptus leaves contain essential oils which, if emitted rise the bush to create the characteristics distant blue haze of the Australian landscape, eucalyptus oil is highly flammable and bush fire can travel through the oil rich air of the tree crowns with an explosive power that can hardly be controlled [1].

Eucalyptus Essential Oils

Eucalyptus oil has a cooling and deodorizing effect on the human body, cure for fever and malaria. For the respiratory track, it helps in curing coughs, bronchitis, asthma, throat infections and catarrhal conditions. Eucalyptus oil is also used in very small quantities in food supplements especially sweets, cough drops and decongestants. It also has insect repellent properties and is an active ingredient in some commercial mosquito repellents [4].

Method and Materials

• Data Collection Methods: Data collected by secondary data method such as, Literature review.
• Data Analysis: data analyzed by Use several mathematical equations, standards, logics, scientifically derived formulas etc. Design of the components based on the requirement and express the components by CATIA V5 including the assembled drawing.
• The Materials Includes: Measuring instruments, (T-square, tri square, steel ruler, protractor and tap rule), sheet metals, Rectangular hallow section (RHS), Ferro, circular hallow pipe, pressure gauge, gate valve, elbows, flasks, drilling, cutting, work bench bending, joining, welding, and painting materials.

Design of the Plant

The steam distillation process for the extraction of essential oils from plant material consists of four basic parts: Steam generator or boiler, still or stripping chamber, Condenser and Oil separator.

The steam generation unit was designed as cylindrical tank with a conical top cover. It is to be fired by using wood fuel stove. This unit is connected to the stripping chamber (still) via a 0.28 mdiameter galvanized pipe and a control valve is fitted in between to control the flow of steam from the unit to the stripping chamber. The stripping chamber, which is also cylindrical in shape with conical top covers, has two openings. The topmost opening is for charging the raw material, while the down opening is for discharging raw material after stripping.

Both the steam generation unit and the steam generator housing were fully lagged with sawdust (sagatura) to minimize the heat loss to the surrounding and enhance boiling efficiency. Top cover of the chamber is connected to the condenser through a fully lagged galvanized pipe for the escape of steam from chamber to the condenser. The condenser is to condense the vapor coming from the chamber, which is basically a combination of water and traces of oil. Cooling water is introduced into the condenser to facilitate the condensation process inside the condenser. Whereas, the decanter is for the collection and separation of the condensate (i.e. oil from water). The overall size of the plant is 1.86 m high by 2.95 m wide by 0.5m deep.

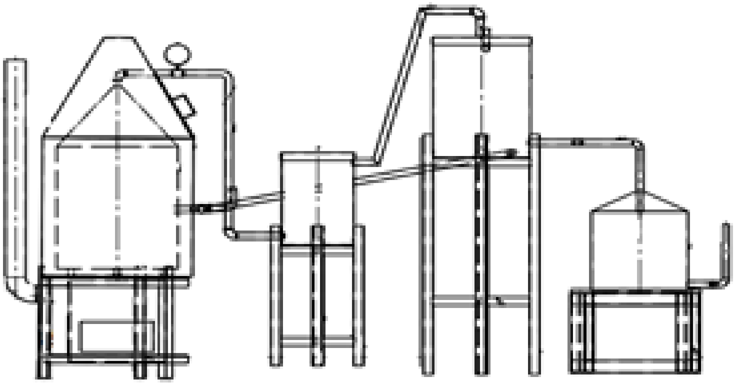

Figure 1: Schematic Diagram of the Extraction Plant

Energy Analysis

The key point for energy modeling is modeling the property of the plant inside the still. By assuming a given mass of plant material has some moisture inside it and considering the oil yield of the plant material, the amount of energy required to liberate the essential oil will be estimated, so that the amount of steam required will be known. According to their local availability and their world, market class three eucalyptus species aromatic plants are selected and the calculation is performed based on the main components available in the plant materials. Source of plants. The plant material used in this study was exclusively Eucalyptus sp. (commonly known as Bahirzaf) as shown in Table 1. Eucalyptus sp. (bahirzaf).

Temp.(oC)	Temp.(oK)	1/T	P(mmHg)	Log (P)
85	358	2.79x10-3	9.82	0.99
99.3	372.3	2.69x10-3	19.1	1.28
110	383	2.61x10-3	30.35	1.48

Table 1: Eucalyptus Species Temperature and Pressure

Latent Heat of Vaporization of Oil Components

The latent heat of vaporization of oil components can be calculated by the following equation;

$$L = \frac{-2.3Rd(\log p)}{d(1/T)} = 12440 \text{ cal.} \qquad \textbf{(1)}$$

For Eucalyptus sp., by considering the basic component 1, 8-cineole (26.2%) Since mol. wt. of 1.8-cineole is 154, then its latent heat is, $\frac{12440\ cal}{154}$= 80.8 cals per gram\

L=80.8*4.2 = 339.36kJ/kg

Then by considering these data, the amount of steam required to liberate the essential oil can be calculated as follows:
Moisture content of the plant material = 55%-60%
Yield of Eucalyptus Citrodora:
Max = 1.88% , Min = 0.66%
Specific heat capacity of plant material, $C = 0.85\frac{cal}{g^oC} = 3.57\frac{kJ}{kg^oC}$

Mass of the plant material in the still: The stripping chamber (still) was designed toprocess a maximum of 10 kg of the raw material per batch M= 10 kg.

The volume of the container for the plant material,

$$V = \frac{m}{\rho} = 0.025 \text{ m}^3 = 25 \text{ L} \qquad \textbf{(2)}$$

Amount of water in the plant material,

M_w= moisture content (%)*mass of plant material

= 6 Kg of water (3)

Amount of Oil in the plant material

$$(M_{oil}) = Yield\ (\frac{w}{w})*mass\ of\ plant\ material \quad (4)$$

= 0.188 kg of oil

Latent Heat of Vaporization of Oil and Water

The amount of energy required to vaporize the oil,

$$E_{oil} = L_{oil} * M_{oil} = 63.8 \text{ kJ} \quad (5)$$

To calculate the energy required to vaporize the water, at one atm. Pressure, the latent heat of vaporization for water is = 2257.1 kj/kg.

the amount of energy required to vaporize the water is, E_{water} =Lw* M_w=13542.6 kJ

Heat gained by the plant material,

$$H_{gained} = C * m * \Delta T = 2677.5 \text{ kJ} \quad (6)$$

$$E_{total} = E_{oil} + E_{water} + H_{gained} = 16283.9 \text{ kJ} \quad (7)$$

The amount of steam required,

$$M_{steam} = \frac{E_{total}}{hg} = 6.086 \text{ kg, taken as, 10 kg,} \quad (8)$$

The total volume of the steam generator tank will be, V_{tank}= 20 L.

Energy loses fluid flowing from boiler to still Major energy losses:

The viscosity causes loss of energy in the flows, which is known asfrictional loss or major energy loss and it is calculated by the following formula;

From Darcy-weisbach formula

The loss of head, h_f =4f L V^2 / (2gD)= 27.3 m

Bending in pipe:
The head loss due to bending equation is

$$h_b=k\ (V^2 /2g) = 0.35\ m \quad (9)$$

Therefore, a total of fewer amounts of lose.

Steam Generators Design

There are numerous types of boilers that can be used as steam generators, some which are heated vats of water that generate saturated steam, while others are industrial boilers that can be made of varying capacity and sophistication. The boiler for steam distillation of essential oils should capable of producing a saturated steam at a pressure of 1 atm.

The steam generation unit was designed to take 20 liters of water, as this quantity will be enough to exhaust the 1O kg raw material charged into the stripping chamber. The diameter of the boiler is taken 0.35m; volume of water to be used is known and that density of water being 1000kg/m3.
Height of the unit was determined from;

$$h = \frac{4xV}{\pi d^2} = 0.102\ m.\ \ say,\ 0.2m \quad (10)$$

These are the fittings, which are mounted on the steam generator for its proper and safe functioning. Pressure gauge, Safety valve, Flow control valve, Pressure reducing valve.

Analysis of Wood Stove

The wood stove is rectangular in section and generally consists of a combustion chamber, a top section and a base. The hearth of the combustion chamber is made of clay the outside of which is encased in a mild steel casing. The grate or fuel bed is at the base of the combustion chamber. The base of the stove consists of adoor for loading fuel wood into the combustion chamber, and it also has a chimney to remove the smoke from the combustion.

Based on the choice of a domestic-size stove, the following parameters are selected for the design: height of the combustion chamber, h_c= 500mm; width of combustion chamber, w = 400mm and depth d = 400mm.

A stoichiometric Air/Fuel ratio, A/F = 6.1kg air/kg fuel.

For an actual air supply which is 20% in excess of stoichiometric, actual air/fuel ratio,

A/Factual = 7.32 kg air/kg fuel.

Combustion Air Inlet

The burning rate, m'', of a typical fuel wood based on mass loss rate is between 2.92gm $^{-2}$ s $^{-1}$ and 9.80gm $^{-2}$ s $^{-1}$ The mass of wood burned per second may then be expressed as, ṁ=14ṁ"a=17.241gs $^{-1}$

The actual air supply rate corresponding to the mass burning rate can also be expressed as,

$$\dot{m}_{air} = \frac{A}{F_{actual}} \times \dot{m} \qquad (11)$$

=0.12620kgs $^{-1}$ of air

Volume rate of air supply,

$$\dot{V}_{air} = \frac{\dot{m}_{air}}{\rho_{air}} = 10.2610^{-2} m^3 s^{-1}$$

The area of air opening, A_{air} is related,

$$\dot{V}_{air} = 23.6 A_{air}\sqrt{h}, A_{air} = 10.86 \times 10^{-3} m^2 \qquad (12)$$

For an air opening being rectangular in section with a vertical dimension, h = 100mm, and a horizontal dimension, l = 108.69mm.

Design of the Still (Stripping Chamber)

The most critical parameter in the design of the still, or number of stills to be serviced is the steam capacity of the boiler. If the amount of steam necessary to displace the oil, and the oil content is known, then the size of the boiler should be able to be determined.

The design of the stripping chamber basically involves the determination of chamber volume and height, the diameter of the chamber used is 0.28m.

Volume ofthe chamber,

$$V = \frac{mass\ of\ raw\ material\ (kg)}{density\ of\ r\ aw\ material\ (kg\ /\ m\ 3\ )} = 0.025 m^3 \quad (13)$$

chamber height, h was determined as:

$$h = \frac{4V}{\pi D^2} = 0.406\ m,\ says,\ 0.45\ m$$

Pressure drop accros the packed bed,

$\Delta P = [2 f_m G^2 L (1-\epsilon)^{3-n}] / [D_p g_c \rho \Phi_s{}^{3-n} \epsilon^3]$ Using the velocity –head concept approx velocity drop can be obtained as:

$\Delta P = \Delta h \cong 50(V^2/2g_c) = 0.00221/g_c$ **(14)**

where, V = mass velocity 0.0094 Kg/s..

Condenser (Heat Exchanger) Design

The steam containing essential oil vapor leaves the still and passes into a condenser by way of tube. Some sort of gauze or screen is often fitted at the mouth of the tube to prevent plant material being blown over into the condenser. In the condenser, the vapors are cooled and condense. It is important that condensation iscomplete or oil may be lost by evaporation. A more efficient type of condenser is the multi-tubular type in which a series of coil tubes are mounted inside a cylindrical jacket through which cooling water is passed.

Flow To The Shell

Volume flow rate, Q=V*A=2.51*10^{-4} m^2 (15)
Mass flow rate, $(\dot{m}_c)$ =ρVA= 0.7455Kg/s (16)

Flow inside tube

The recommended speed of steam in pipelines is 80 $ft/$sec (24.5 m/sec)

the mass flow rate: $\dot{m}_c$= 0.01414 $kg/$sec

Total number of tubes taken is to be 20.

Energy And Thermal Balance

Since the steam is saturated gas, it has latent heat of condensation and sensible heat rejection

$Q_v = L\ x\ \dot{m} = 31.914$kw, Where L= latent heat of vaporization (2257 kj/kg)

Sensible heat reduction, $Q_s = \dot{m}\ c\ \Delta t$ =3.545 kw,
Where, $\Delta T = T_f - T_i = 60^0$c

The total amount of heat energy released is,

$Q_t = Q_v + Q_s$= 35.46 kw (17)

Thermal Balance

Amount of heat released by steam= Amount of heat absorbed by cold water,

$\boldsymbol{Q_{steam}=Q_{water}}$, or $Q_v + Q_s = Q_w = \dot{m}c\ \Delta T$
(18)

where: C =specific heat capacity of water at mean temperature =4.183

Change in temprature, $\Delta T = \frac{Qv+Qs}{\dot{m}C} = 11.4\ ^0$c, then final temprature, $\Delta T = T_f - T_i = T_f + 25\ ^0$c, T_f = 36.4 °c, The raw water is heated at this temperature.

Shell Side

Log mean temperature,

$$LMTD = \frac{(T_1-t_2)-(T_2-t_1)}{ln\left[\frac{T_1-t_2}{T_2-t_1}\right]} = 33.64^0\text{c} \qquad (19)$$

Dimensionless Correction Factors

Ratio of shell - side and tube - side fluid temperatures,

$$R = \frac{(T_1-T_2)}{(t_2-t_1)} = 5.26 \qquad (20)$$

Measure of temperature efficiency ofthe exchanger,

$$S = \frac{(t_2-t_1)}{(T_1-t_2)} = 0.164 \qquad (21)$$

1.85145,0.09688.

True Temperature Difference

$\Delta T_m = F_t \Delta T_{lm} = 20.83^0$c, where,
(22)

$$F_t = \frac{\sqrt{(R^2+1)\ln\left[\frac{1+S}{1-RS}\right]}}{(R-1)\ln\left[\frac{2-S\left(R+1-\sqrt{R^2+1}\right)}{2-S\left(R+1+\sqrt{(R^2+1}\right)}\right]} = 0.6192$$

From the correction Table of hot fluid versus cold fluid, Average value of heat transfer coefficient, Uass was taken from the table as 300 W/m ^{2}°C.

$$\textit{Heat transfer area, } \boldsymbol{A} = \frac{Q}{U_{ass} * \Delta Tm} = 5.674\ m^2 \quad \textbf{(23)}$$

Area ofone tube, at length of tube in the shell, l =38cm, A_t =πdl= π* 0.4*0.38= 0.4775m^2

Number Oftubes

$$N_t = \frac{\textbf{heat transfer area,A}}{\textbf{Area of one tube,}A_t} = 11.88\ ,\ \text{say}\ \ 12. \qquad \textbf{(24)}$$

Tube pitch for equilateral tube arrangement,

Pt = 1.25d_0 = 1.25*403 = 503.75mm

Bundle diameter, $D_b = D_o(\frac{N_t}{K_1})^{0.453} = 3.06\ m$, Where, K_1 is constant = 0.215

Shell diameter, Ds =(bundle diameter,Db)+ (clearance) = 3.20 m

Reynolds number to check the flow is laminar or turbulent,

$$Rs = \frac{G_s * D_e}{v} = 31.795*10^5\ Rs=31.795*10^5 \qquad \textbf{(25)}$$

hence, Rs $\geq$ 2300 the flow inside the tube is turbulent
For turbulent flow,use nulsent number,

$$\text{Nu} = \frac{hD_e}{K} = 0.023\text{Rs}^{0.8}\text{P}_\text{r} = 20451.8$$

Convection Coefficients,

$$h_o = \frac{Nu * K_S}{D_e} = 1.27*10^5 w/m^2 \quad , \qquad \textbf{(26)}$$

out side heat transfer rate

Tube Side:

Mass velocity in tube side,

$$\boldsymbol{G_t} = \frac{\dot{\boldsymbol{m}}}{\boldsymbol{A_t}} = 0.0094\ Kg/\ ms, \qquad \textbf{(27)}$$

where, A_t= no of tubes $*\frac{\pi * D_i{}^2}{4}$

Reynolds number to check the flow is laminar or turbulent, $R_t = \frac{\boldsymbol{G_s * d_h}}{\boldsymbol{v}}$ =10.836 $\leq$2300

Hence, the flow inside the tube is laminar,

$$\text{Use, } h_i = 0.555\left[\frac{g\ \rho_f\left(1-\frac{\rho_v}{\rho_f}\right)K_f{}^3 h_{fg}}{v_f(T_g - T_w)OD_t}\right]^{1/4} \qquad \textbf{(28)}$$

=2303.51 w/m^2k s, where, $h'_{fg}=h_{fg}+3/8cp(t_s-t_w)$

And $h_{io}=h_i\frac{id}{od}$=1785.3 w/m^2k

Then the clean over all heat transfer coefficient, $Uc=\frac{h_{io}+h_o}{h_{io}+h_o}$ =1762.5 w/m^2k *(29)*

Then dirty factor for resistance is taken to be Rf =0.0003 for city water

Over all heat transfer coefficient is Ud , $\frac{1}{U_d}=R_f+\frac{1}{Uc}$, U_d =1152.9 w/m^2k *(30)*

Know that: Q=U_d A (ΔTm) l_m, , where;

(ΔTm) l_m, is log mean temperature [5].

The area then; $A=\frac{Q}{U_d*\Delta T_m}=0.10\ m^2$

Then the total surface area will be

$A=\pi*id*L$ *(31)*

The length of the tubes, $L=nx\frac{A}{\pi D_i}=$ 0.95 *m,* say 1.0 m of tube length is required

The separator (Decanter or Settler)

Once the oil and water vapors have condensed, the oil droplets must have time to coalesce. This is done in the oil separator; Oils separate from water according to their density because they are immiscible or only sparingly soluble. If their density is less than 1.00, then they will float and are called "lighter than water" oils, whereas if their density is greater than 1.00, then they will sink and are referred to as "heavier than water" oils. Most of the oils from herbaceous plants and leaves are lighter than oils,

Some constants used in the decanter design such as density of dispersed phase (i.e. eucalyptus oil), ρ_d was found to be 823.16kg/m3, that of the continuous (heavy) phase (i.e. water), ρ_c is 1000kg/m3; acceleration due to gravity, g=9.81m/s2 and viscosity of the continuous phase, μ_c is 1Ns/m^2. Then, diameter of the decanter vessel, d was taken the half of the boiler, which is hold the amount of water that comes from boiler 0.25m.

Interfacial area, A=πr^2= 0.0491 m^2

The decanter vessel height,h_v=2d= 0.5 m
droplet diameter,dd used for the design was 150 μm.

Settling velocity of the dispersed phase droplets, $u_d=\frac{d_d{}^2g(\rho_d-\rho_c)}{18\mu_c}=2.16mm/s$ *(rising)* *(32)*

Residence time of droplets in the dispersion band, $t_r=\frac{h_v}{u_d}=\frac{500\ mm}{2.16\ mm/s}=231.5sec.\ (4min.)$

Velocity of oil phase,

$u_{oil}=20\ \%\ of\ u_d=0.432\ mm/s.$

Entrained droplet size,

$d_{drop}=[\frac{u_{oil}\,18\mu_c}{g(\rho_d-\rho_c)}]^{1/2}=0.07\mu m.$ *(33)*

Height from datum to light liquid overflow, $z_1=0.9h_v=0.45\ m$ *(34)*

Position ofthe interface (heightfrom datum to interface), $z_3=0.5h_v=\ 0.25\ m$ *(35)*

Height from datum to heavy liquid overflow, $z_2=\frac{(z_2-z_3)\rho_1}{\rho_2}+z_3=\ 0.49m.$ *(38)*

Fabrication and Assembly of the Plant

The components of the plant designed such as steam generation unit, stripping chamber, condenser and support frame were fabricated and assembled to obtain the plant.An assembly of the fabricated plant is shown in Fig.2 below.

Figure 2: Prototypic View of Steam Distilator

Testing of the Plant

The procedure for testing the plant involves ensuring that the plant is in good condition and this could be initiated by closing all valves that are supposed. The boiler tank was filled with clean water and the stove was put on and burns the wood and the starting time was recorded. The leaves were prepared, weighed on a scale and charged into the stripping chamber. When the thermometer reading on the boiler reads 100°C, and steam pass through pipe to the stripping chamber (still), the effectiveness of the steam generation unit was monitored to ensure its ability to generate steam rapidly and that of the stripping chamber by its ability to strip the leaves effectively. The condenser vents were also monitored.

The water on top of the condensate was drained thus leaving the oil in the separating funnel. The oil collected was put in a bottle and closed. The process above was repeated until no oil was observed in the condensate. The time from starting the stove to when no more oil drops was recorded as the maximum extraction time. The procedure was repeated for other batch runs, each time recording the maximum extraction time and the corresponding quantity of oil collected. From the tests carried out, from 10 Kg leaves the plant extracted only 15.5 mLof eucalyptus oil for 78 minutes run.

Cost Analysis

Cost is a major factor that determines the materials to be used as well as the method of fabrication to be used in the manufacture of an item. Hence, it is very vital to ensure that the cost of the finished item is moderate and affordable. The total cost incurred in the cause of developing the designed extraction plant consists of machine cost, material cost, and labor cost. The overhead cost was taken as 20% of the total materials cost. The total cost incurred is:
Total Production cost = (Labor cost + (machine cost + material cost)) = 10,000 + 200,312 = 210,312 ETB, which is appropriate for micro enterprise that have capital of less than 300,000 ETB it creates good job opportunity [6-11].

Conclusion

The development and testing of prototype steam distillation equipment for essential oil extraction have demonstrated several key findings. The equipment efficiently extracted essential oils from eucalyptus leaves, producing 0.188 kg or 15.5 mL of oil per batch from 10 kg of leaves using 20 liters of water. The study revealed that increasing the temperature while maintaining constant heating time enhances essential oil yield. Additionally, reducing pressure facilitated the extraction process at lower temperatures and shorter heating durations.

Energy efficiency was significantly improved by recycling hot waste water to the boiler and employing improved biomass stoves, thereby reducing overall energy losses. These improvements in the steam distillation process highlight the potential for more sustainable and efficient essential oil production in the agro-based industry. This prototype offers a promising solution for maximizing essential oil yield while minimizing energy consumption, making it a valuable contribution to the essential oil industry in Ethiopia and potentially other regions with abundant aromatic plant resources.

Declaration of Competing Interest

The authors declare that there is no conflict of competing interest.

Declaration of Funding

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Data Availability

The data that support the findings of this study are available from the corresponding author, [Yaregal Eneyew Bizuneh], upon reasonable request.

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