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Designing a Mechanical System That Will Be Used To Extract and Separate Lemon Grass Oil

[1]Braimah, S. R., [2]Andoh, P. Y., [2]Tawiah, P. O.

[1]Department of Mechanical Engineering, Tamale Polytechnic, Tamale, Ghana

[2]Department of Mechanical Engineering, College of engineering, KNUST, Kumasi, Ghana

ABSTRACT

Lemon grass is broadly used in medicine, perfumery industry, vitamin A manufacturing and pharmaceuticals. The need for lemon grass oil, especially in human health and its problem of extracting the oil, have directed this paper in designing a mechanical system that will be used to extract and separate lemon grass oil. The extraction of essential oil from lemon grass was done using direct steam distillation process. In all, three concepts were developed based on the orientation of the condensers, source of power, and method of oil production. The three (3) concepts were evaluated and the best concept was selected as the final design. Design analysis was performed on each part to determine their specification, the material to be used and manufacturing processes for the fabrication. Two tests were performed to determine the performance of machine and the quality of the oil produced. From the results, it can be established that the prototype machine developed can be used to extract lemon grass oil from the leaves. The efficiencies were then computed and favorable results were obtained. Also, the results obtained for the four tests responded positive given an indication of the pureness of the oil. It can then be concluded that the prototype machine developed can be used to extract lemon grass oil from the leaves and its efficiency ranges from 2.37 to 3.95 ml/kg and it is economically viable, effective and efficient.

Keywords: *Designing, Mechanical System, Extract, Separate, Lemon grass*

1. INTRODUCTION

Lemon grass *(Cymbopogon citratus)* is a fragrant tropical grass which yields oil that smells of lemon, used in cooking, perfumery and medicine. The genus *Cymbopogon* belongs to the grass family, *Poaceae (syn. Gramineae)*. The *Poaceae* family has about 700 genera and 11,000 species widely distributed in all regions of the world. *Cymbopogon* is a genus comprising about 180 species, subspecies, varieties, and sub-varieties (Bertea and Maffei, 2010).

There are two main types of Lemon grass, East Indian lemon grass (*Cymbopogon flexuosus)* which is considered to have its origins in southern India and West Indian lemon grass (*Cymbopogon citratus)* which is thought to have its origin in Malaysia and is mainly cultivated in Central and South America and parts of Africa, South East Asia and the Indian Ocean Islands. Both species produce an essential oil rich in citral (Bertea and Maffei, 2010).

Fig.1 Lemon grass from a domestic backyard garden Tamale

Lemon grass is largely grown as a decorative plant, in spite of that, it has so many other uses, for example (i) as food crop, e.g., it is used in herbal tea because of its sharp lemon flavour, (ii) as perfume in soaps, and (iii) as medicine to treat various health diseases, such as acne, athlete's foot, turgidity, muscle aches and scabies (W. R. L. Masamba et al., 2003).

Cymbopogon citratus has been used by the Brazilian *Quilombolas* tribe to decrease blood pressure and to calm individual's anxiolytic (Rodriques and Carlini, 2004). *Cymbopogon citratus* has been traditionally used to treat gastrointestinal discomforts (Devi R. C. et al., 2011).

Lemon grass oil is widely used in perfumery, cosmetics, soaps, detergents and confectionary and in the production of vitamin A. (Ganjewala, 2008). The essential oils of the grasses of species of *Cymbopogon* have an industrial profile; they are used in beverages, foodstuffs, fragrances, household products, personal care products such as deodorants, herbal tea, skin care products, insect repellents, pharmaceuticals, in tobacco etc., (Akhila, 2010). Local people use lemon grass oil to subdue toothache. A drop of lemon grass oil is put on a cotton bud and put on the exact place where the toothache occurs (Karma Dukpa 2008). In Nigeria, lemon grass is used for stomach problem and it is also used in combination with few other plants for effective treatment of malaria and typhoid. It is often used as a tea in African countries such as Ghana, Togo and the Democratic Republic of the Congo (Bhoj Raj Singh et al., 2011).

There are so many extraction methods developed worldwide over the years for the extraction of lemongrass oil such as hypercritical carbon dioxide gas extraction, solvent extraction, cold pressing extraction, hydro diffusion extraction, carbon dioxide extraction and water distillation. The problem of extracting this valuable oil has directed this paper in designing a mechanical system that will be used to extract and separate lemon grass oil using direct steam method ~~and~~ LPG was used as its fuel to produce steam. Steam distillation is the most common method used to extract essential oils from flowers, leaves, stems, bark, grass and seeds of botanicals. Steam distillation is a special type of distillation or a separation process for temperature sensitive materials like oils, resins, hydrocarbons, etc. which are insoluble in water and may decompose at their boiling point (Nurul Azlina Binti Mohamed, 2005). The fundamental nature of steam distillation is that it enables a compound or mixture of compounds to be distilled at a temperature substantially below that of the boiling point(s) of the individual constituent(s). The lemon grass is placed in a still and steam is forced over the material. The hot steam helps to release the aromatic molecules from the plant material since the steam forces open the pockets in which the oils are kept in the plant material. The molecules of these volatile oils then escape from the plant material and evaporate into the steam. The steam which then contains the essential oil is passed through a cooling system to condense the steam, which form a liquid from which the essential oil and water is then separated (V. K. Koul et al 2003). The essential oil forms a film on the surface of the water. To separate the essential oil from the water, the film is then decanted or skimmed off the top (Virendra P. S. Rao 2007). The remaining water, a byproduct of distillation, is called floral water, distillate, or hydrosol. The hydrosol retains many of the therapeutic properties of the plant, making it valuable in skin care for facial mists (Virendra P. S. Rao 2007).

In certain situations, floral water may be preferable to be pure essential oil, such as when treating a sensitive individual or a child, or when a more diluted treatment is required. Rose hydrosol, for example, is commonly used for its mild antiseptic and soothing properties, as well as its pleasing floral aroma (Akhila, 2010).

The essential oils of the grasses of species of *Cymbopogon* have an industrial profile; they are used in beverages, foodstuffs, fragrances, household products, personal care products such as deodorants, herbal tea, skin care products, fragrances insect repellents, pharmaceuticals, etc. (Akhila, 2010). The oil is a sherry colored with a pungent taste and lemon like odour with citral as the principal constituent. The current increasing demand of lemon grass oil as in pharmaceutical and aromatherapy applications beside their traditional role in cosmetics not only as potent ingredient but also as a fragrance donor have opened up wide opportunity for worldwide marketing (Nurul Azlina Binti Mohamed, 2005). Hence the objective of this paper is to design a mechanical system that will be used to extract and separate lemon grass oil from the parent plant,

2. MATERIALS AND METHODS

Development of the Extracting Machine

Three concepts were developed and evaluated based on the orientation of the condensers, source of power, method of producing the oil, components parts, weight, manufacturability, cost, portability, ease of assembling and maintenance. After the consideration and selection of the final design, the selected concept is presented in Figure 2.

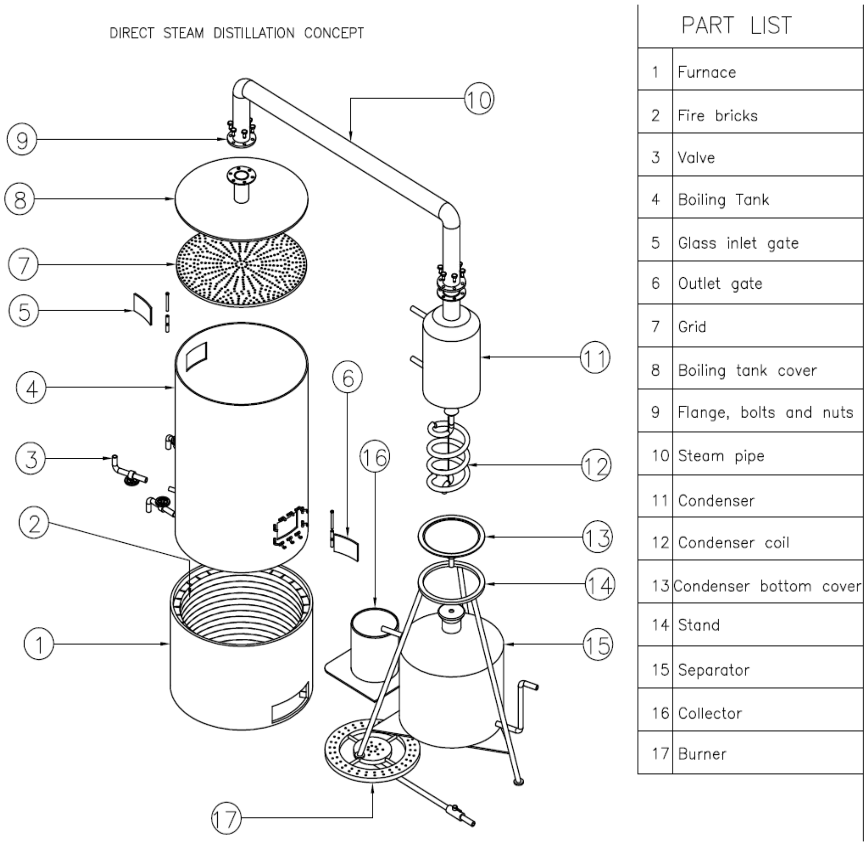


Figure 2 exploded drawing of the selected concept

The design specifications of individual parts and subassemblies of various units which were based on various design equations. The unit consists of seventeen (17) parts as listed in Figure 2. Table 1 shows the dimensions, the material and the manufacturing processes selected for the individual parts.

Table 1 : Design Specification

Part #	Part name	Dimention (mm)	Material used	Manufacturing process
01	Furnace	Dia. 825.5 x 609.6	Mild steel (3mm)	Measuring, cutting, folding, welding and grinding.
	Furnace gate	457.2 x 457.2	Mild steel	Measuring, cutting, folding, and grinding
02	Fire bricks	68.58 x 114.3 x 238.76	Clay	Purchased
03	Valve			Purchased
04	Boiling Tank	Dia. 825.5 x 1245	Stainless steel	Measuring, cutting, folding, welding and grinding.
05	Inlet Gate		Stainless steel	Measuring, cutting, drilling and grinding.
06	Outlet Gate		Stainless steel	Measuring, cutting, drilling and grinding.
07	Gride	Dia. 812.8 x 3	Stainless steel	Measuring, cutting, drilling and grinding.
08	Boiling Tank cover (conical)	Dia. 825.5 x 101.6	Stainless steel	Measuring, cutting, folding, welding and grinding.
09	Flange	Dia. 50.8 x 5 thick	Stainless steel	Measuring, cutting, drilling and grinding.

Table 1 Continues

Part #	Part name	Dimention (mm)	Material used	Manufacturing process
10	Steam pipe	Dia. 50.8 x 1178.4 x 371	Stainless steel	Measuring, cutting, drilling welding and grinding.
	Condenser	Dia. 203.2 x 914.4		Measuring, cutting, folding welding and grinding.
11	Conical side	Dia. 101.6 x 202.8	Stainless steel	Measuring, cutting, folding welding and grinding.
	Throat side	Dia. 50.8 x 202.8		Measuring, cutting, welding and grinding.
12	Condenser coil	Dia. 15.875 x 18 turns	Copper pipe	Measuring, burning and cutting
13	Condenser -bottom cover			
	Conical side	Dia. 101.6 x 202.8	Stainless steel	Measuring, cutting, folding welding and grinding.
	Throat side	Dia. 50.8 x 202.8	Stainless steel	Measuring, cutting, welding and grinding.
14	Stand	3 mm square pipe	Mild stell	Measuring, cutting, welding and grinding.
15	Separator	Dia. 368.3 x 531.5	Stainless steel	Measuring, cutting, folding welding and grinding.
16	Collector		Any stailess steel container/plastic	Purchased
17	Burner	-	Mild steel	Purchased

Performance Tests on the Prototype Machine

Lemon grass *(Cymbopogon citratus)*, water and LPG gas were the main materials used for the production of the oil. Petroleum ether, Sudan IV, grease and soap were also used to perform the chemical test on the oil extracted.

The direct steam method of extraction was used as the steam was generated from the boiling tank and made to pass through the plant material in the boiler forcing the pockets of the lemon grass opened to extract the oil. Both the oil and water in the form of steam is made to passed through the steam pipe which was eventually condenses in the condenser collected and separated from water.

Figure 3 illustrates the experimental set-up for the extraction of the lemon oil. Two tests were performed here, to determine the performance of machine (the extraction test) and the chemical test on the oil produced.

Figure 3 Experimental Set-up

For the extraction test, the lemon grass was weighed and introduced into the boiler chamber and close tightly with bolts and nuts, so that oil and vapour do not leak out the system. A temperature and pressure transducers were used to record the temperature and the pressure at the boiling chamber. Also the burner's temperature was recorded. The steam generated from the boiling tank passes through the grid into the tank which contains the plant material (lemon grass). This steam forces open the pockets of the lemon grass to vaporize the oil in it in a form of steam, which then passes through the steam pipe to the condensing unit. Water runs through the condenser which serves as a heat exchanger to condense the steam into liquid and drops into the separator. By virtue of density differences the oil is separated from the hydrosol as shown in Figure 4. The time duration for the whole process was recorded and the a mass flow rate for the LPG used was set at 1.00 kg per hour.. The amount of oil collected were measured and recorded and presented in Table 2.

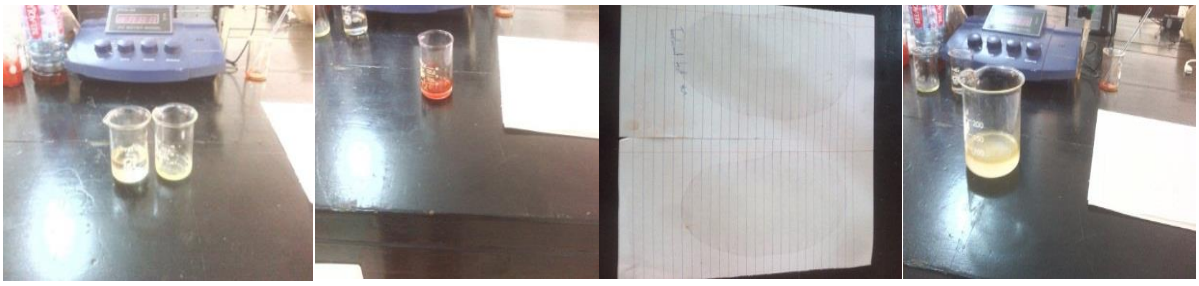
Table 2: Test Results

EXPT	Quantity of Grass (kg)	Burner Temp. ºC	Boiler Temp. ºC	Boiler pressure (bar)	Time consumed (hours)	Volume of oil collected (ml)
1	27.00	270.00	110.00	1.60	3.03	100.00
2	27.00	250.00	108.00	1.40	3.30	80.80
3	27.00	230.00	106.50	1.40	3.45	80.10
4	27.00	180.00	105.00	0.20	3.55	75.00
5	22.00	290.00	110.00	1.40	3.48	80.70
6	34.00	270.00	65.00	1.40	3.33	80.50
7	28.80	270.00	100.00	1.40	3.30	98.00
8	22.00	265.00	95.00	1.45	3.37	87.00

Figure 4 Sample Oil Obtained

Four chemical tests were performed on the sample oil to determine its pureness. These include solubility test, Sudan IV test, grease spot test and emulsification test. In the solubility test, the Lemon grass oil was poured in test container and a small quantity of water was added to the lemon grass in the test container. The mixture was stirred vigorously and allowed to settle for a few minutes. After sometime it was realized that the lemon oil remains as a separate phase from the water showing an indication that it is pure lemon grass oil. The result for the test is shown in Figure 5A.

Sudan IV ($C_{24}H_{20}N_4O$) is a lysochrome (fat-soluble dye) diazo dye used for the staining of lipids, triglycerides and lipoproteins on frozen paraffin sections. It has the appearance of reddish brown crystals. Sudan IV was added to a mixture of lemon grass oil and water and stirred vigorously and the solution was allowed to settle for some time. The Sudan IV only moved into the lemon grass layer coloring it red as shown in Figure 5B. The red colour obtained with only the lemon grass oil is an indication that the lemon grass oil is pure.



A **B** **C** **D**

Figure 5 Test results for the four (4) chemical tests

The grease spot test was performed by smearing some oil and water onto two pieces of paper and allowed for some time. The water smear would become not translucent. But the smear of oil would keep translucent for a long time as shown in Figure 5C. Emulsification test was carried out by mixing soup solution with lemon grass in water. The lemon grass oil was broken down into smaller fragments, which remain suspended for long periods of time in water as illustrated in Figure 5D. This implies that the oil is pure. The results obtained is tabulated and presented in Table 3.

Table 3 Chemical Test

PARAMETER	RESULT
Solubility in water	Not Soluble (Positive)
Sudan IV test	Positive
Grease spot test	Positive
Emulsification test	Positive

Analysis was performed on the results obtained to determine the efficiency of the machine and how to improve upon it. Also, the quality of the oil produced and economic viability were determined.

3. DISCUSSION OF RESULTS

Efficiency of the Machine

Table 2 shows the results obtained during the extraction of the oil using the developed prototype machine. From the results, it can be established that the prototype machine developed can be used to extract lemon grass oil from the leaves. The efficiencies were then computed from Table 2 and the results obtained are tabulated and presented in Table 4.

Table 4: Efficiency of the Machine

EXPT	Quantity of Grass (kg)	Volume of oil collected (ml)	Efficiency (ml/Kg)
1	27.0	100.0	3.70
2	27.0	80.8	2.99
3	27.0	80.1	2.97
4	27.0	75.0	2.78
5	22.0	80.7	3.67
6	34.0	80.5	2.37
7	28.8	98.0	3.40
8	22.0	87.0	3.95

From Table 4, it can be established that, the efficiency of the machine ranges from 2.37 to 3.95 ml/kg. The result also shows that, the mass of the lemon grass has an effect on the amount of oil produced, and the boiler's temperature. The investigation reveals that using an optimized quantity of lemon grass may improve the efficiency of the machine.

From Table 3, the results for the solubility in water test performed indicate that there was not soluble meaning a positive results is attained; hence, the sample is pure oil. Sudan IV test, grease spot test, and emulsification test also responded positive given an indication of the pureness of the oil.

The cost analysis for the extraction of the oil was also estimated. Table 5 shows the prices of the items used to produce the oil. From Table 2 with a 27 kg of lemon grass at burner's temperature of 270 ^{o}C having boiler's temperature and pressure of 110 ^{o}C and 1.6 bar produces 100 ml of lemon grass oil for a time duration of 3.03 hours at a LPG flow rate of 1 kg per hour, then the cost of production can then be estimated.

Table 5: Cost of Material Used

Material	Price (GH¢)
Cost of building the machine	2349.00
18 kg of LPG	42.00
Cost of 27 kg of lemon grass	30.00
Cost of 35 liters of water (GWCL)	7.27
Cost of 5ml of lemon grass oil	9.54

A 35 litres of water was used for this purpose and the total time duration including the set-up was estimated to be six (6) with a labor cost of GH¢ 7.00. The machine was to be run once a day for two hundred and fifty (250) days having a life expectancy to be between ten (10) to twelve (12 years) , the machine cost per day is GH¢ 1.00, then the production is GH¢ 0.66/ml of oil produced. It is also estimated from Table 4 that the cost of the lemon grass oil is GH¢ 1.90/ml, yielding an amount of GH¢ 1.24. This procedure was repeated for the remaining seven experiments and the computed results are tabulated and presented in Table 5. It can be established that the machine seems to be economically viable, effective and efficient.

Table 5: Cost Analysis

EXPT	Quantity of Grass (kg)	Volume of oil collected (ml)	Time consumed (hours)	Cost of Grass (GH¢)	Cost of LPG Used (GH¢)	Cost of Water Used (GH¢)	Production Cost (GH¢/ml)	Gain (GH¢/ml)
1	27	100	3.03	30.00	7.07	7.26	0.66	1.24
2	27	80.8	3.3	30.00	7.70	7.26	0.83	1.08
3	27	80.1	3.45	30.00	8.05	7.26	0.84	1.07
4	27	75	3.55	30.00	8.28	7.26	0.90	1.01
5	22	80.7	3.48	24.44	8.12	7.26	0.77	1.14
6	34	80.5	3.33	37.78	7.77	7.26	0.93	0.98
7	28.8	98	3.3	32.00	7.70	7.26	0.70	1.20
8	22	87	3.37	24.44	7.86	7.26	0.71	1.20

Note: Cost of Lemon grass oil: GH¢1.90/ml; Labour cost for 3 laborers: GH¢21.00; Machine Cost: GH¢1.00/day

Referring to Table 2, it was observed that, when a mass of 27 kg of the lemon grass was used the amount of oil produced differs for the four experiments performed. This means that the amount of oil produced do not depend on the quantity of lemon grass used. However, when the mass of the lemon grass was varied for the same burner temperature, the amount of the oil produced changes (Figure 6a).

Further observation shows that as the quantity of lemon grass changes, with the same burner temperature, the boiler's temperature changes as illustrated in the Figure 6b. This implies that the boiler temp increases with decreasing in the quantity of the lemon grass at constant burner temperature. Also increasing boiler's temperature increases the amount of oil produced (Figure 6a).

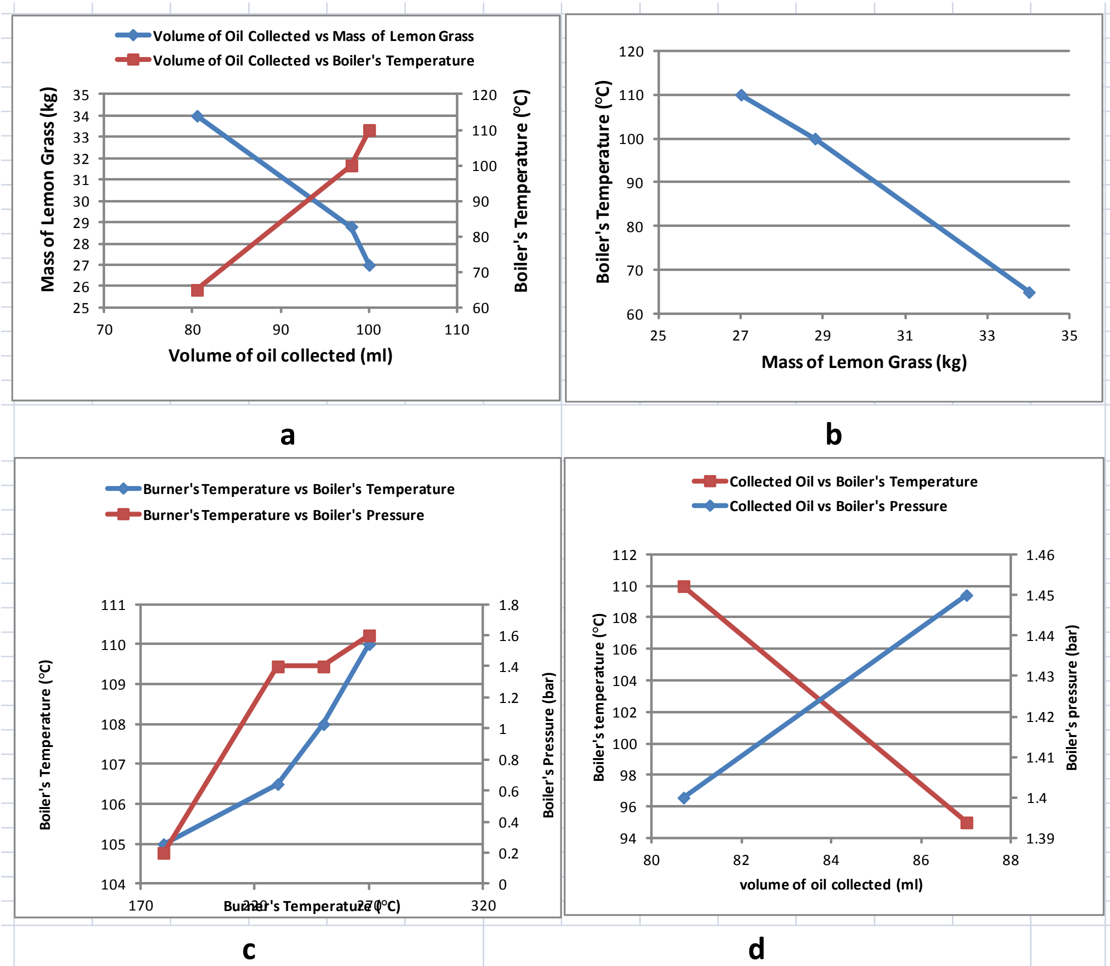


Figure 6: a:-Given the burner's temperature, a graph of volume of oil collected vs. boiler's temperature and mass of lemon grass; b:- Given the burner's temperature, a graph of mass of lemon grass vs. boiler's temperature; c:-Given mass of lemon grass, a graph of burner's temperature vs. boiler's temperature and pressure; d:- Given mass of lemon grass, a graph of volume of oil collected vs. boiler's temperature and pressure

From Figure 6c, the boiler's temperature and pressure increases with increasing burner's temperature. In Figure 6a, it was stated that, the volume of oil collected increases with increasing boiler's temperature, however, in Figure 6d, or Table 2, using the 22 kg mass of lemon grass, increasing the boiler temperature decreases the amount of oil produced. This is due to the fact that when the boiler's temperature increases with decreasing in the boiler pressure may causes the decrease. Hence this is the possibility an interaction that may exist between the boiler's temperature and pressure. Therefore, a further investigation can be performed to optimize the amount of oil produced.

4. CONCLUSION

This paper presents the design of a mechanical system for the extraction of lemon grass oil using the direct steam distillation technique. It can be concluded that the prototype machine developed can be used to extract lemon grass oil from the leaves and its efficiency ranges from 2.37 to 3.95 ml/kg. The oil produced is pure and the machine seems to be economically viable, effective and efficient. However, the burner's temperature has an effect on both the temperature and pressure boiling chamber. Also, the mass of the lemon grass, the temperature and pressure of the boiling chamber affect the volume of oil produced. For commercial application, the direct steam technique is recommended because it eliminate contaminant in the oil and also environmentally friendly. Ghana government through its poverty eradication strategy should inculcate or encourage private individuals to set up small scale industries for the extraction of lemon grass oil. This would not only reduce the unemployment rate but also meet the high demand of this God given commodity.

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