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ENGINEERING INTERVENTIONS FOR EXTRACTION OF ESSENTIAL OILS FROM PLANTS

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1. INTRODUCTION

Essential oils or etheric oils mean volatile oils and are obtained from plants by steam distillation method [19, 29]. Essential oils are used for medicinal and pharmaceutical purposes, food and food ingredients, herbal tea, cosmetics, perfumery, aromatherapy, pest and disease control, gelling agents, dying in fabrics, plant growth regulators and paper making, etc. Munir and Hensel [28] indicated that essential oils have been used in the medicinal and pharmaceutical purposes, as well as food industries, cosmetics, perfumes, physical therapy, the struggle of insects, diseases treatment, dye fabrics and jellies processing, plant growth regulator and manufacturing paper.

Malle and Schmickl [26] stated that the advantages of distillation methods are extracting pure and refine essential oils by evaporating the volatile essence from the plant. Essential oils can be extracted from all plants or different parts of the plant like bark, leaves, roots, wood, seeds or fruits, flowers, burgeons, branches [29]. Also, Alhakeem and Hassan [4] mentioned that essential oils are extracted from various parts of plants such as roots, stems, leaves, buds, fruits, flowers, seeds and bark. About 65% of the essential oils are produced from the woody plants such as trees and bushes [8]. Herbal products are marketed as fresh, dry products, and essential oils. In general, the plants are used as raw or dried materials for the extraction of essential oils [35]. The author developed and evaluated his own steam equipment to extract the essential oils [7].

This chapter discusses engineering interventions for extraction of essential oils from plants.

2. EXTRACTION METHODS FOR ESSENTIAL OILS

2.1. Hydro Distillation

Hydro distillation is used to isolate essential oil from the aromatic plant via boiling water and plants or using steam. Due to the effect of hot water or steam, the essential oils are separated from the oil glands, which are present in the plant tissue. Separated water and oil (vapor mixture) go to the condenser for conversion to liquid and then is transferred to the separator for separating essential oil from water.

2.2. Physiochemical Process During Hydro Distillation mechanism

2.2.1. Hydro-diffusion

Hydro-diffusion is a diffusion of hot water (water distillation method) and essential oils through aromatic plant membranes, contrary to steam distillation method in which the dry steam cannot penetrate the dry cell membrane. Therefore, the aromatic plant must be milled when it is distilled by steam distillation method because the essential oils are free after comminution process. The another method for improving steam distillation method is soaking aromatic plant material in the water because plants cell membranes are impermeable to essential oils, and when soaking plants materials in water makes plants cell membranes to be permeable. Also, boiling water causes liquefaction of essential oil in the water inside the glands. In this process, the solution of oil-water permeate plants cell membranes via osmosis and go out of the membrane, the vaporized oil is transferred with steam. On the other hand, the speed of essential oil vaporization is affected by its degree of solubility in water and is not affected by oil components volatility. The time to distillate milled plant material is less than that for the non-milled plant [32].

2.2.2. Hydrolysis

Hydrolysis is a chemical reaction between components of essential oils and water. At high temperatures, the esters (essential oils constituents) incline to react with water to produce alcohol and acids but the reaction is not complete in all directions. Increasing the amount of water (in water distillation method) leads to increase the amount of the alcohol and acid and as a result essential oil yield is decreased. Hydrolysis depends on the time of contact between water and oil, and the hydrolysis increases with increasing of distillation time [32].

2.2.3. Decomposition by Heat Treatment

At high temperatures, all essential oils constituents are unstable. For improving oil quality, the hydro-distillation temperature must be low. Hydro-diffusion, hydrolysis and decomposition by heat occur at the same time and affect one another. Hydro-distillation is a common traditional extraction method. There are three types of hydro-distillation method for extracting of essential oils from plants.

2.3. Water Distillation

Water distillation is used to extract of essential oils from raw or dried plants by diffusion mechanism (Fig. 1). The plants are soaked in the container, which has water for preventing overheating and charring of the plants, and then heating water with plants till the steam comes out. The oil comes out and it goes to the condenser where the oil and water are collected in separation flasks. The oil collected in the top layer of hydrosol can be isolated. In this method, the extraction temperature always is below 100°C at the surface of the plants to avoid the evaporation of water and oil together [29, 32]. Heating systems in the extraction of essential oils using water distillation are direct fire, steam jacket, closed steam jacket, closed or open steam coil. Figure 2 illustrates the flow diagram of water distillation process.

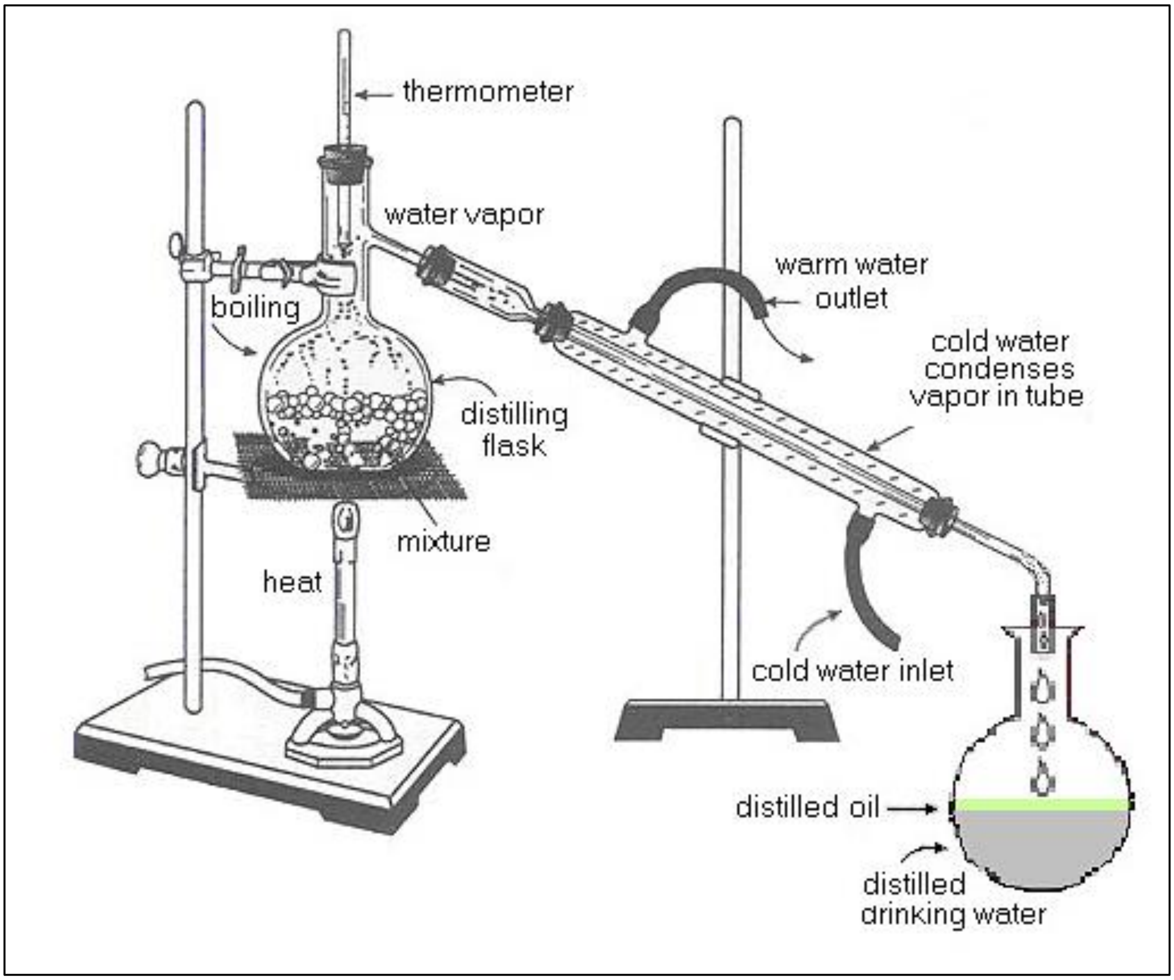

FIGURE 1 Components of water distillation method [38].

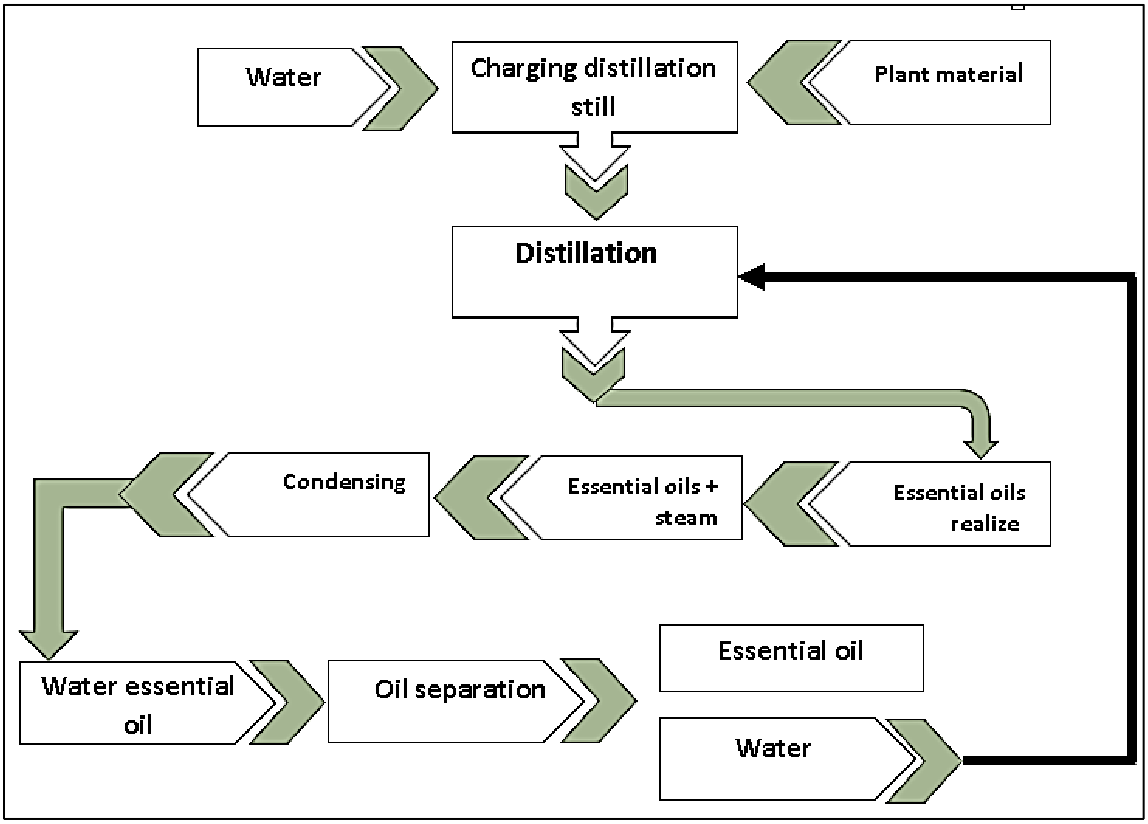

FIGURE 2 Flow diagram of water distillation method [25, 29].

Advantages of water distillation [20]

- It is widely used in the world.
- Water distillation method is inexpensive and easy to construct. It is proper for field operation.
- Boiling water causes motion of plant into distilling flask, which leads to improvement heat transfer.
- There is a direct contact between plant and boiling water.

Disadvantages of water distillation [20]

- Complete extraction is not possible.
- Oil ingredients such as esters are sensitive to hydrolysis while other compounds like acyclic monoterpene hydrocarbons and aldehydes are susceptive to polymerization (water pH is mostly reduced during distillation result in readily hydrolytic reactions).
- Oxygenated ingredients like phenols have a tendency to liquefy in the distilled water, as a result water distillation is not able to removal them completely.

- Water distillation takes a long time to accumulate much oil, as a result the good and bad quality oil are mixed.
- Water distillation is a slow process. On the other hand, it needs much fuel, large area and experience.
- It requires large number of stills.
- Produced oil quality is lower.

2.4. Mathematical Modeling of Essential Oil Extraction

The model of second order mechanism is used to calculate the concentration of oil extracted at any time [31]. Dissolution rate for the oil contained in the solid to solution can be calculated as follows:

$$\frac{dC_s}{dt} = k(C_s - C_t)^2 \tag{1}$$

Where, k is the rate constant of the second order extraction (ml/g min.), C_t is the oil concentration in the solution at any time (g/l), C_s is the oil concentration at saturation (g/l), t is the time (min.).

The integrated rate for the second order extraction has been obtained by considering the boundary condition at t = 0 to t and C_t = 0 to C_t.

$$C_t = \frac{{C_s}^2 k\, t}{(1+C_s kt)^2} \tag{2}$$

By transforming Eq. (2) to linear equation, we get:

$$\frac{t}{C_t} = \frac{1}{{C_s}^2 k} + \frac{t}{C_s} \tag{3}$$

Extraction rate can be expressed as:

$$\frac{C_t}{t} = \frac{1}{\left\{\frac{1}{{C_s}^2 k} + \frac{t}{C_s}\right\}} \tag{4}$$

The initial extraction rate (h), when t is close to 0, can be written as:

$$h = {C_s}^2 k \tag{5}$$

The concentration of solute at any time can be obtained after rearrangement as:

$$C_t = \frac{t}{\left\{\frac{1}{h} + \frac{t}{C_s}\right\}} \tag{6}$$

Where, h,C_s, k can be determined experimentally from the slope and intercept by plotting $[\frac{t}{C_t}]$ versus t.

2.5. Ohmic Heated–Water Distillation [OHWD]

Ohmic heating (Joule heating) is a novel thermal treatment. In this technology, internal heat generates in food via passing of alternative electric current within the food, then food converts to electrical resistance [39]. In addition, Ohmic-hydro-distillation is an advanced hydro-distillation technique using ohmic heating process and could be considered as a novel method for the extraction of essential oils. As well as, the results of this study introduced a verdant technology because of less power required per ml of essential oil extraction [14]. Heat generates in the internal of food, in addition, the temperature of heated food is lower than the wall. The control of treatment uniformity requires best modelling inputs. The initial process is varied according to food type. Electric and thermal characteristics are varied during operation.

Advantages of ohmic heating [17, 44]

- Ohmic heating has a high energy efficiency and volumetric heating.
- Particles temperature is higher than liquid by the same factor of conductivity.
- Decreased fouling.
- Can be done in case solid-liquid food mixture.
- Safe technology; and the product treated by ohmic heating has a high quality.
- Rapid and relatively homogenous heating.
- Alternative voltage is implemented to the electrodes at both ends of food.
- Heating rate depends on the electrical field intensity square and the electric conductivity.
- The electric field intensity had varied with change the distance between electrodes and the applied voltage.
- Formation of fouling on the electrodes when used high voltage for milk pasteurization by ohmic heating because whey proteins denaturation during ohmic heating at high voltage.

Disadvantages of ohmic heating [18]

- Part of treated food has a high temperature, but the other parts have a low temperature because the food composition is complex.
- A corrosion happens in the electrodes and it needs cleaning continuously.
- Capital investment is higher than the other traditional methods.
- Some processes need pretreatment like blanching.

Al-Hilphy [5, 7] designed a new distiller for essential oils by using ohmic heating (Fig. 3). It consists of two electrodes and the dimensions of each electrode are 0.075×0.14 m, which are manufactured from stainless steel-316, inner cylinder made of heat plastic, its diameter and height are 0.14 m and 0.195 m respectively provided with the double jacket. Its optimum capacity was 150 g of dried aromatic plants. Glass condenser, a container for condensate water and oil and voltage regulator are also shown in Fig. 3. The distillation temperature in this apparatus is 100°C. Figure 4 illustrates the change in temperature during extraction time at different voltages. The required time to evaporate essential oils with vapor was decreased with the increase in voltage.

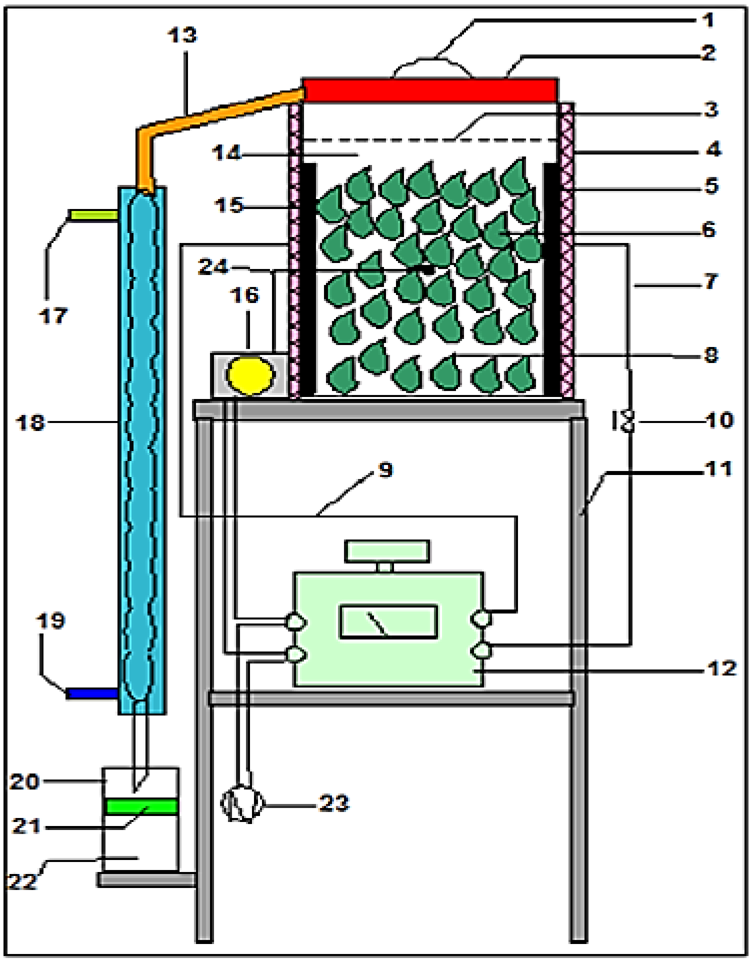

FIGURE 3 Components of the essential oils distiller using Ohmic heating [5].

1.Handle, 2.cover, 3.water level, 4.insulator, 5and15.electric poles, 6.plants, 7.wire, 8.water, 9.wire, 10.electric switch, 11.wood body, 12.voltage regulator, 13.plastic pipe, 14.cylinder, 16.temperature indicator, 17.hot water outlet, 18.heat exchanger (condenser), 19.cold water inlet, 20.flask, 21.essential oil layer, 22. Collected water,23.AC voltage supply, 24.Thermocouple.

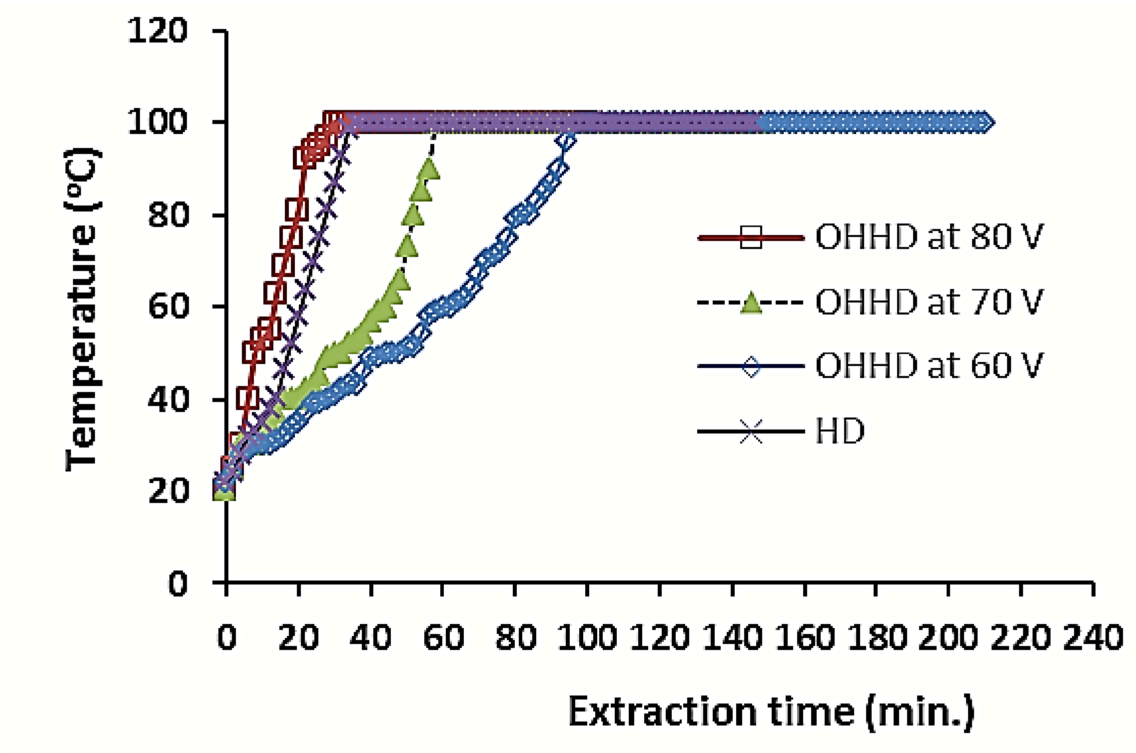

FIGURE 4 Temperature of Eucalypts leaves during extraction of essential oil with a distillator [5].

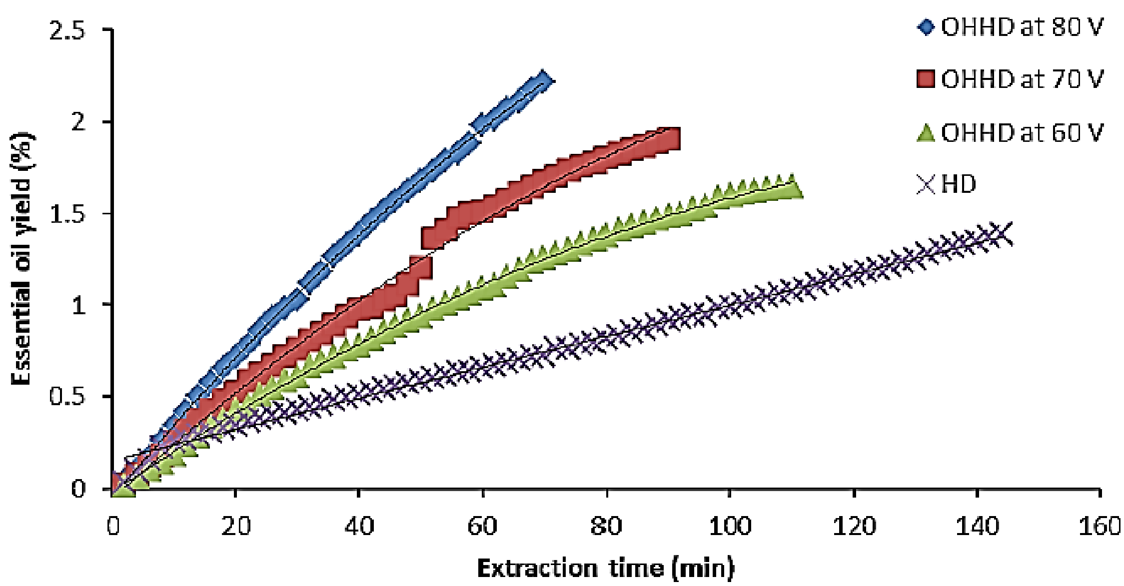

FIGURE 5 Essential oil yield extracted from eucalyptus leaves by OHHD and HD methods [5].

Figure 5 illustrates that the essential oil yield (%) is directly proportional to extraction time. However, the relationship between the yield of essential oil and extraction time follows a second degree polynomial. The required time to essential oil distillation was 110, 90, and 142 minutes for ohmic heating hydro (water) distillation (OHHD) at 60, 70, 80 V and HD, respectively. This may be attributed to the higher efficiuency of OHHD. The internal heating rate in the case of Ohmic heating is higher. Therefore, its ability to generate heat is high [18, 37]. Also, it can be seen in Figure 5 that the percentage of essential oil yield was 1.648, 1.894, 2.177, and 1.369% by using OHHD at 60, 70, 80 V and hydro (water) distillation, respectively.

System performance coefficient is given by Eq. (7) [21, 22]:

$$SPC = \frac{Q_t}{E_g} \quad (7)$$

$$E_g = Q_t + E_{loss} = \sum[\Delta VIt] \quad (8)$$

$$Q_t = m\, C_p(T_f - T_i) \quad (9)$$

Where, m is plant mass (kg), $(T_f - T_i)$ is the difference between extraction temperature and initial temperature (°C), E_g is the given energy (J), Q_t is the heat extracted (J), SPC is the System performance coefficient, and C_p is the specific heat (J/kg.K) at constant pressure.

The specific heat can be calculated from the following empirical equation [40]:

$$Cp = 4176.2 - 9.0864 \times 10^{-3}T + 5473.1 \times 10^{-6}T_2 \quad (10)$$

Heat loss to the ambient is shown below:

$$E_{\ loss} = \bar{h}\pi DL(T_{\ w} - T_{\ amb.})\Delta t \quad (11)$$

Where, h is the heat transfer coefficient (W/m^{2}K), D is the cylinder diameter (m), T_w is the outer cylinder wall temperature (°C), $T_{amb.}$ is the ambient temperature (°C), E_{loss} is the heat loss via natural convection (J), and t is the time**.**

Average heat transfer coefficient is calculated [15] as follows:

$$\bar{h} = \left[\frac{\Delta T}{D}\right]^{1/4} \quad (12)$$

Where, ΔT is the temperature difference between the final and the ambient temperature of wall.

It can be seen in Fig. 6 that the relationship between SPC and voltage gradient is linear (first order) as follows:

$$SPC = -0.007E + 1.0292 \quad (13)$$

Where, E is the voltage gradient**.**

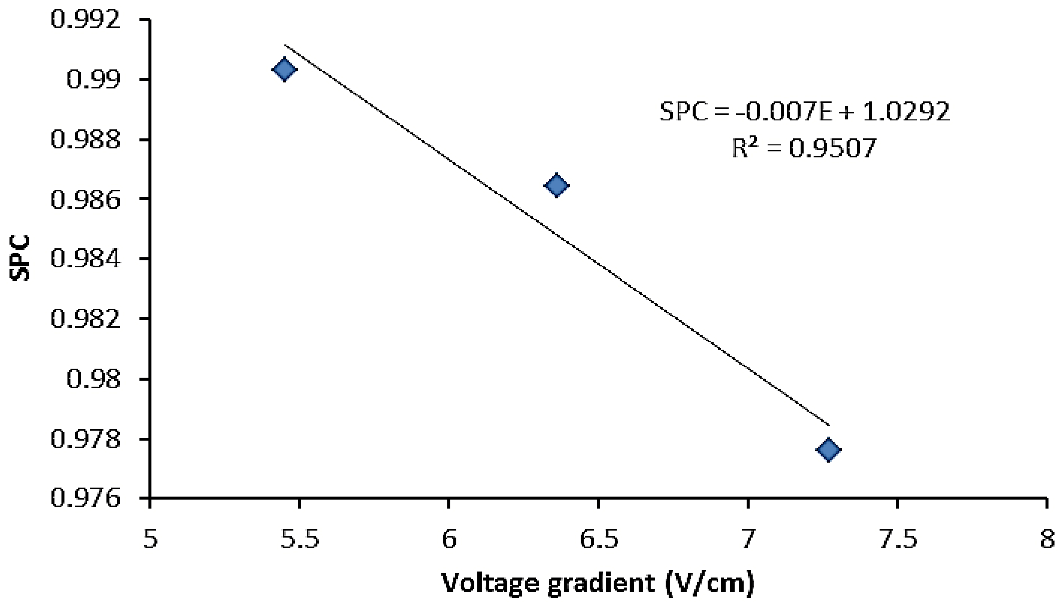

FIGURE 6 System performance coefficient versus voltage gradient for Eucalyptus leaves [5].

2.6. Effects of Ohmic Heating on Specific gravity and Refractive Index of Essential Oils

The specific gravity and reflective index for essential oils was not affected significantly by extraction methods (OHWD at 60, 70, 80 V and WD) as shown in Table 1. Alhakeem and Hasan [4] demonstrated that the reflective index and specific gravity of extracted Eucalyptus oil fluctuated between 1.4631 – 1.4644 and 0.9160 - 0.9300. Moreover, the reflective index and specific gravity of extracted Eucalyptus oil by water distillation method were 1.4928 and 0.9162, respectively [1]. Therefore, the extracted essential oils from Eucalyptus leaves by using ohmic heating is an extraction technology that extracts the essential oils with high quality.

TABLE 1 The Reflective Index and Specific Gravity of Eucalyptus Essential Oils Extracted by Ohmic Heating [5]

Water distillation methods	**Specific Gravity**	**Reflective Index**
OHWD 60 V	0.914^{a}±0.0022	1.4959^{a}±0.0012
OHWD 70 V	0.913^{a}±0.0041	1.4945^{a}±0.0011
OHWD 80 V	0.913^{a}±0.0033	1.4946^{a}±0.0014
WD	0.914^{a}±0.0051	1.4998^{a}±0.0016

2.7. Effects of Ohmic Heating (OHWD) on Chemical Composition of Essential Oils

It Tables 2 to 5 indicate the essential oils ingredients of Eucalyptus leaves, which were analyzed by GC-MS. The total components of essential oils were 29, 30, 27 and 28% by using OHWD at 60, 70, 80 V and WD, respectively. The main component of Eucalyptus essential oil is Eucalyptol. Eucalyptol content in Eucalyptus essential oil was 12.54, 15.66, 39.49, and 15.96% by using OHWD at 60, 70, and 80 V, as well as WD, respectively. Other main ingredients of Eucalyptus essential oil extracted by using OHWD at 60, 70, 80 V and WD were: {alpha.-Pinene (6.07%), Benzene,1-methyl-3-(1-methylethyl)-(22.09%), 1H-Cycloprop[e]azulen-7-ol,decahydro-1,1(7.39%) and (-)-Globulol (5.66%)}, {alpha.-Pinene (6.37%), Benzene, 1-methyl-3-(1-methylethyl)-(21.65%), 3-Allyl-6-methoxyphenol(6.53%), 2-Naphthalenemethanol, decahydro-.alpha.,(8.69%)}, {.alpha.-Pinene(7.46), Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-(5.27%), 3-Allyl-6-methoxyphenol(9.46%), 2-Naphthalenemethanol, decahydro-.alpha.,.(5.83)}, {alpha.-Pinene(11.40%), Benzene, 1-methyl-3-(1-methylethyl)-(5.16%), Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-(10.25%), 3-Allyl-6-methoxyphenol(12.47%), (-)-Globulol(6.85%)}, respectively. The results illustrated that the Eucalyptol content was significantly affected by using ohmic heating. In the case of using OHWD at 60, 70, 80 V and WD, the oil consisted of 72.41, 56.66, 62.96 and 85.71% of oxygenated monoterpenes ingredients respectively, and 27.58, 43.33, 37.03 and 14.28% of monoterpenes hydrocarbons, respectively.

TABLE 2 Chemical Compounds of Eucalypts Oil, which was extracted by OHWD at 60 V [5]

No	Chemical compound	R.T. (min)	Formula	Area (%)	Mol. Weight
1	alpha.-Pinene	5.255	C10H16	6.07	136
2	Benzene, 1-methyl-3-(1-methylethyl)-	7.067	C10H14	3.67	134
3	Benzene, 1-methyl-3-(1-methylethyl)-	7.267	C10H14	22.09	134
4	Eucalyptol	7.373	C10H18O	12.54	154
5	1,4-Cyclohexadiene, 1-methyl-4-(1-methyle	7.716	C10H16	1.42	136
6	1,6-Octadien-3-ol, 3,7dimethyl-	8.454	C10H18O	0.69	154
7	Butanoic acid, 3-methyl-, 3-methylbutyl este	8.559	C10H20O2	0.45	172
8	Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-m	9.168	C10H16O	4.11	152
9	2(10)-Pinen-3-one, (.+/-.)-	9.495	C10H14O	1.00	150
10	Borneol	9.660	C10H18O	0.68	154
11	3-Cyclohexen-1-ol, 4-methyl-1-(1-methyleth	9.809	C10H18O	2.68	154
12	Bicyclo[3.2.0]heptan-3-ol, 2-methylene-6,6-	9.922	C10H16O	1.88	152
13	3-Cyclohexene-1-methanol, .alpha.,.alpha.,4	10.067	C10H18O	2.59	154
14	Cyclohexanol, 2-methylene-5-(1-methylethe	10.591	C10H16O	1.00	152
15	1-Cyclohexene-1-carboxaldehyde, 4-(1-meth	11.311	C10H16O	0.95	152

16	Phenol, 2-methyl-5-(1-methylethyl)-	11.649	C10H14O	0.80	150
17	1H-Cycloprop[e]azulene, decahydro-1,1,7-t	13.585	C15H24	1.17	204
18	1H-Cycloprop[e]azulene, decahydro-1,1,7-tr	13.875	C15H24	1.58	204
19	Oxalic acid, monoamide, N-(2-phenylethyl)	14.257	C16H23NO 3	0.91	277
20	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	15.458	C15H24O	7.39	220
21	(-)-Globulol	15.560	C15H26O	5.66	222
22	Cubenol	15.644	C15H26O	1.28	222
23	2-Naphthalenemethanol, 2,3,4,4a,5,6,7,8-oct	15.974	C15H26O	0.45	222
24	2-Naphthalenemethanol, 1,2,3,4,4a,5,6,7-oc	16.067	C15H26O	0.62	222
25	2-Naphthalenemethanol, decahydro-.alpha.	16.375	C15H26O	3.85	222
26	Spiro[5.5]undec-2-ene, 3,7,7-trimethyl-11-m	17.296	C15H24	3.96	204
27	1,2-Benzenedicarboxylic acid, bis(2-methyl	18.640	C16H22O4	3.34	278
28	1,2-Benzenedicarboxylic acid, butyl 2-methy	19.619	C24H38O4	1.37	390
29	1,2-Benzenedicarboxylic acid, diisooctyl est	24.889		5.80	

TABLE 3 Chemical Compounds of Eucalypts Oil extracted by OHWD at 70 V [5]

No	Chemical compound	R.T (min)	Formula	Area (%)	Mol. Weight
1	.alpha.-Pinene	5.247	C10H16	6.37	136
2	Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-meth	6.096	C10H16	0.44	136
3	Benzene, 1-methyl-3-(1-methylethyl)-	7.056	C10H14	2.68	134
4	Benzene, 1-methyl-3-(1-methylethyl)-	7.258		21.65	
5	Eucalyptol	7.363	C10H18O	15.66	154
6	1,4-Cyclohexadiene, 1-methyl-4-(1-methyle	7.715	C10H16	1.69	136
7	(+)-4-Carene	8.181	C10H16	0.88	136
8	Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-	9.160	C10H16O	4.25	152
9	2(10)-Pinen-3-one, (.+/-.)-	9.486	C10H14O	0.95	150
10	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-,	9.642	C10H18O	0.41	154
11	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylet	9.786	C10H18O	1.92	154
12	Cyclohexanol, 2-methylene-5-(1-methylethe	9.930	C10H16O	1.32	152
13	3-Cyclohexene-1-methanol, .alpha.,.alpha.,4	10.044	C10H18O	1.62	154
14	Cyclohexanol, 2-methylene-5-(1-methylethe	10.578	C10H16O	0.91	152
15	3-Allyl-6-methoxyphenol	12.458	C10H12O2	6.53	164
16	Caryophyllene	13.323	C15H24	0.37	204
17	1H-Cycloprop[e]azulene, decahydro-1,1,7-t	13.586	C15H24	1.46	204

18	1H-Cycloprop[e]azulene, decahydro-1,1,7-t	13.877	C15H24O	2.02	220
19	.beta.-Guaiene	14.248	C15H24	0.69	204
20	2-Isopropenyl-4a,8-dimethyl-1,2,3,4,4a,5,6,	14.342	C15H24	0.40	204
21	Phenol, 2-methoxy-4-(2-propenyl)-, acetate	14.591	C12H14O3	0.98	206
22	Cyclohexanemethanol, 4-ethenyl-.alpha.,.al	15.033	C15H26O	2.36	222
23	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	15.430	C15H24O	4.83	220
24	(-)-Globulol	15.530	C15H26O	4.50	222
25	(-)-Globulol	15.620	C15H26O	0.92	222
26	Ledol	15.737	C15H26O	0.49	222
27	2-Naphthalenemethanol, 1,2,3,4,4a,5,6,7-oct	16.071	C15H26O	1.65	222
28	2-Naphthalenemethanol, decahydro-.alpha.,.	16.404	C15H26O	8.69	222
29	.gamma.-Neoclovene	17.277	C15H24	2.76	204
30	1,2-Benzenedicarboxylic acid, bis(2-methyl	18.597	C16H22O4	0.61	278

TABLE 4 Chemical Compounds of Eucalypts Oil Extracted by OHWD at 80 V [5]

No	Chemical compound	R.T (min)	Formula	Area (%)	Mol. Weight
1	.alpha.-Pinene	5.255	C10H16	7.46	136
2	Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-meth	6.098	C10H16	0.54	136
3	.alpha.-Phellandrene	6.689	C10H16	0.70	136
4	Benzene, 1-methyl-3-(1-methylethyl)-	7.054	C10H14	2.04	134
5	Eucalyptol	7.379	C10H18O	39.49	154
6	1,4-Cyclohexadiene, 1-methyl-4-(1-methyle	7.714	C10H16	1.42	136
7	(+)-4-Carene	8.182	C10H16	0.80	136
8	Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-	9.173	C10H16O	5.27	152
9	2(10)-Pinen-3-one, (.+/-.)-	9.497	C10H14O	1.39	150
10	Isoborneol	9.646	C10H18O	0.53	154
11	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylet	9.788	C10H18O	1.60	154
12	Cyclohexanol, 2-methylene-5-(1-methylethe	9.931	C10H16O	1.42	152
13	3-Cyclohexene-1-methanol, .alpha.,.alpha.,4	10.042	C10H18O	1.35	154
14	Cyclohexanol, 2-methylene-5-(1-methylethe	10.581	C10H16O	1.04	152
15	3-Allyl-6-methoxyphenol	12.481	C10H12O2	9.46	164

16	1H-Cycloprop[e]azulene, decahydro-1,1,7-t	13.589	C15H24	1.68	204
17	1H-Benzocycloheptene, 2,4a,5,6,7,8-hexahy	14.249	C15H24	0.79	204
18	1,5-Cyclodecadiene, 1,5-dimethyl-8-(1-met	14.342	C15H24	0.41	204
19	Phenol, 2-methoxy-4-(2-propenyl)-, acetate	14.607	C12H14O3	2.00	206
20	Cyclohexanemethanol, 4-ethenyl-.alpha.,.al	15.022	C15H26O	1.19	222
21	Epiglobulol	15.192	C15H26O	0.53	222
22	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	15.425	C15H24O	4.50	220
23	(-)-Globulol	15.530	C15H26O	4.14	222
24	2-Naphthalenemethanol, 1,2,3,4,4a,5,6,7-oct	16.066	C15H26O	1.19	222
25	2-Naphthalenemethanol, decahydro-.alpha.	16.381	C15H26O	5.83	222
26	.gamma.-Neoclovene	17.272	C15H24	2.52	204
27	1,2-Benzenedicarboxylic acid, bis(2-methyl	18.598	C16H22O4	0.71	278

TABLE 5 Chemical Compounds of Eucalypts Oil extracted by water distillation (WD) [5]

No	Chemical compound	R.T (min)	Formula	Area (%)	Mol. Weight
1	.alpha.-Pinene	5.279	C10H16	11.40	136
2	Benzene, 1-methyl-3-(1-methylethyl)-	7.063	C10H14	5.16	134
3	Eucalyptol	7.364	C10H18O	15.96	154
4	1,4-Cyclohexadiene, 1-methyl-4-(1-methyle	7.708	C10H16	1.46	136
5	Bicyclo[3.1.1]heptan-3-ol, 6,6-dimethyl-2-	9.213	C10H16O	10.25	152
6	2(10)-Pinen-3-one, (.+/-.)-	9.522	C10H14O	3.42	150
7	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-,	9.657	C10H18O	1.08	154
8	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylet	9.787	C10H18O	1.21	154
9	Cyclohexanol, 2-methylene-5-(1-methylethe	9.934	C10H16O	1.38	152
10	3-Cyclohexene-1-methanol, .alpha.,.alpha.,4	10.042	C10H18O	1.35	154
11	Cyclohexanol, 2-methylene-5-(1-methylethe	10.584	C10H16O	1.09	152
12	2-Cyclohexen-1-one, 2-methyl-5-(1-methyle	10.792	C10H14O	0.83	150
13	3-Allyl-6-methoxyphenol	12.504	C10H12O2	12.47	164
14	1H-Cycloprop[e]azulene, decahydro-1,1,7-t	13.607	C15H24	4.08	204

15	3-Phenylpropanoic acid, dodec-9-ynyl ester	14.249	C21H30O2	0.70	314
16	Phenol, 2-methoxy-4-(2-propenyl)-, acetate	14.624	C12H14O3	2.97	206
17	Epiglobulol	15.198	C15H26O	1.16	222
18	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	15.418	C15H24O	3.15	220
19	(-)-Globulol	15.548	C15H26O	6.85	222
20	Cubenol	15.632	C15H26O	1.54	222
21	Apiol	15.913	C12H14O4	1.89	222
22	2-Naphthalenemethanol, decahydro-.alpha,	16.353	C15H26O	1.90	222
23	Apiol	16.559	C12H14O4	1.08	222
24	4,6,6-Trimethyl-2-(3-methylbuta-1,3-dienyl	17.256	C15H22O	1.27	218
25	1,2-Benzenedicarboxylic acid, bis(2-methyl	18.597	C16H22O4	0.54	278
26	12-Oleanen-3-yl acetate, (3.alpha.)-	25.709	C32H52O2	1.05	468
27	4,4,6a,6b,8a,11,11,14b-Octamethyl-1,4,4a,5	26.405	C30H48O	3.07	424
28	9, 19-Cyclolanost-24-en-3-ol, (3.beta.)-	27.268	C30H50O	1.67	426

2.8. Microwave Assisted Water Distillation (MAWD)

Microwave is an electromagnetic field lies between frequencies of 300 MHz to 300 GHz (Fig. 7). *International Telecommunication Union* (ITU) determined 2450 MHZ as the vibration range for heating by microwave. Its characteristics are same as the visible light. The electromagnetic waves can be transferred through the materials without absorption.

Microwave assisted water distillation (MAWD) occurs by electromagnetic waves, which cause structural changes in the cells. Heat and mass transfer are in the same direction, it is from inside to outside, contrary to traditional extraction where mass transfer occurs from outside to inside (from medium heating to the inner of sample), but heat transfer moves from inside to outside. There are two mechanisms of microwave assisted water distillation:

- The **ionic polarization,** which means that when electromagnetic field is applied on the food solutions which have a lot of ions, the ions move with high speed resulting impact among ions and friction of which lead to conversion of dynamic energy of ions to heat energy, and the movement increases with the increase of ions concentration; and as a result, the temperature increases highly.
- The **dipole rotation,** which means rearrangement of dipoles with the applied electromagnetic field. Water contains polarity molecules that have randomized rotation.

Microwave energy arrives directly to aromatic plants (materials) through molecular interaction with the electromagnetic field via conversion of electromagnetic energy into heat energy [12, 34, 41].

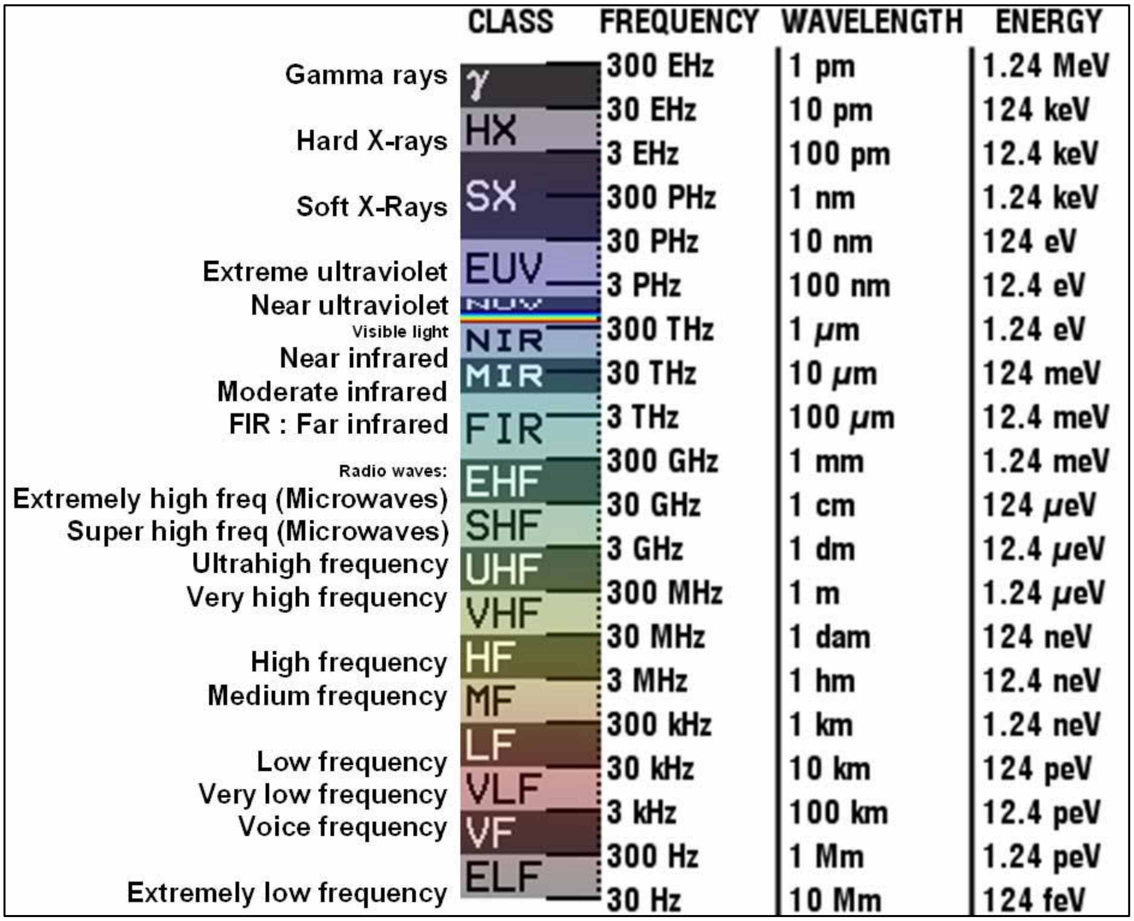

FIGURE 7 The electromagnetic Spectrum [16].

MAWD has been used to extract essential oil from Rosemary [24], Lippia alba [40], and Rosmarinus Dwarfed *Cinnamomum camphora* var. *Linaolifera Fujito* [12]. Wei et al. [43] extracted the essential oils of Dwarfed *Cinnamomum comphora* var *Linaolifera Fujita* using microwave-assisted water distillation and compared it with the traditional water distillation. They stated that the time required to extract essential oil using microwave-assisted water distillation and conventional water distillation reached 37.5 and 120 minutes, respectively and oil yield reached 1.73 and 1.71% respectively. Fadel et al. [13] indicated that the total essential oil yield obtained by using water distillation and microwave-assisted water distillation reached 1.21 and 1.47%, respectively.

Resan [33] manufactured an apparatus for extracting essential oils by using microwave assisted water distillation (Fig. 8). It consisted of microwave apparatus with a power and frequency of 1000 W and 2.45 GHz, respectively, glass condenser, separator and flask.

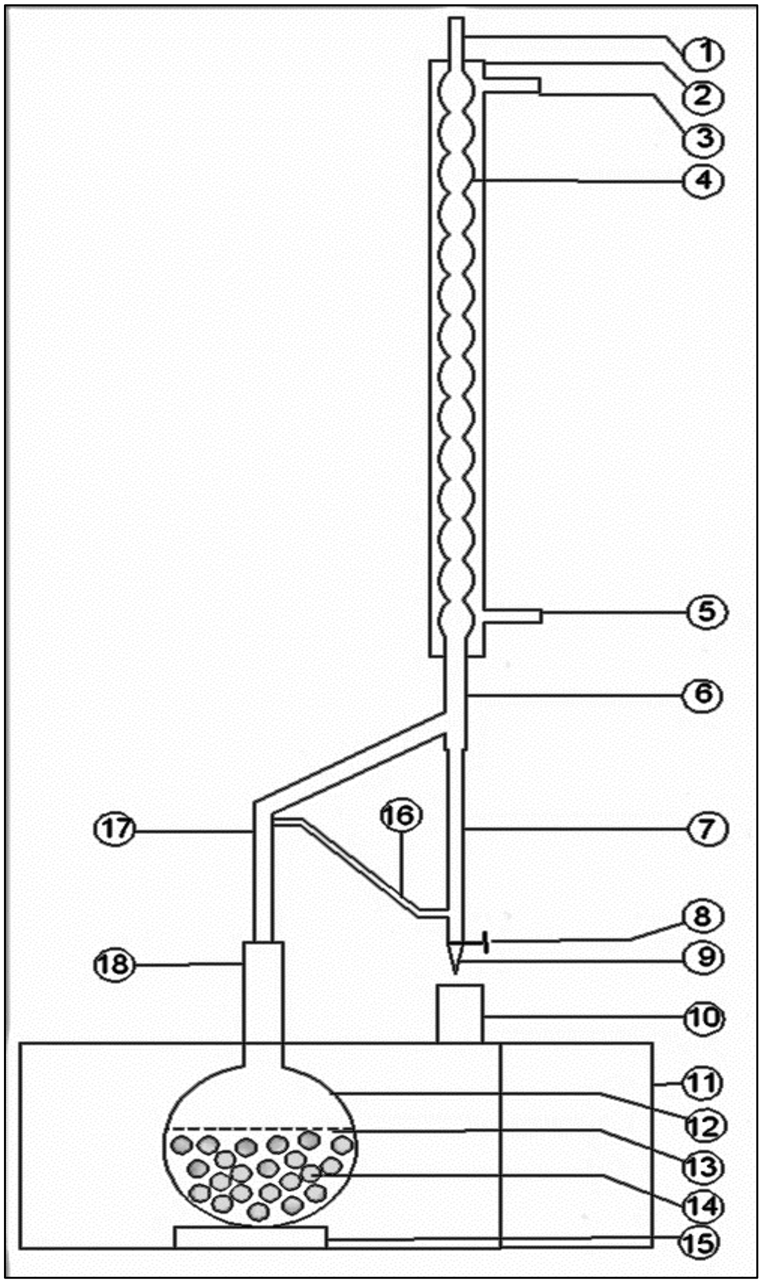

FIGURE 8 Microwave-assisted water distillation apparatus [33]:

1.ventilation port, 2.condenser, 3.outlet hot water, 4.requlated tube, 5.inlet cold water, 6.glass pipe, 7.measuring tube, 8.valve, 9.discharge port, 10.container, 11.microwave, 12.round flask, 13.water level, 14.aromatic plant, 15.base, 16.recycling tube or return tube, 17.vertical glass tube,18. Rubber tube connector.

Figure 9 shows the temperature variation of essential oils that were extracted from caraway using MAWD and conventional water distillation (TWD). The results illustrated that the extraction temperature of essential oils from caraway was increased with increase in extraction time. The extraction temperature by using microwave-assisted water distillation was higher than that for conventional method. The MAWD gave a highest extraction temperature compared with TWD and reached to 98.65 and 96.21°C, respectively. These variations in the extraction temperatures between both extraction methods are due to the direction of heating. In the case of microwave, the heat transfer will be from inner towards outer and therefore, the heat loss is contrary to TWD.

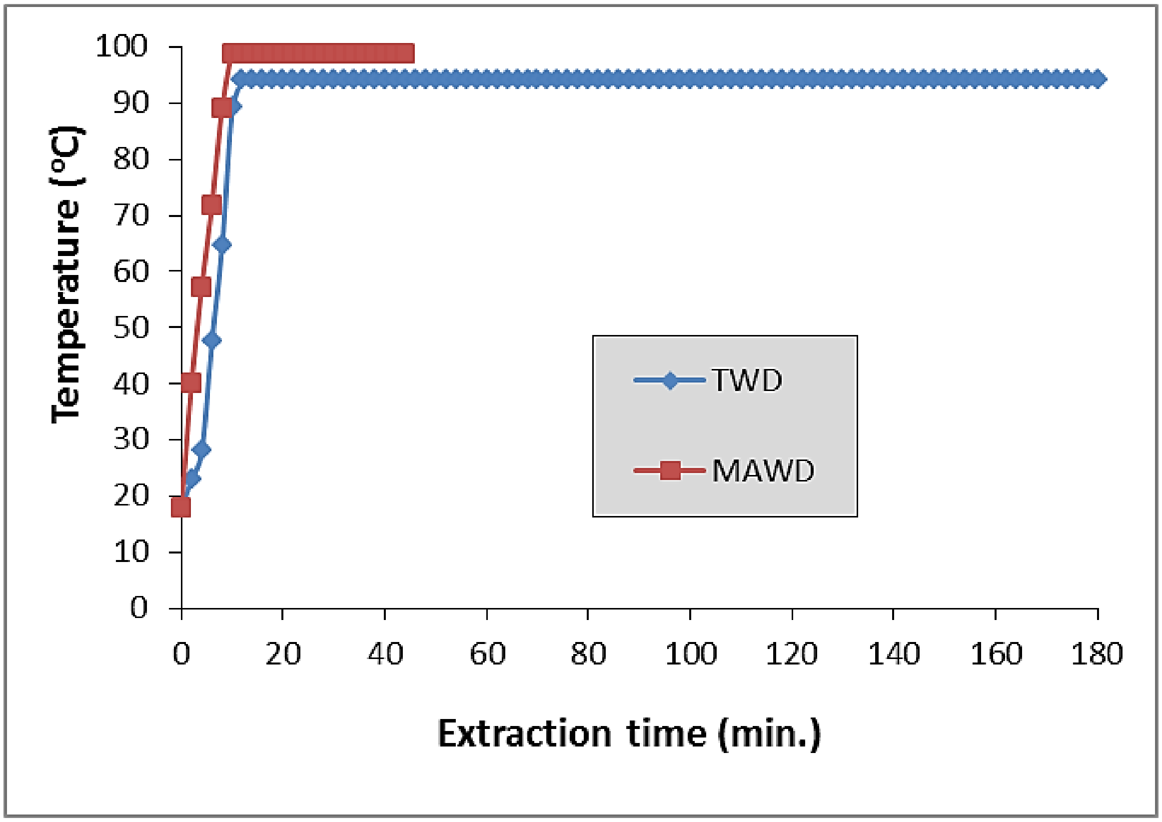

FIGURE 9 Temperature of essential oil extraction of caraway by MAWD and TWD [6].

It can be seen in Fig. 10 that the oil yield distilled from aniseed and fennel by using MAWD was highest compared with TWD because of increasing heat efficiency. Therefore, randomized ions movement velocity increases which leads to increase in the impact energy among ions, thereby the cells walls, which containing oil, are destroyed and release maximum amount of essential oils in water. As shown in Figure 10, oil yield extracted from aniseed by using MAWD and TWD reached 3.7 and 2.8%, respectively. Chemat *et al.*, [10] demonstrated that heat generated by microwave causes variation in the pressure between inner and exterior of plant cells, as well as most compounds are easily released with increasing coefficient of mass transfer and outside cells are destroyed completely. Kapas *et al*. [23] and Azar [8] indicated that the essential oils extracted by MAWD are higher by 7.5% compared with TWD. The results illustrates that the variation between MAWD and TWD in oil yield of caraway and cumin is not significant.

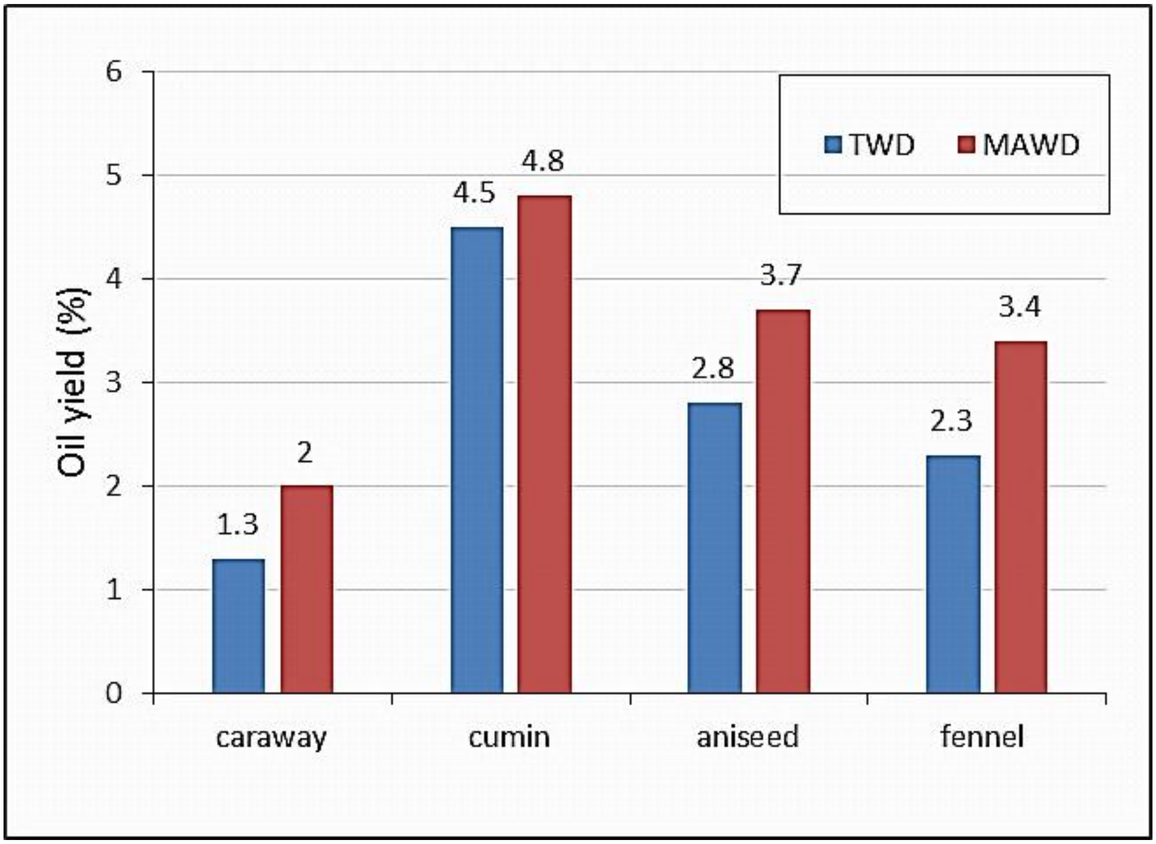

FIGURE 10 Oil Yield of Essential Oils from caraway, cumin, anis and fennel seeds extracted by using MAWD and TWD [6].

2.8.1. Effects of MAWD on the physical properties of essential oils

Refractive index of essential oils extracted from caraway, cumin and aniseed by using MAWD is less than TWD, but for Fennel oil it was higher due to increase in number of unsaturated bonds as shown in Table 6. The refractive index of essential oils extracted from Cumin by using MAWD and TWD reached to 1.5056 and 1.5059, respectively, and for Fennel reached to 1.5561 and 1.5449, respectively. Sainin et al. [36] stated that the refractive index of cumin essential oil is 1.4675. Abo-zaid [2] demonstrated that the refractive index of cumin essential oil is 1.4720. Whereas, Abo-zaid [2] indicated that the refractive index of Caraway essential oil range was between 1.4860 - 1.4878. Al-mayah [3] revealed presence of slow evaporating ingredients in the essential oils as a lot of oxygenated compounds cause an increase of refractive index of essential oils. In addition to the variance in the refractive index, it may be attributed to the presence of lot of unsaturated bonds [3]. Pronpunyapat et. al. [30] stated that the increase of refractive index and relative density makes essential oils color as dark.

The viscosity of all essential oil extracted by using MAWD is insignificantly lower than that for TWD except viscosity of Cumin oil has the same value in both methods. There is no significant effect between MAWD and TWD in the specific density of all essential oils. Abo-zaid [2] demonstrated that the specific density of cumin essential oil is 0.887. The specific density of cumin essential oil extracted by TWD and MAWD reached 0.724 and 0.744, respectively. Sainin et al. [36] stated that the specific density of cumin essential oil is 0.7455. Damayanti and Setyawn [11] showed that the specific density of fennel essential oil ranged from 0.978 to 0.988.

TABLE 6 Physical Properties of Essential Oil extracted by using MAWD and TWD [33]

Essential oils	Refractive index		Viscosity (pa.s.)		Specific density	
	MAWD	TWD	MAWD	TWD	MAWD	TWD
Caraway	1.4941[a]	1.4843[a]	1.762×10^{-3} [a]	1.763×10^{-3} [a]	0.646 [a]	0.641 [a]
Cumin	1.5056[a]	1.5059[a]	2.091×10^{-3} [a]	2.091×10^{-3} [a]	0.744[a]	0.724[a]
Aniseed	1.5451[a]	1.5559[a]	3.495×10^{-3} [a]	3.595×10^{-3} [a]	0.733 [a]	0.737 [a]
Fennel	1.5561[a]	1.5449[a]	2.882×10^{-3} [a]	2.883×10^{-3} [a]	0.825 [a]	0.927 [a]

2.8.2. Effects of MAWD on Chemical Composition of Essential Oils

Resan [32] carried out a study on the identification of active compounds by GC-MS of essential oil extracted from caraway using Clevenger and microwave-assisted water distillation. The researcher demonstrated appearance of Carvon compound by high ratio and it reached 47.12 and 40.5% for both extraction methods, respectively, while compound ratio of Anethol and D-Limonene of caraway oil extracted by Clevenger were 16.18 and 11.67%, respectively and by microwave-assisted water distillation were 22.19 and 10.96%, respectively.

The chemical compounds like Alpha –Isopropylbenzyl alcohol, Cumic aldehyde and betapinene, that were extracted from essential oil of cumin by using Clevenger, reached 35.19, 22.60 and 13.26%, respectively, while values were 33.77, 21.24 and 13.26%, respectively by using microwave assisted water distillation [32]. On the other hand, the Alpha –Isopropyl-benzyl alcohol compound had higher concentration compared with other prevailing compounds in the extracted oil by these two methods. Results by Resan [32] showed appearance of chemical compounds in aniseed oil extracted by Clevenger and the higher ratio was registered by Anethol compound that reached 75.33% compared with other prevailing compounds. Also appearance of the same compound with high ratio reached 77.58% in the extracted oil by microwave-assisted water distillation. The prevailing compounds in the essential oil of fennel extracted were Anethol, L-Fenchon and Estrago and their ratio was 72.78, 7.41 and 5.52% by Clevenger method, compared to 67.01, 8.28 and 4.93%, respectively by using microwave-assisted water distillation. Among these results, the Anethol compound was the prevailing compound among the two extraction methods.

2.9. Steam Distillation

Steam distillation (SD) is a widespread method for isolating essential oils commercially. About 80 to 90% of the essential oils are produced by steam distillation method. This method is used for extracting essential oils from fresh plant materials that have a high boiling point such as roots and seeds. Also, the essential oil in the peppermint, spearmint, oil roses and chamomile are extracted by using steam distillation method (Fig. 11). In this method, the plant material is placed on the perforated grid, then steam is released from steam boiler to the extraction vat and passing through the plant material, and as a result the essential oil is separated from plant material by the diffusion process, and comes out with steam to the condenser, and then to the separation unit. Flow chart of the essential oil extraction by using steam distillation is shown in Fig. 11. The components of SD are shown in (Fig. 12).

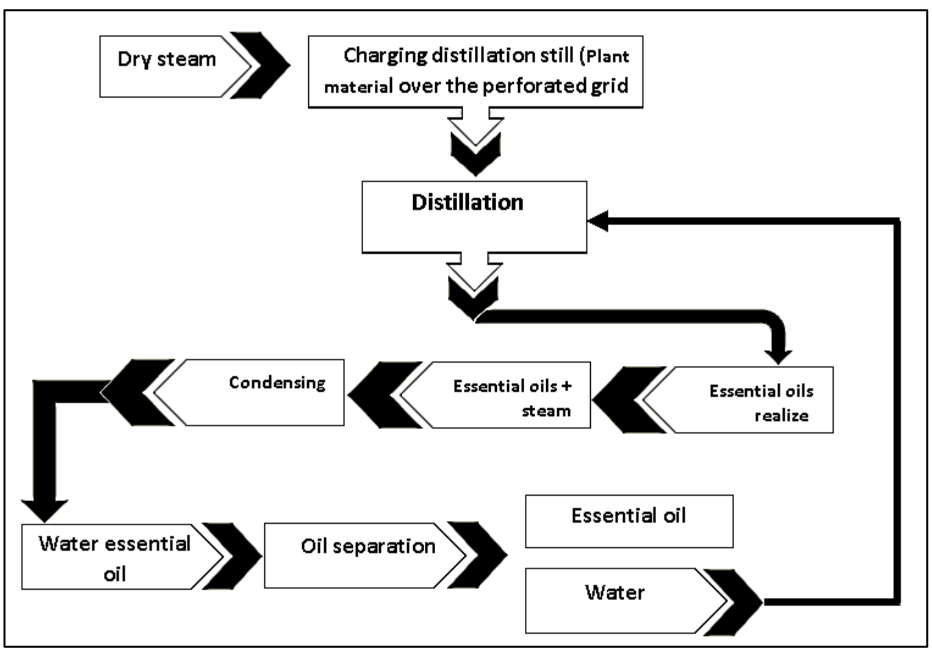

FIGURE 11 Flow diagram of steam distillation method [25, 29].

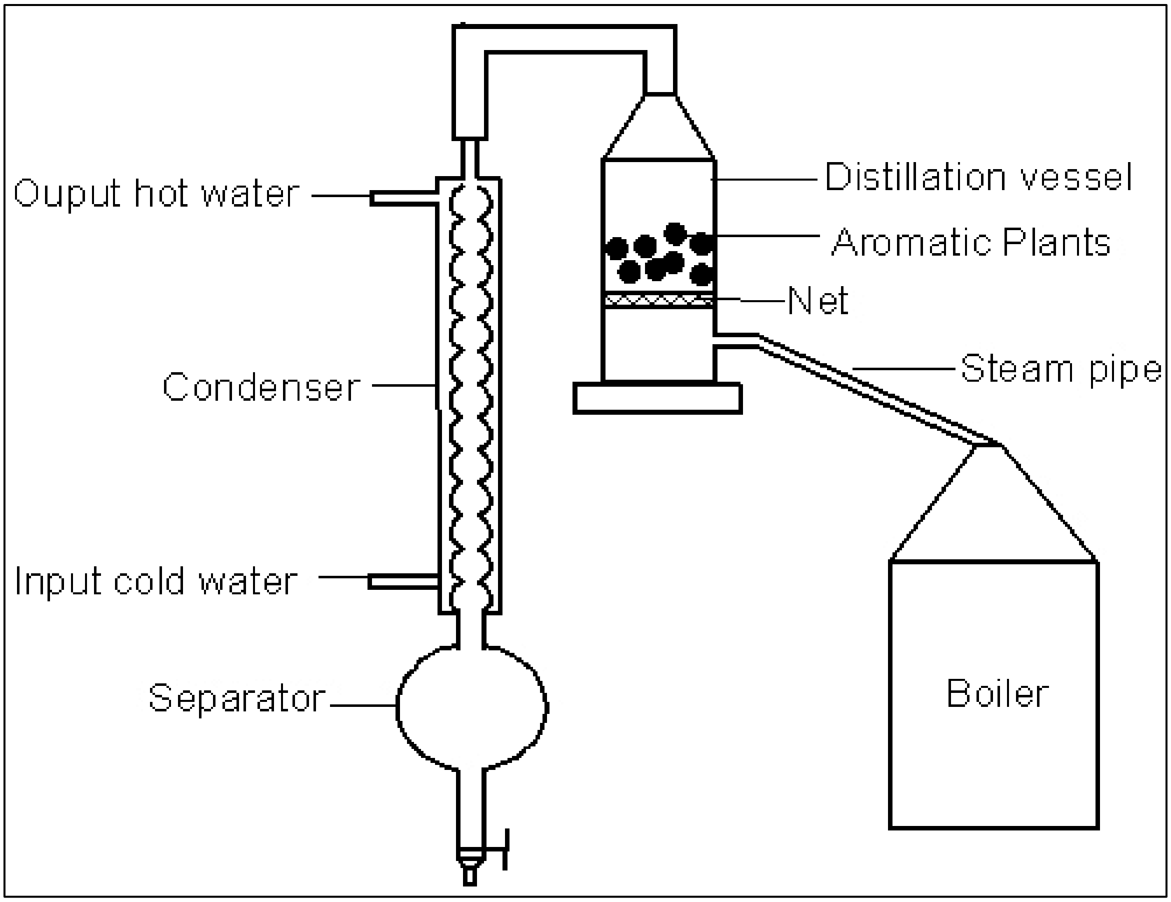

FIGURE 12 Components of steam distillation method for extraction of the essential oils [7].

Advantages of steam distillation

- It has high energy efficient.
- Cheapest way for extracting essential oils when on a small scale.
- Essential oils produced by steam distillation have a high quality.
- The control on the distillation rate is better.
- Working pressure can be changed according to the working conditions.
- No decomposition of in oil compounds due to steam.

Disadvantages of steam distillation

- Set up cost of a large scale of essential oil extractor by this method is high.

2.9.2. Calculation of extracted oil ratio

Ratio of extracted oil explains that extraction of essential oil occurs via washing and diffusion mechanisms as follows [27]:

$$\frac{q}{q_\infty} = 1 - fe^{-k_1 t} - (1-f)e^{-k_2 t} \quad (14)$$

Where: q is the quantity of clove oil extracted at time (t), q_∞ is the quantity of clove oil found in clove flowers at 100% extraction, f is the washing factor, k_1 is the washing constant, k_2 is the diffusion constant.

If washing is very fast and occurs instantaneously, then $k \to \infty$ and we get:

$$\frac{q}{q_\infty} = 1 - (1-f)e^{-k_2 t} \quad (15)$$

If no washing of the essential oil occurs (f = 0), then we have:

$$\frac{q}{q_\infty} = 1 - e^{-k_2 t} \quad (16)$$

The constants f, k_1, k_2 in Eqs. (14) to (16) are very important to predict [q / q_∞]. The constants f, k_1, k_2 can be calculated by using the worksheet in excel.

2.10. Development of Essential Oils Extracted by Steam Distillation

Development of steam extractor for essential oils was carried out by the author [7] and the equipment consisted of following components (Fig. 13):

- Small boiler.
- **Extraction unit** consisted of a stainless steel cylinder of 120 cm length and 5 cm outside diameter and 2 mm thickness. There is a side slot in the bottom of the cylinder to permit entrance the steam, as well as it has another orifice in the bottom provided with a valve to drain the water from the cylinder. Also, the upper part of the upper cylinder contains an orifice that permits to exit both the steam and oil together. There is a shaft of 125 cm length with slide perforated stainless steel disk that is put inside the cylinder Also, a thermocouple is used to measure of plant temperature.
- Glass condenser is used as a heat exchanger. It contains an internal corrugated glass tube.
- Separator flask of 1 liter is used to isolate the oil layer from water.

2.10.1. Distillation temperature

Figure 14 illustrates that clove temperature using developed steam distiller is less than the traditional steam distiller. This is due to the fact that steam loses a part of its energy during the passage in the cylinder by using developed and traditional steam extractor. Mean temperatures were 84.77 and 97.76^{o}C by using developed and traditional steam distiller, respectively. The time required to reach these temperatures was 30 and 15 minutes, respectively. The required total time for complete distillation was 180 and 150 minutes, respectively.

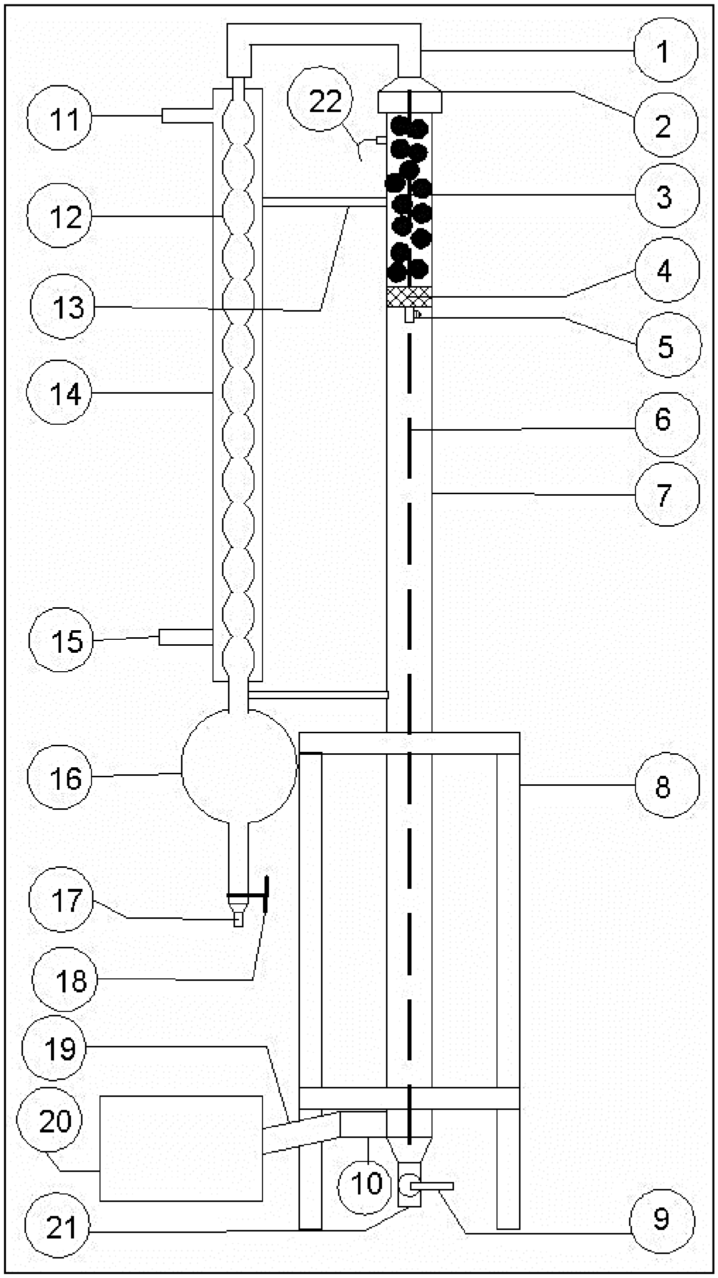

FIGURE 13 Developed steam extractor [7]: 1. Heat plastic pipe, 2.cover, 3. Clove flowers, 4. Net metal, 5. Slide cylinder, 6.bar, 7. Cylinder 8. Wood matrix, 9. Valve, 10. Steam inlet, 11. Water outlet, 12. Corrugated pipe, 13. Bar, 14.outer cylinder, 15. Water inlet, 16. Separation flask, 17. Water out let, 18. Valve, 19. Heat pipe, 20. Steam generator, 21. Water out let, 22. Thermocouple.

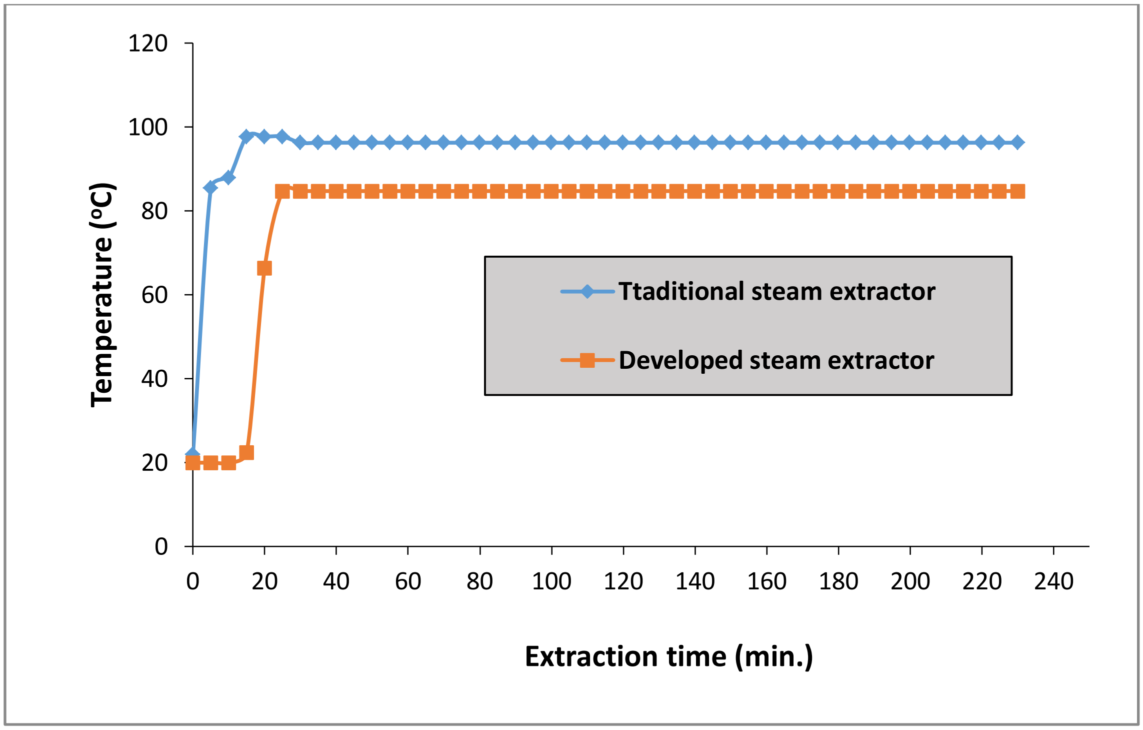

FIGURE 14 Relationship for clove oil temperature versus extraction time during the distillation process by using developed and traditional distillers [7].

2.10.2. Effects of the developed and traditional distiller on physical properties, oil yield and energy consumption

Table 7 Illustrates that clove oil yield extracted with developed extractor was higher than the clove oil yield extracted by using the traditional extractor. Clove oil yield extracted by the developed and traditional extractor was 13.5 and 11%, respectively. This is due to fact that the increase in oil temperature by using the traditional distiller led to the decomposition of oil compounds that are volatile. The differences in the distilled oil density by developed and traditional distiller were significant.

Table 7 shows that the oil viscosity distilled by developed distiller was significantly higher than that with traditional distiller. This is because of increase of oil density distilled by developed distiller. Oil viscosity distilled by using developed and traditional distillers was 0.011029 and 0.00947 Pa-sec, respectively. The differences between the refractive index of oil distilled using developed and traditional distillers were significant. In spite of the energy consumption per ml using developed distiller was lower than traditional distiller, but the differences were not significant.

TABLE 7 Oil yield (%), Energy Consumption and Physical Properties of Clove oil distilled by using developed and traditional distillers [7]

Extractor type	Energy consumption per ml. kW.h/ml.	Reflective index	Oil viscosity Pa-sec	Oil density g/cm^3	Oil yield (%)
Developed	0.1875a	1.5324[a]	0.01029[a]	1.0896[a]	13.5[a]
Traditional	0.1904[a]	1.4509[b]	0.00947[b]	1.0012[b]	11[b]

2.10.3. Effect of developed distiller on the chemical composition of clove essential oil

Tables 8 and 9 show the chemical compounds in the extracted clove oil by the developed and traditional distiller. The significant chemical compounds in the clove oil are Eugenol (72.69%), 3-Allyl-6-methoxyphenyl acetate (18.83%), Caryophyllene (3.10%) by using developed distiller and reached to 78.1, 14.85, and 1.89%, respectively by using traditional distiller. On the other hand, the highest percentage of compounds is oxygenated compounds that were reached 95.62 and 97.52% by the developed and traditional distillers, respectively. The percentage of terpene, nitrogen compounds was 4.06, 0.07 and 0.25% by developed distiller, and 2.37 and 0.25% by traditional distiller, respectively. In fact, oil quality had a significant effect due to the distillation methods as illustrated by the author [7], which explains that there is a decomposition in the clove oil when the traditional distillation is used at temperature of 97.76^{o}C, but this problem did not occur when the developed distiller is used because the operation temperature was 84.77^{o}C.

TABLE 8 Identification of Chemical Compounds Using GC-MS of Clove Oil That was Distillated by Developed Distiller [7]

Peak	Name	R. Time	Area %	Formula	M.W.
1	1R-.alpha.-Pinene	5.138	0.12	C10H16	136
2	Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-meth	5.999	0.09	C10H16	136
3	Benzene, 1-methyl-3-(1-methylethyl)-	6.915	0.09	C10H14	134
4	Eucalyptol	7.037	1.64	C10H18O	154
5	Acetic acid, sec-octyl ester	7.243	0.06	C10H20O2	172
6	Bicyclo[2.2.1]heptan-2-one, 1,7,7-trimethyl-	8.985	0.07	C10H16O	152
7	Cyclohexanone, 4-(benzoyloxy)-, oxime	9.388	0.07	C13H15NO3	233
8	Methyl salicylate	9.713	0.27	C8H8O3	152
9	Phenol, 4-(2-propenyl)-, acetate	10.652	0.42	C11H12O2	176
10	Eugenol	12.114	72.69	C10H12O2	164
11	Palladium(0), bis(.eta.-2-butadiene) 1,1,4,5,8	12.293	0.25	C36H74P4Pd2	842

12	Copaene	12.342	0.17	C15H24	204
13	Benzene, 1,2-dimethoxy-4-(2-propenyl)-	12.675	0.07	C11H14O2	178
14	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	12.723	0.14	C10H12O2	164
15	Caryophyllene	12.906	3.10	C15H24	204
16	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	13.283	0.11	C10H12O2	164
17	1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethy	13.359	0.49	C15H24	204
18	3-Allyl-6-methoxyphenyl acetate	14.149	18.43	C12H14O3	206
19	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	14.853	0.25	C15H24O	220
20	Caryophyllene oxide	14.917	0.70	C15H24O	220
21	12-Oxabicyclo[9.1.0]dodeca-3,7-diene, 1,5,	15.241	0.11	C15H24O	220
22	Cubenol	15.508	0.08	C15H26O	222
23	Tetracyclo[6.3.2.0(2,5).0(1,8)]tridecan-9-ol,	15.558	0.17	C15H24O	220
24	Cubenol	15.765	0.09	C15H26O	222
25	Ar-tumerone	15.862	0.08	C15H20O	216
26	Kauran-18-al, 17-(acetyloxy)-, (4.beta.)-	15.940	0.14	C22H34O3	346
27	Benzyl Benzoate	17.017	0.09	C14H12O2	212
			100.00		

TABLE 9 Identification of Chemical Compounds using GC-MS of clove oil That Was Distillated by Traditional Distiller [7]

Peak	Name	R. Time	Area %	Formula	M.W.
1	Eucalyptol	7.034	0.15	C10H18O	154
2	-------------------------------------	9.711	0.16	------	------
3	Benzaldehyde, 4-(1-methylethyl)-	10.472	0.30	C10H12O	148
4	Phenol, 4-(2-propenyl)-, acetate	10.648	0.33	C11H12O2	176
5	2-Propenal, 3-phenyl-	10.941	0.30	C9H8O	132
6	Benzene, 1-methoxy-4-(1-propenyl)-	11.110	0.27	C10H12O	148
7	Eugenol	12.114	78.71	C10H12O2	164
8	Dimethyl 2,7,12,18-tetramethyl-3,8-di(2,2-d	12.158	0.11	C46H54N4O8	790
9	------------------------------------	12.295	0.25	------	------
10	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	12.710	0.55	C10H12O2	164
11	Caryophyllene	12.903	1.89	C15H24	204
12	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	13.273	0.59	C10H12O2	164
13	1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethy	13.357	0.31	C15H24	204
14	1,3-Cyclohexadiene, 5-(1,5-dimethyl-4-hexe	13.850	0.05	C15H24	204
15	1,3,6,10-Dodecatetraene, 3,7,11-	13.967	0.03	C15H24	204

	trimethyl-,				
16	3-Allyl-6-methoxyphenyl acetate	14.138	14.85	C12H14O3	206
17	Cyclohexene, 3-(1,5-dimethyl-4-hexenyl)-6-	14.217	0.04	C15H24	204
18	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1	14.851	0.07	C15H24O	220
19	Caryophyllene oxide	14.915	0.49	C15H24O	220
20	2-Naphthalenemethanol, 1,2,3,4,4a,5,6,7-oc	15.500	0.07	C15H26O	222
21	Tetracyclo[6.3.2.0(2,5).0(1,8)]tridecan-9-ol,	15.550	0.12	C15H24O	220
22	2-Naphthalenemethanol, decahydro-.alpha.	15.757	0.17	C15H26O	222
23	Spiro[5.5]undec-2-ene, 3,7,7-trimethyl-11-m	16.617	0.05	C15H24	204
24	Benzyl Benzoate	17.018	0.07	C14H12O2	212
25	1,2-Benzenedicarboxylic acid, diisooctyl est	23.900	0.05	C24H38O4	390
		100.00			

3. FUTURE PROSPECTIVES AND RESEARCH OPPORTUNITIES

The prospective future of essential oils distillation depends on the improvement of water distillation and steam distillation methods by using new technologies such as ultrasonic treatments, super-critical fluids especially supercritical CO_2, as well as designing systems for distilling essential oils using infrared radiation technology.

4. SUMMARY

Water distillation and steam distillation methods are common traditional methods that are used to distillate the essential oils. The novel technology for distillation of essential oils is ohmic heating, which can be used as an assisted water distillation. This technology reduces distillation time and it gives essential oils with high quality and high oil yield. On the other hand, steam distiller was been developed to reduce distillation temperature, by the author. In this case, the quality of essential oil was better than the traditional methods.

KEYWORDS

Acids

Acyclic monoterpene hydrocarbons

Alcohol

Aldehydes

Alternative electric current

Hot water
Hydro distillation
Hydrocarbons
Hydro-diffusion
Hydro-distillation technique
Hydrolysis
Hydrolytic reactions
Inner cylinder
Ions concentration
Joule heating
Layer of hydrosol
Lippia alba
Mass transfer
Mathematical modeling
Medicinal
Microwave
Microwave assisted water distillation
Microwave energy
Milk pasteurization
Monoterpene
Novel technology
Novel thermal treatment
Ohmic heating
Ohmic heating process
Ohmic-hydro-distillation
Oil glands
Oil ingredients
Oil quality
Oil yield
Oils extraction methods
Osmosis
Particles temperature
Pharmaceutical
Physical properties

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APPENDIX – A

Glossary of Technical Terms

Essential oils are volatile oils, which are present in the medicinal plants.

Extraction time is the required time to extract entirely essential oils from plants.

GC-Ms is a new technique used for finding chemical composition of essential oils..

Hydro-diffusion is a diffusion of hot water and essential oils via aromatic plant membranes,

Hydro-distillation is a common traditional extraction method.

Hydrolysis is a chemical reaction between essential oils components and water.

Microwave is an apparatus used to heat the mixture of water and plant via electromagnetic waves.

Ohmic heating is a novel technique for pasteurizing milk via passing electric current through food.

Ohmic-hydro-distillation is an advanced method using ohmic heating process and could be considered as a novel method for the extraction of essential oils.

Oil yield represents the produced essential oils from the weight of plant.

Pasteurization is a heat treatment used for eliminating pathogenic microorganisms.

Physical properties are used for evaluating essential oils via many parameters such as refractive index, specific gravity, density and viscosity.

Steam distillation is a widespread method for isolating essential oils commercially.

System performance coefficient is defined as the ratio of taken heat to the given energy.

Water distillation is used to extract of essential oils from raw or dried plants by diffusion mechanism.

LIST OF ABBREVIATIONS

GC-MS	Gas Chromatography Mass Spectrometry
HD	Hydro (water) distillation
ITU	International Telecommunication Union
MAWD	Microwave-assisted Water Distillation
OH	Ohmic Heating
OHHD	Ohmic Heating Hydro (Water) Distillation
SPC	System Performance Coefficient
TWD	Traditional Water Distillation