BirEx JOURNAL
Budapest International Research in Exact Sciences
Medical, Biological, Argiculture, Engineering Science and other related areas
e-ISSN : 2655-7827
p-ISSN : 2655-7835
http://www.bircu-journal.com/index.php/birex

Design and Manufacture of a Mobile Electric Alembic for Naturally Occuring Essential Oils Extraction

Ravelomanantsoa H.[1], Ranaivoson S.L.O.[2], Razafindrakoto F.N.R.[3], Letsara R.[4], Razafindramanga A.W.[5], Rakotomamonjy P.[6], Razafimahefa M.V.[7], Koto-Te-Nyiwa Jean-Paul Ngbolua[8], Randriana N.R.F.[9], Robijaona Rahelivololoniaina B.[10]

[1,2,3,4,5,6,9,10]*Engineering and Industrial Process, Agricultural and Food Systems, Polytechnic High School of Antananarivo, Madagascar*

[1,2,3,7,10]*Laboratory for the valorization of natural resources, Polytechnic High School of Antananarivo, Madagascar*

[4]*Zoological and botanical park of Tsimbazaza, Antananarivo, Madagascar*

[8]*Department of Biology, Faculty of Science, University of Kinshasa, Kinshasa, Democratic Republic of the Congo*

[8]*Department of Environmental Sciences, Faculty of Science, University of Gbado -Lite, Gbado-Lite, Democratic Republic of the Congo*

Corresponding author: valorena1357@gmail.com

Abstract: *The present study concerns the design and manufacturing of a mobile electric alembic, for its use in the distillation of three essential oils (EOs). The design was based on thermodynamic and fluid mechanics calculations to establish the sizing of the device. The heating source used is electricity using electrical resistors. Tests were carried out to verify the ability of the alembic to extract some essential oils (Eos) from aromatic plant, such as Cinnamomum camphora, Cymbopogon citratus, Corymbia citriodora. The EO yields obtained were comparable to those described in the AFNOR. The results of the Gas Chromatography analysis were similar to the published data.*

Keywords: *alembic; electric; manufacturing; essential oil; extraction*

I. Introduction

When we talk about essential oils, we think about perfumery, religious rites, food flavorings and especially aromatherapy. Essential oils (Eos) already existed in ancient civilizations (Couic-Marinier & Touboul, 2017; Bourry & Lebrun, 2020; Morgan, 2015).

Madagascar is an island rich in biodiversity. Known for its flora, the soil, the relief and the specific climate for each region allow the diversification of its flora (Myers et al. 2000; Goodman & Benstead, 2005). Its isolation and its ecological variation favor this richness as well as the endemism of the Malagasy plant species (Lowry Il, et al. 2018). This also concerns the medicinal and aromatic plants which are very much exploited for the distillation of EOs (Rabehaja, 2013; Randrianjohany, 1996).

Thanks to a better knowledge of their virtues, essential oils occupy an important place in a field in full expansion: the medicinal and cosmetological research (Randriamiharisoa, 1996). Several laboratories are interested in this product, which is why it is becoming more and more common on the market, both in Madagascar and abroad. Is it then necessary to know how to extract these EOs from the plant, and how to conceive a more efficient installation at the laboratory scale to better develop this research.

In research laboratories, the extraction of EO is generally limited to a small quantity of about 500g (Boukhatem et al., 2019). It is not easy to ensure measurable results for the extraction of essential oil from new and unstudied plants and especially for low yielding plants.

This study then consists in designing a mobile electric alembic with a capacity of 6 to 10 kg, which we can use to explore the distillation of not yet studied new plants. Would it be feasible to make this stainless steel alembic "in miniature" using heating resistors? Would it be efficient and profitable to get a good quality and quantity of EO, really usable for the aromatic plants, solicited for export either in aromatherapy, cosmetology or perfumery?

II. Material and Methods

2.1 Material

As pointed out by Randriamiharisoa (1995) in his manual for the MAEL-USAID Project (1995), there is no standard size for building alembics. According to the same author, medium-sized alembics allow for quality essential oils and appreciable yields compared to large-sized stills.

Each operator must define the exact size of his alembic, the nature of the building materials and the energy source. The knowledge of these three notions allows the manufacturer to advance in his approach. The ratio between the diameter and the height of the alembic must be between 1.5 and 2.

Stainless steel is the most recommended because of its quality and price. The choice of the nature of the sheets to be used is dictated by the price of the finished product that we want to obtain.

a. Design of the Alembic Mobile Electric

The goal is to design a small still that can hold 6-10kg of plant matter, yielding a minimum amount of oil sufficient for further chemical and biological analysis. As it is a mobile device, intended to be transported to different locations, its design should then allow for easy transport, and a labor-saving implementation. These conditions are imposed to choose particular arrangements for the installation.

b. Constitution of an Alembic

The apparatus is divided into five elementary parts:

- One part consists of the cucurbit which includes the hearth and the boiler. These two are separated by a perforated stainless steel plate which serves as a sieve. This sieve is the upper limit of the water level in the boiler. The water is therefore stored in the lower part. The heating system is placed under the cucurbit. Three 1800W resistors were used for the heating.
- The third part of the apparatus is the gooseneck. The cucurbit and the cover are connected to the gooseneck by a hydraulic joint system.
- The fourth is the condenser.
- Finally, the “essencier” is the fifth portion of the apparatus.

c. The Boiler - Cucurbit

The heating source is provided by three electric resistances of 1.8 kW each. The heating power is 5.4kW. The resistors are powered by 220 V - 50 Hz electric current. They are housed in three stainless steel cylindrical tubes forming a star, making an angle of 220 ° from one to the other, to distribute the heat well.

The boiler water is separated from the plant mass by a perforated plate used as a sieve to avoid any contact of the plant with the water. This sieve is about ¼ of the total height of the alembic.

Around the cucurbit, a rock wool cover has been placed to insulate the system thermally and then, still coaxially outside, a galvanized sheet metal envelope.

Figure 1: *The Tank Wrapped in Rock Wool*

2.2 The Condenser

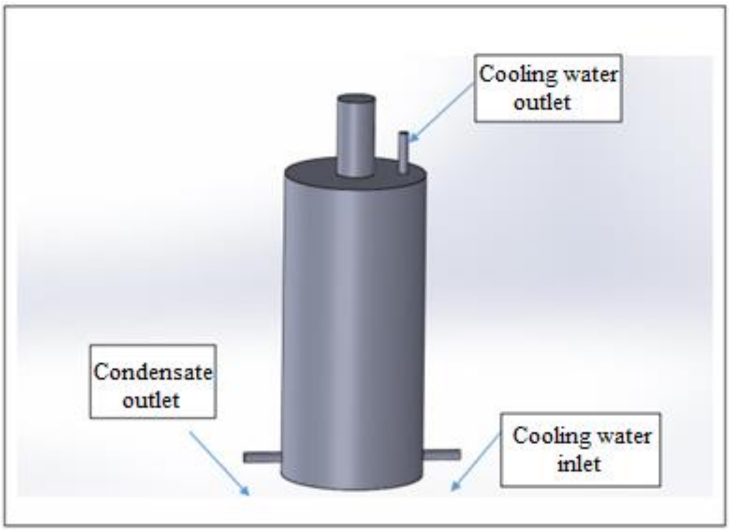

Figure 2. *External View of the Condenser*

<u>Operating principle of the condenser:</u>

The condenser is the second part of the extraction unit. In the condenser, a heat exchange takes place between the coolant and the steam consisting of oil and water. The steam condenses and the cooling water heats up. The amount of heat given up by the steam must be equal to the amount of heat absorbed by the coolant, according to the law of conservation of energy.

a. Sizing

Here are the dimensions of the different parts of this mobile electric still described above.

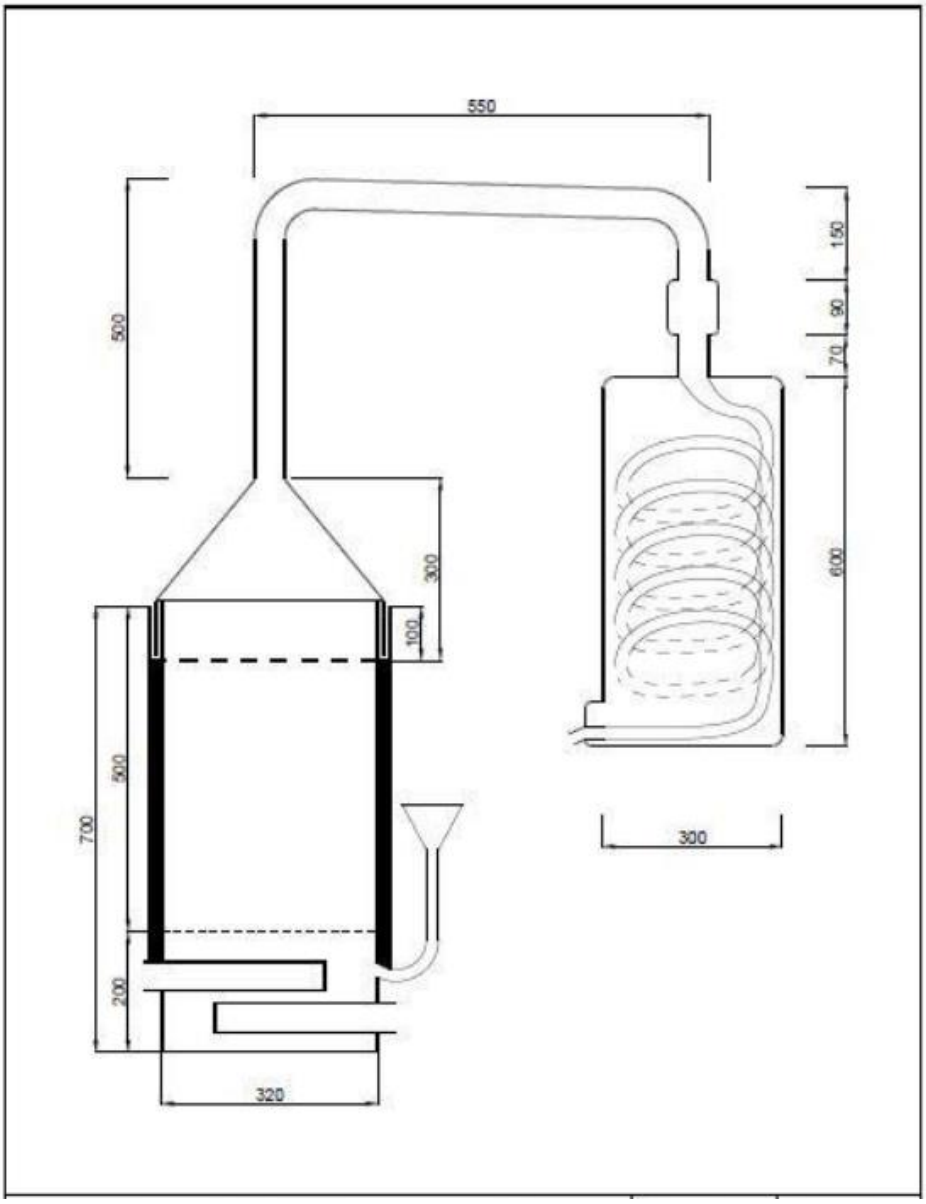

Figure 3. *Size of the Installation (Author)*

Thus conceived, the various characteristics for its realization of this mobile still are detailed in the following paragraphs.

b. For the energy source

- The heating power is P_{heat} = 5.4 kW for all of the tests.

c. For the cucurbit

- Thickness of the steel of the tank: t_s = 2 mm
- Diameter D = 0.32 m
- Total height H = 0.7 m
- Height of the boiler h = 0.20 m
- Volume of the cucurbit: 30L
- Maximum water volume: 16L
- Raw material capacity: maximum 10Kg
- Rock wool

d. For the condenser

- Copper coil
- Length of the coil L = 7.70 m
- Diameter of the coil d = 0.021 m
- Exchange surface of the coil S = 0.507 m2
- TCE = 99.63°C
- TCS = 16.87°C
- Tfe = 16.12°C
- Tfs = 47.63°C
- Steam flow rate rs = 4.5Kg/h

e. At the level of the gooseneck

- Length of the gooseneck: *L*g = 1.2 m
- Existence of a hydraulic seal between the lid of the cucurbit and the swan neck

Detailed studies of the equipment for the extraction of EO have been made thoroughly, as well as the basic sciences governing distillation. Now its applications are with three plants such as *Cinnamomum camphora*, *Corymbia citriodora* and *Cymbopogon citratus*

III. Research Methods

3.1 The Distillation Test of the Mobile Alembic

To ensure the proper functioning of the equipment designed, tests of extraction of EO from some plants were conducted. The plants chosen were the following: the false Camphor tree (because its EO is devoid of camphor) of Madagascar (*Cinnamomum camphora*), the Lemon Eucalyptus (*Corymbia citriodora*) and the Citronella or Lemongrass (*Cymbopogon citratus*). Some bibliographical synthesis on these plants had to be collected to later collate them with the results of the planned distillations to verify if the designed apparatus is efficient or not.

- **First test with *Cinnamomum camphora***

The Camphor tree, scientifically known as *Cinnamomum camphora*, is a tree of the Lauraceae family. It is a medium-sized tree, from 15 to 25m high, with alternate, whole, leathery and evergreen leaves. Generally oval in shape, they are about 10 cm long and give off a strong smell of camphor when rubbed. The fruits are spherical fleshy drupes carried by a thick green peduncle. They are dark blue to black with maturity (Andrianoelina, 2008; Oussou, et *al.* 2017).

Here is a picture of *Cinnamomum camphora.*

Figure 4*. Photo of Cinnamomum camphora leaves*

a. Botanical classification of *Cinnamomum camphora*

(i). Hierarchical classification (MNHN & OFB [Ed]. 2003-2023.)

Domain : Biota Endl. (D.Don)
Reign : Plantae Haeckel, 1866
Subkingdom : Viridaeplantae
Infra-kingdom : Streptophyta John, Williamson & Guiry, 2011
Class : Equisetopsida C. Agardh, 1825
Clade : Tracheophyta Sinnott ex Cavalier-Smith, 1998
Clade : SpermatophytaSubclass : Magnoliidae Novák ex Takht., 1967
Superorder : Magnolianae Takht., 1967
Order : Laurales Juss. ex Bercht. & J.Presl, 1820
Family : Lauraceae Juss., 1789 [con. name]
Tribe : Cinnamomeae Nees, 1836
Genus : *Cinnamomum* Schaeff., 1760 [cons. name]
Species : *Cinnamomum camphora* (L.) J.Presl, 1825
Synonymy
Camphora officinarum Nees, 1831
Laurus camphora L., 1753

Camphor oil is extracted from the camphor tree, *Cinnamomum camphora*, which is indigenous to Vietnam and an area extending from southern China to southern Japan.

Distilled part: leaves

Some clarification would be helpful because it is important to look at the chemotype(ct).

The *Cinnamomum camphora*, the camphor of Japan is naturalized to Madagascar. Its chemotype is 1.8 cineole (over 50%) (Möllenbeck et *al.*, 1997).

(ii). Main components of the EO of *Cinnamomum camphora* ct

- Monoterpenes (27%): alpha-pinene 5,4%, beta-pinene 3,7%, sabinene 14,5%, myrcene 1,7%, gamma-terpinene 1,6%
- Terpenic oxides: 1,8-cineole (56,5%)
- Monoterpenols (9%): terpinene-4-ol 2,3%, alpha-terpineol 6,7%

- **Second test with *Corymbia citriodora***

Corymbia citriodora, commonly known as lemon-scented gum, also called lemon *Eucalyptus* belongs to the family Myrtaceae. Its genus includes 450 species, classified among the *Eucalyptus* hence its vernacular name. These fragrant trees grow in mountains and hillside woods. They have acclimatized like their cousins (*Eucalyptus globulus*, *Eucalyptus radiata*) in a large number of countries around the Mediterranean, also in America.

(i). Botanical classification of *Corymbia citriodora*

It is a large tree, measuring on average up to 40 to 50m high, and has a smooth trunk. Its bark is fibrous, grey or grey-brown, and detaches itself in long ribbons. Its branches, of small size, are green. Its leaves are oblong, alternate, narrow, lanceolate and tapered at the ends, ending in points. Its foliage has a lemony smell and it gives off a peppermint smell when kneaded. The flowers of *Corymbia citriodora* are white and are characterized by the presence of stamens in the leaf axils. The adult leaves are colored brown and varied in brown. Their hatching takes place in summer **(**Ramezani et *al.*, 2002; Sahouo et *al.*, 2003; Silva et *al.*, 2003 ; Mulyaningsih et *al.*, 2011 ; Gbenou et *al.*, 2013).

***Figure 5**. Photo of Corymbia citriodora*

Hierarchical classification (MNHN & OFB [Ed], 2003-2023.):

Domain : Biota Endl.(D.Don)
Reign : Plantae Haeckel, 1866
Subkingdom : Viridaeplantae
Infra-kingdom : Streptophyta John, Williamson & Guiry, 2011
Class : Equisetopsida C.Agardh, 1825
Clade : Tracheophyta Sinnott ex Cavalier-Smith, 1998
Clade : Spermatophyta
Subclass : Magnoliidae Novák ex Takht., 1967
Superorder: Rosanae Takht., 1967

Order : Myrtales Juss. ex Bercht. & J.Presl, 1820
Family : Myrtaceae Juss., 1789 [nom. cons.]
Subfamily : Myrtoideae Sweet, 1827
Tribe: Eucalypteae Peter G.Wilson, 2005
Genus : *Corymbia* K.D.Hill & L.A.S.Johnson, 1995
Species : *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson, 1995

Synonymy
Eucalyptus citriodora Hook., 1848
Eucalyptus maculata var. *citriodora* (Hook.) F.M.Bailey
Eucalyptus melissiodora Lindl., 1848
Eucalyptus variegata F.Muell., 1859
Origin: It is endemic to the north-eastern Australia.
Distilled part: Leaves

b. Main components of the EO of *Corymbia citriodora* (AFNOR)

- Monoterpene aldehyde: citronellal 75-85%.
- Monoterpenols: 10-25% (citronellol 3-10%, isopulegol 5-10%, neoisopulegol 3- 6%, linalool <1%)
- Monoterpene-related organic compound, derived from menthol, p-menthane-3,8-diol or PMD <1%
- Monoterpenes: 3% (alpha-pinene <1%, beta-pinene <1%, limonene <1%, betamyrcene <1%)
- Sesquiterpenes: <3% (beta-caryophyllene 1%, bicyclogermacrene <1,33%)
- Esters: < 2% (citronellyl acetate < 0,1-2%, citronellyl formate < 1 %, beta-phenylethyl acetate < 1%)
- 1,8 cineole <0,5-3%, rose oxide <1%
- Acids: < 1% (citronnel acid)

c. Major components of the EO of *Corymbia citriodora* (AFNOR)

- Monoterpene aldehyde: citronellal (70%, the richest essential oil)
- Monoterpene alcohols: citronellol, isopulegol
- Oxide: 1,8-cineole 0,5 to 3 %.

d. Third test with *Cymbopogon citratus*

1. Botanical classification of *Cymbopogon citratus*

West-Indian lemongrass (*Cymbopogon citratus*) is a wild or cultcitronellalceous plant from tropical regions. It belongs to the Poaceae family, cultivated for its stems and leaves with aromatic qualities. This herbaceous plant has long linear leaves, erect, 90 cm to 2m long, with rough and sharp edges, bluish-green color rather pale, hollow stems, bulbous at the base, wrapped in the sheath of the leaves (Andrianoelina, 2008; Lee et *al*., 2008; Melo et *al*., 2010).

***Figure 6**. Photo of Cymbopogon citratus*

***Hierarchical classification* (MNHN & OFB [Ed], 2003-2023):**

Domain : Biota Endl.(D.Don)
Reign : Plantae Haeckel, 1866
Subkingdom : Viridaeplantae
Infra-kingdom : Streptophyta John, Williamson & Guiry, 2011
Class : Equisetopsida C.Agardh, 1825
Clade : Tracheophyta Sinnott ex Cavalier-Smith, 1998
Clade : Spermatophyta
Subclass: Magnoliidae Novák ex Takht., 1967
Superorder: Lilianae Takht., 1967
Clade : Commelinids
Order : Poales Small, 1903
Family : Poaceae Barnhart, 1895
Subfamily : Panicoideae A.Braun, 1864
Supertribe : Andropogonodae L.Liu, 1980
Tribe : Andropogoneae Dumort., 1824
Subtribe : Andropogoninae J.Presl, 1830
Genus : *Cymbopogon* Spreng., 1815
Species : *Cymbopogon citratus* (DC.) Stapf, 1906.

Synonymy

Andropogon nardus L., 1753
Andropogon citratus DC., 1813
Andropogon citratus DC., 1835
Cymbopogon nardus (L.) Rendle, 1899
Distilled part: stems and leaves (aerial part of the plant)
West-Indian lemongrass (C. *citratus*), is of a Malaysian origin.

2. Main components of the EO of *Cymbopogon citratus* (AFNOR)

- Citral (Neral + geranial) >75 %
- Myrcene : 5.5 to 23.2 %
- Geraniol :1 to 8 %
- E-isocitral : 0.9 to 2.1
- Geranyl acetate 0.4 to 1.2 %
- Cis-β-ocimen 0.2 to 1.2 %
- Trans-β-ocimene 0.2 to 1.1%
- n-Hexanol < 3.3%
- Z-isocitral 0.4 to 1.8 %

3. Major components of the EO of *Cymbopogon citratus* (AFNOR)

- Néral: 25 à 35 % + géranial 35 à 45 % = citrals 60 à 80 %
- Géraniol (monoterpène) : 1 à 8 %
- Myrcene : 5.5 to 23.2 %

3.2 The Methods of Extractions

The distillation of these plants was done in the workshop ARTICOM in Itaosy. Figure 7 shows the assembly of the distillation unit.

Figure 7. *Photo of the Installed Alembic*

In this 30l tank, water was introduced, then the leaves and stems of the plants were distilled. Once the system was heated, the water vapors loaded with oils slowly passed through the swan neck and then entered the condenser. These condensed vapors were collected in the essencier and formed two phases of which the upper low-density phase contained the EO. And so, the distillates are reinjected into the tank using a funnel.

This distillation protocol was applied to all samples of the three plant genera.

3.3 Determination of the yield in EO

The yield of essential oil for these three plants was calculated from the following formula:

$$Y = 100 \frac{MA}{MB}$$

With:

Y: yield in EO
MA: EO mass
MB -: mass of leaves and stems to be distilled

3.4 Method of Analysis of the EO

The separation and identification of all the constituents in the oil of the leaves of *Cinnamomum camphora* and *Corymbia citriodora* leaves and stems of *Cymbopogon citratus* were carried out by Gas Chromatography (GC-14A SHIMADZU) in the Laboratory of Pesticide Control in the Directorate of Plant Protection (DPV), Division of Phytopharmacy.

The column used was a non-polar silica capillary column (BP 20) whose stationary phase properties are: length 30m, diameter 0.32 mm and thickness 0.25µm. The detector (FID) of temperature set at 260°C and the injector at a temperature of 240°C were used. The carrier gas used was nitrogen U with a flow rate of 3ml/min. The volume of the sample injected was 1 µl diluted hexane.

IV. Results and Discussion

4.1 Results

a. Quantitative Results of the Extraction

Here is a table showing the yields of the extractions. The duration of each operation was about 4 hours.

Before each extraction, a meticulous cleaning had to be done with pure steam for about 2 hours. This step was necessary to avoid any contamination of the condensate.

Table 1. Results of the Extraction

Plant	Collection date	Mass of the plant to be used	Distilled part of the plant	Oil volume-mass	Yield (%)
Cinnamomum camphora	2019/07/25	6 Kg (faded)	Leaves	91ml - 83.63g	1.39
	2019/07/29	7 Kg (fresh)		94ml- 86.39g	1.23
Cymbopogon citratus	2019/07/21	7 Kg (faded)	Stems and leaves	41ml-36,40g	0.52
Corymbia citriodora	2019/07/27	7 kg (faded)	Leaves	136ml - 118.47g	1.69

The leaves of *Cinnamomum camphora* and *Corymbia citriodora* provided a yield of 1.39% and 1.69% respectively, and the leaves and stems of *Cymbopogon citratus* had a yield of 0.52%.

The color of the EO:

- *Cinnamomum camphora*: pale yellow to colorless
- *Corymbia citriodora*: very light yellow
- *Cymbopogon citratus*: yellow brown

b. Chemical Composition of the Essential Oil

Gas chromatography (GC) analysis to detect and identify all components in the EO of these plants gave the results described in the following tables.

c. Results for the first plant *Cinnamomum camphora*

Operating codes*:*

- Capillary column, BP 20 (30m x 0,32mm x 0,25µm)
- Oven : 60°C to 230°C (3°C/mn)
- Detector temperature (FID) : 280°C - Injector temperature: 250°C
- Carrier gas: Nitrogen U - Flow rate: 3ml/mn
- Volume injected: 1µl
- Calculation of the contents proportionally to the respective surfaces of the constituents compared to the total surface of the compounds

Table 2. Results of the Analysis : *Cinnamomum camphora*

Constituents	Analyzed batch (%)	Indicative values (%)
α-pinene	5.51	2.5 to 10
β-pinene	4.08	2.5 to 5
Sabinene	16.93	8.5 to 15.5
β-myrcene	1.36	1.5 to 3.5
1,8-cineole+Limonene	56.58	50 to 72.6
γ-terpinene	0.78	-
Terpinolene	0.49	Trace to 0.6
Linalol	0.18	Trace to 0.5
Camphor	-	-
Geranyl acetate	1.04	0.4 to 1.2
β-caryophylene	0.58	-
Terpinene-4-ol-1	1.47	1 to 4
α-humulene	0.36	0.1 to 3
α-terpineol	7.20	3.5 to 11

(Extract from the analysis report N°1096/19 issued by the Nanisana Pesticide Control Laboratory)

1,8-cineole (56.58%), Sabinene (16.93%) and Terpineol (7.20%) are the major components of the EO. The chromatographic profile of the EO is generally comparable to that of a leafy *Cinnamomum camphora* EO.

d. Results for the second plant *Corymbia citriodora*

Operating codes*:*

- Capillary column, BP 20 (30m x 0,32mm x 0,25µm)
- Oven : 45°C (4,5mn) to 210°C (3°C/mn)
- Detector temperature (FID) : 250°C - Injector temperature: 249°C
- Carrier gas: Nitrogen U - Flow rate: 3ml/mn

- Volume injected: 1µl
- Calculation of the contents proportionally to the respective surfaces of the constituents compared to the total surface of the compounds

Table 3. Results of the analyses : *Corymbia citriodora* (Author)

Constituents	Analyzed batch (%)	AFNOR standard NF T75-247 (1991)
α-pinene	0.93	-
Limonene	0.20	-
Citronellal	69.59	More than 75%
Néo-isopulegol	3.52	Less than 10%
Isopulegol	7.48	
Citronelol	7.47	

(*Extract from the analysis report N°1097/19 issued by the Nanisana Pesticide Control Laboratory)*

The chromatographic profile of the analyzed sample presents a Citronellal content of (69.59%), lower than that of the standard AFNOR NF T75-247 relating to the E.O of *Corymbia citriodora*.

e. Results for the third plant *Cymbopogon citratus*

Operating codes*:*

- Capillary column, BP 20 (30m x 0,32mm x 0,25µm)
- Oven : 60°C to 210°C (3°C/mn)
- Detector temperature (FID) : 260°C - Injector temperature: 240°C
- Carrier gas: Nitrogen U - Flow rate: 3ml/mn
- Volume injected: 1µl
- Integration: percentage of area

Table 4. Results of the analyses : *Cymbopogon citratus*

Constituents	Analyzed batch (%)	Indicative values (*) (%)	AFNOR NF T75 -231 (1974) (%)
Myrcene	7.09	5.5 to 23.2	
Cis-β -ocimene	4.34	0.2 to 1.2	
Trans-β -ocimene	2.17	0.2 to 1.1	
n-Hexanol	1.65	nd to 3.3	
Z-isocitral	2.04	0.4 to 1.8	
E-isocitral	3.22	0.9 to 2.1	
Neral	27.53	27.9 to 32.5	Citral (Neral + Geranial)
Geranial	38.63	26.7 to 43.7	Min : 75%
Geraniol	2.42	1.5 to 5.5	
Geranyl acetate	1.04	0.4 to 1.2	

nd: not determined

(Extract from the analysis report N°1098/19 issued by the Nanisana Pesticide Control Laboratory)

The chromatographic profile of the analyzed sample is globally comparable to that of the E.O. of LEMONGRASS (*Cymbopogon citratus*) usually met. However, it presents a Citral content (Neral+Geranial) of (66.16%), lower than the accepted standard (NF T75-231).

(*) : values already found in the laboratory given as an indication of the customer's use.

4.2 Discussions

a. Comparative Studies of the Essential Oils Obtained

The EOs resulting from the distillation with the help of the made still were compared with those of the bibliographic synthesis on the physical and chemical levels.

Table 5. Distillation Yield (Author)

Plants	Performance of the test (%)	Yield according to AFNOR
Cinnamomum camphora **(faded)**	1.39	0.7 to 1 % and up to 1.5% between December and February
Cinnamomum camphora **(fresh)**	1.23	
Corymbia Citriodora	1.69	1.25 %
Cymbopogon citratus	0.52	0.5 à 0.85 %

According to these results, it is judicious to let the plants to be extracted wither, that is to say, to make them lose their freshness, to let them dehydrate partially so that they wither. It is not a drying process that causes the loss of 50 to 75% of the water content of the fresh plant.

It goes without saying that this water loss implies a mass loss and thus increases the yield. This explains the mass yield of fresh and withered *Cinnamum camphora*: 1.23% and 1.39%. This process of partial drying is done strictly in the shade and in a dry place to avoid the degrading effect of photons on the plant material.

b. Chemical Composition

Analyses by gas chromatography were made to illustrate the difference in the quality of the oils obtained with the designed apparatus compared to those made with other apparatus according to the bibliography.

The main and majority components of the EO of *Cinnamomum camphora*, *Corymbia citriodora* and *Cymbopogon citratus* described in the literature were found.

Table 6. Rate of EO (Author)

EO	Main constituents identified	Total compounds identified	Rate in EO (%)
Cinnamum camphora	α- pinene, β-pinene, Sabinene, β-myrcene, 1.8-cineole, Limonene, γ-terpinene, Terpinolene, Linalol, β-caryophyllene, Terpinene-4-ol-1, α-humulene, α-terpineol	20	99.70
Corymbia citriodora	α- pinene, Limonene, Citronellal, Neo-isopulegol, Isopulegol, Citronellol	13	96.40
Cymbopogon citratus	Myrcene, Cis-β-ocimene, Trans- β-ocimene,	12	90.77

	n-hexanol, Z-isocitral, E-isocitral, Neral, Geranial, Geraniol, Geranyl acetate		

In comparison, a slight difference in the rate of each component is observed. However, the results of the distillation carried out with the prepared alembic are in line with international quality standards.

The chemotypes described in the bibliographic synthesis are found there.

During these tests, it was difficult to verify ideally the factors which intervene in the qualitative and quantitative variation of the EO of these 3 plants.

For the *Cymbopogon citratus*, it had a problem during its extraction, the apparatus stopped for 1h during the distillation because of an electric cut, these are considered here as the first factors of change of the chemical composition in EO and also in yield.

This alembic can therefore be used as a laboratory alembic for hydrodistillation of small quantities of well aromatic plant material, around 10 kg, with a not-too-high yield, not being able to be realized on a Clevenger apparatus.

V. Conclusion

The extraction of essential oil can be carried out according to several methods but the distillation by steam entrainment proves to be more practical and more efficient. Nevertheless, its handling requires great care. This study goes beyond the framework of the existing laboratory; the construction of a mobile alembic was then imposed. The knowledge of fluid mechanics and thermodynamics was applied to establish the dimensioning sizing of the device. The workshop ARTICOM, located in Itaosy Antananarivo, specialized in industrial machinery such as stills, grinders, dryers, etc. has hosted this confection. The electric alembic thus manufactured was tested to measure its capacity to extract EO.

The yields are better compared to those of the AFNOR: 1.69% instead of 1.25% for *Corymbia Citriodora*, 0.52% if 0.5 to 0.85% for *Cymbopogon citratus*, and 1.39% instead of 0.7 to 1% for *Cinnamomum camphora*. At the laboratory scale, the apparatus is functional and can be used under optimal conditions for the extraction of EO from new plants. Madagascar still has many unexplored aromatic plants that deserve to be valorized.

Acknowledgements

This study represents the completion of part of a laborious but rewarding work that would not have been possible without the advice, help, and presence of many people. We would like to thank the BEMIRAY team of the ED GPSIAA and the LCM, LCP and ARTICOM team, for having offered excellent working conditions.

References

Andrianoelina, T. N. (2008). Conception et confection d’un alambic mobile à l’échelon semi-pilote, application à l’extraction des huiles essentielles de quelques plantes. Mémoire de fin d’études pour l’obtention du diplôme d’ingénieur en Génie Chimique, Ecole Supérieure Polytechnique d’Antananarivo.

Bourry, C. et Lebrun, L. (2020). L'aromathérapie et ses alliés naturels - Savoir les associer Collection : Santé/Bien-être ; ISBN 2359811398

Couic-Marinier, F. et Touboul, A. (2017). Le guide Terre Vivante des huiles essentielles. 476 p. ISBN : 9782360985715

Gbenou, J.D., Ahounou, J.F., Akakpo, H. B., Laleye, A., Yayi, E., Gbaguidi, F., Baba-Moussa, L., Darboux, R., Dansou, P., Moudachirou, M., Kotchoni, S. O. (2013). Phytochemical composition of *Cymbopogon citratus* and *Corymbia citriodora*essential oils and their anti-inflammatory and analgesic properties on Wistar rats. Mol Biol Rep.;40(2):1127-1134. doi: 10.1007/s11033-012-2155-1. PMID 23065287

Lee, Y. S., Kim, J., Shin, S. C., Lee, S. G. Park, I. K. (2008). Antifungal activity of Myrtaceae essential oils and their components against three phytopathogenic fungi. Flavour and Fragrance Journal.; 23: 23–28. https://doi.org/10.1002/ffj.1850

Lowry II, P. P., Phillipson, P. B., Andriamahefarivo, L., Schatz, G. E., Rajaonary, F. and Andriambololonera, S. (2018). Flora. Pp. 243–255 in Goodman S. M., Raherilalao M. J. and Wohlhauser S. (eds.), The terrestrial protected areas of Madagascar: Their history, description, and biota. Association Vahatra, Antananarivo.

Melo, M. S., Sena, L.C., Barreto, F. J., Bonjardim, L.R., Almeida, J. R., Lima, J.T., De Sousa, D. P., Quintans-Júnior, L. J. (2010). Antinociceptive effect of citronellal in mice. Pharm Biol.;48(4):411-416. doi :10.3109/13880200903150419, PMID 20645719

MNHN & OFB [Ed]. 2003-2023. Inventaire national du patrimoine naturel (INPN), Site web : https://inpn.mnhn.fr Le 29 janvier 2023

Möllenbeck, S., König, T., Schreier, P., Schwab, W., Rajaonarivony, J., Ranarivelo, L. (1997). Chemical Composition and Analyses of Enantiomers of Essential Oils from Madagascar. https://doi.org/10.1002/(SICI)1099-1026(199703)12:2<63::AID-FFJ614>3.0.CO;2-Z

Morgan, L. (2015). History of Essential Oils. https://healingscents.net/blogs/learn/18685859-history-of-essential-oils

Mulyaningsih, S., Sporer, F., Reichling, J., Wink, M. (2011) Antibacterial activity of essential oils from Eucalyptus and of selected components against multidrug-resistant bacterial pathogens. Pharm Biol.;49(9):893-899. doi: 10.3109/13880209.2011.553625. PMID 21591991

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403: 853-858.

NORME AFNOR, « HUILES ESSENTIELLES », recueil de normes françaises 1992, 4ème édition.

Oussou, K. R., Angaman, D.M., Ackah, J., Koffi, M. and Guessennd, N. (2017). Composition chimique et effets antibactérien des huiles essentielles de trois plantes de Côte d'Ivoire. Int. J. Adv. Res. 5(11), 626-632. doi :10.21474/IJAR01/5811

Rabehaja, D. J. R. (2013). Production et analyse d'huiles essentielles de plantes aromatiques et médicinales de Madagascar. Caractérisation par RMN13C, CPG(Ir) et CPG-SM. Chimie organique. Université Pascal Paoli ; Université d'Antananarivo. Ecole Supérieure Polytechnique d'Antananarivo (ESPA). HAL Id : tel-01086548

Ramezani, H., Singh, H. P., Batish, D. R., Kohli, R. K., Dargan, J. S. (2002). Fungicidal effect of volatile oils from *Corymbia citriodora*and its major constituent citronellal. New Zealand Plant Protection, 55 :327-330. ISSN 1175-9003

Randriamiharisoa P.R. (1995) Manuel rapide et utile pour producteurs d'huiles essentielles. Pour le compte de ABT/Associates, Conseiller Principal du Projet MAELP-USAID

Randriamiharisoa, P. R. (1996). La Filière Huiles Essentielles, une opportunité pour l'avenir. Acte. Séminaire sur les Plantes Aromatiques et Médicinales à Madagascar au CITE du 17 au 22 Juin 1996 organisé par CIRAD.

Randrianjohany, E. (1996). La Diversité des plantes aromatiques de Madagascar. Acte. Séminaire sur les Plantes Aromatiques et Médicinales à Madagascar au CITE du 17 au 22 Juin 1996 organisé par CIRAD.

Sahouo, G. B., Tonzibo, Z. F., Boti B., Chopard, C., Mahy, J. P. & N'guessan, Y. T. (2003). Anti-inflammatory and analgesic activities: Chemical constituents of essential oils of Ocimum gratissimum, *Corymbia citriodora*and *Cymbopogon giganteus* inhibited lipoxygenase L-1 and cyclooxygenase of PGHS. Bulletin of the Chemical Society of Ethiopia. Vol.17 No 2. doi: 10.4314/bcse.v17i2.61681.

Silva, J., Abebe, W., Sousa, S. M., Duarte, V. G., Machado, M. I. L. and Matos, F. J. A. (2003). Analgesic and anti-inflammatory effects of essential oils of Eucalyptus. Journal of Ethnopharmacology, Volume 89, Issues 2-3 : 277-283. doi :10.1016/j.jep.2003.09.007