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Review Article

Emerging extraction processes of essential oils: A review

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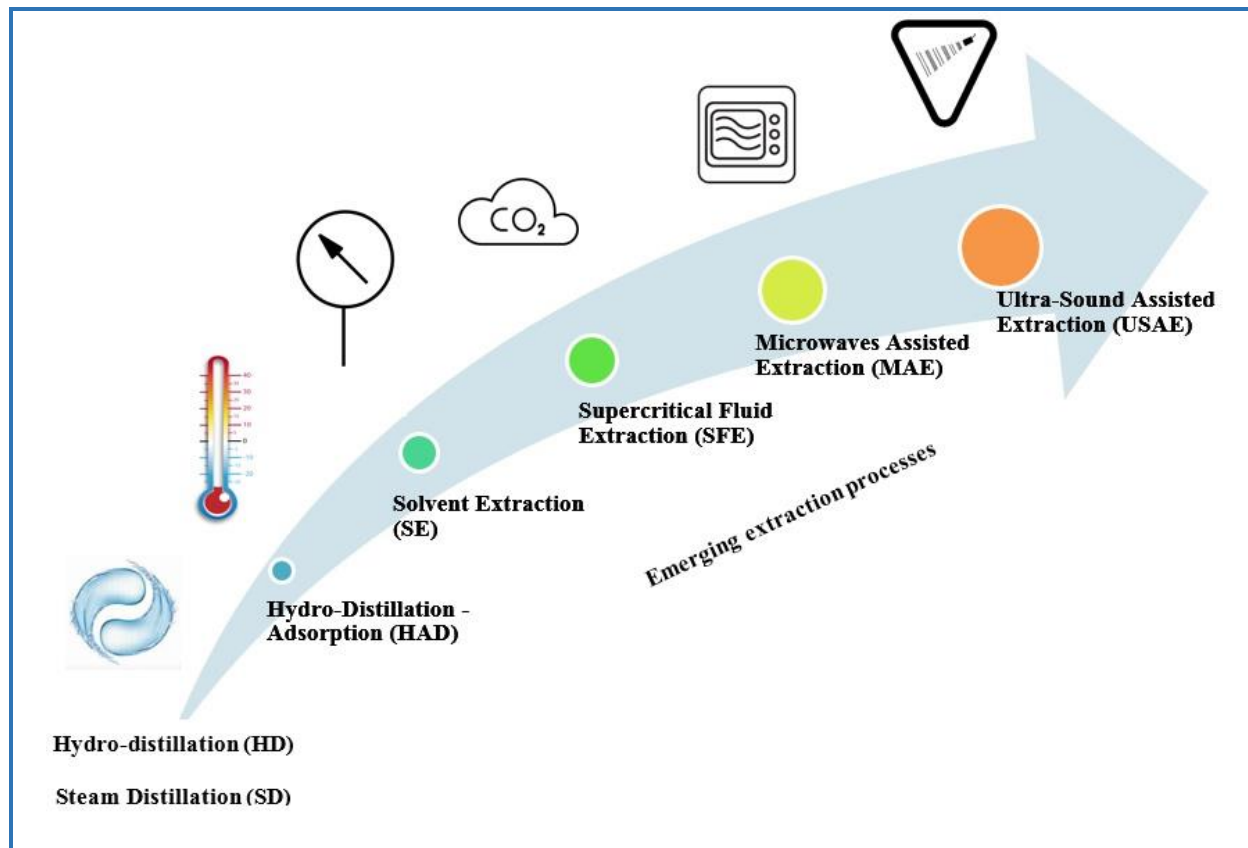
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Essential oil
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ABSTRACT

The aim of this work is to study the extraction of the essential oil as a process that appeared to obtain the bioactive substances among the several extraction processes. A great number of extraction processes are available. In this study, the recent processes were compared with the conventional ones. Also, the economic evaluation of the extraction process plant including energy cost, manual labor, raw materials, and fixed costs were studied. We assessed the costs involved in the extraction process of the bioactive compounds. Carbon dioxide is the most desirable solvent for Supercritical Fluid Extraction (SFE). Its attraction for the extraction of the heat-sensitive compounds is due to its critical temperature (304 °K). Solvent extraction and steam distillation process (SE-SD) may overcome many disadvantages that conventional solvent extraction and hydrodistillation bring about in the extraction of essential oil. This combination technology has been used in the extraction of essential oil from plant material for high quality, simple technology, and low cost. The microwave assisted hydro-distillation (MAHD) is less tedious and minimizes the risk of the compound degradation at high temperatures. The MAHD presents distinct advantages for the fast and reproducible production process. The study of the ultrasound-enhanced subcritical water extraction process (USWE) showed many advantages such as: time-saving, environment-friendliness, and high efficiency.

Graphical Abstract



Biographies



Dr. Jamel Mejri currently works at the Higher School of Engineers of Medjez el Bab (ESIM), University of Jendouba and Preparatory Institute for Scientific and Technical Studies, La Marsa (IPEST), University of Carthage. Jamel does research in Food Engineering, Food Science and Food Processing, Animal and Human Nutrition.



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Introduction

The Egyptians and Asian countries such as China and India have used essential oils and spices for several centuries. Some spices like cloves, cinnamon, mustard, garlic, ginger, and mint were applied as alternative medicine in India. Essential oils have been extracted for 3000 years in Egypt for their importance in various fields. The production of the essential oils dates back to more than 2000 years in the Far East, with early modern technologies taking place in Saudi Arabia in the 9th century [1]. However, during this period, the medical application of essential oils became secondary as they were essentially used as flavors. Extraction methods are not developed because all parts of the aromatic plants and herbs are used.

Over time, several extraction processes emerged. These processes have been developed to optimize the performance of the essential oil in both quantitative and qualitative terms. Alongside the development of the extraction processes, characterization methods and analysis have also experienced a significant progress that has allowed the determination of the chemical composition and physical properties of the various extracts. We can even identify the molecules responsible for each property.

Conventional methods of extraction (Hydro-distillation or steam distillation) have a number of drawbacks. These involve the internal diffusion process that limits the operation. Indeed, the actual structure of the plant cell walls inhibits the transfer of the fluids to the outside. For steam distillation and hydro-distillation, high temperatures can cause chemical changes in the compounds of the essential oils and losses of the volatile compounds [2]. The obtained solvent extract contains a trace amount of solvent. Some volatile compounds can be lost during distillation of solvent. Thus, the choice of an extraction process depends on the desired objectives, such as cost, energy, compositions, and bioactive molecules.

All the extraction processes are designed to provide more concentrated product form of the desired material. Although the cost should never compromise the quality, it can be a decisive factor. However, the effectiveness of the extraction and the safety of the process is a priority and, as the limits of solvent residues are increasingly subject to the review, the extracts obtained using supercritical fluids could play a central role to replace toxic solvents. One of the most important aspects of any extraction is probably an intimate substrate; it can be a key element in defining the quality of the extract in order to have a desired product which meets the requirements of consumers.

However, extraction with supercritical fluids allows the extraction of the high quality products which are solvents-free [3]. But, technological conditions for the use of the supercritical fluids are

expensive, which limits their use [4, 5]. Beside the essential oils, the supercritical CO₂ extracts contains various compounds [6, 7].

Essential oils

Essential oils are the complex mixture of several bioactive chemical components, such as terpenes, terpenoids, and phenylpropenes. They can be produced by more than 17,000 aromatic plant species commonly belonging to angiospermic families, such as Lamiaceae, Zingiberaceae, and Asteraceae [8].

Essential oils, also known as "essences" are volatile and odorous substances found in plants and are extracted by steam distillation, or by co-distillation with solvents [9]. They are concentrated and complex substances which have the form of oily drops present in one or more organs of the aromatic plant: in flowers (Jasmine), leaves (Sage), fruits (Orange), seeds (Fennel), bark (Cinnamon) and in roots (Angelica).

Aromatic plant and their essential oils have been used since antiquity as condiments, spices, antimicrobial, insecticidal and agents to protect stored products [10]. Natural additives from plants can be compounds, groups of compounds or essential oils. Essential oils have an antiseptic activity. They exhibit antibacterial, antiviral, antifungal, antioxidant, antiparasitic, and insecticidal effects. They have been shown to exert many biological activities, such as antimicrobial, analgesic, sedative, anti-inflammatory and spasmolytic [11].

The essential oil is a natural secretion of a plant. It is produced by secretory organs that are located in different parts of aromatic plants and trees: seed, root, wood, leaf, flower and fruit. Only an essential oil obtained by distillation of a plant, botanically defined, in an alembic through steam under low pressure corresponds to the french association for standardization (AFNOR standard) [12]. The product, which is obtained by mechanical pressure on citrus essence, is called non-essential oil.

Essential oils are aromatic and volatile liquids, mixtures of organic compounds extracted from plant materials and characterized by a strong and generally pleasant flavor. The essential oils have been widely used as safe flavoring agents or preservatives in foods, in cosmetic or pharmaceutical products [13]. Essence is a natural substance secreted by the aromatic plant. For citrus, essences are extracted by expression of the zest, also known as lemon oil and lemon essential oil note. At its transformation by distillation, gas undergoes biochemical modifications and becomes essential oil. The essential oil is the essence of the distilled plant. It is made up of volatile molecules and a pure essential oil contains no natural fats. Essential oils are used in foods, medicines and cosmetics [14].

Essential oils extraction

Steam distillation (SD)

The apparatus contained a steam generator flask, a distilling flask, a condenser and a receiving vessel, which was used to perform the steam distillation. In this process, the plant material is not in direct contact with the heat source to avoid damaging the essential oil. Vapor, produced in a steam generator flask (Boiler), passed through the essential oil rich plant material. Then, the solute was dragged after it was condensed by contact with a cold fluid. This condensation causes the detachment of oily molecules from water vapor particles. Due to the difference of density between oil and water, two phases are obtained: an organic phase and an aqueous phase [1, 15–20].

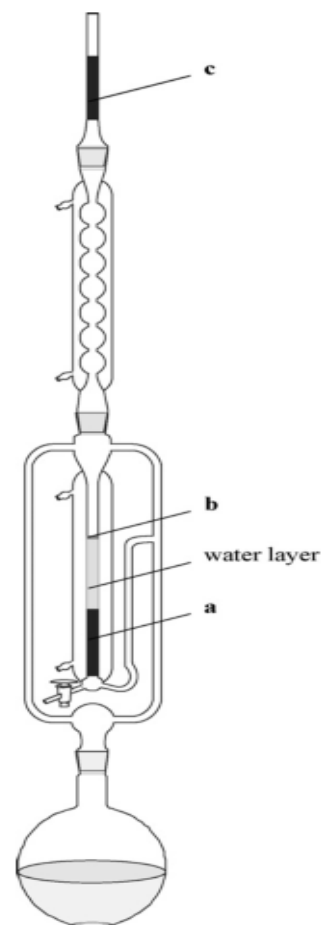
Hydro-distillation adsorption (HAD)

A clevenger apparatus (Figure 1) is used for the HDA process [21]. Coal granules, which have a diameter between 0.3 and 0.5 mm, are activated in a muffle furnace at a temperature of 800 °C for 2 h in a reducing atmosphere. After cooling to room temperature, the carbon is placed in water and deaerated under pressure for 10 min. The activated carbon is placed in the separator (Inside the tube) for the adsorption of water-soluble compounds and in a small column (Activated carbon) located above the condenser for adsorption of highly volatile compounds in the gas phase.

The height of the water layer above the carbon column is 5 cm. The plant material and water are introduced into a flask. The distillate is passed through the layer of water: The compounds, which are not soluble in water, are collected in the water layer (Figure 1b), while the water-soluble compounds are adsorbed in the coal column (Figure 1a). Most of the volatile compounds from the gas phase are adsorbed in the coal column at top of the condenser (Figure 1c).

After steam distillation and adsorption (Which last 3 h), the layer compounds which are not soluble in water (Figure 1b) are dissolved in pentane and separated from the water layer. This operation is repeated twice and the extracts are mixed with pentane (Fraction d). After the removal of water through a conduit at the bottom of the installation, the extraction of adsorbed compounds is performed in the same apparatus using 50 mL of di-ethyl ether for 8 hours. The ether obtained extract is concentrated by distillation to a small volume (Fraction a). Highly volatile compounds are extracted from the top of the column (Figure 1c) (with ether and the obtained extract is concentrated) (Fraction c). All extracts are dried up with anhydrous MgSO₄.

Figure 1. Apparatus for hydrodistillation-adsorption (HDA): a) column of activated carbon for the adsorption of water-soluble components, b) fraction of water non soluble compounds, c) column of activated carbon for the adsorption of high volatile compounds



Solvent extraction

Solvent extraction is also named solid-liquid extraction. It is a transfer of matter which intends to separate the soluble to a solid substrate by their diffusion in a solvent [22]. This method is used for essential oil (EO) that cannot be removed by distillation as the heat alters perfumes. The solvents are then removed by evaporation or rectification. The quality and composition of the extracts depend on the nature of solvents and in particular on their polarity [23]. This process is the most commonly used in the cosmetic industry [1].

Supercritical fluid extraction (SFE)

A supercritical solvent is a solvent which is an intermediate state between liquid and vapor. Several products have been studied for their use as supercritical fluids [23]. However, some were eliminated for technical reasons (The water is removed to its critical temperature: too high), and others for economic reasons (Xenon for its high price). Carbon dioxide (CO₂) is the most suitable in the food industry.

The process uses supercritical carbon dioxide (SCO₂), which under certain conditions of pressure and temperature, behaves as a solvent. This technique allows working at a moderate temperature (31 °C), which does not alter the organoleptic quality of the obtained extracts [24]. At the end of the extraction by pressure reduction (Relaxation), CO₂ passage in the supercritical state to the gaseous state is induced. Thus, CO₂ is removed alone from the extract under atmospheric pressure.

Generally, supercritical CO₂ cannot solubilize polar compounds and low molecular weights. Due to its low critical temperature (T_c = 31 °C), CO₂ is leading industrial supercritical fluids: It facilitates to develop the processes for low temperature sensitive products. Its density at 31.1 °C and 73.8 bars is about 0.47 g/cm³.

The process is described as follows: The plant material is introduced into the extractor, which is filled in a symmetrical manner with inert material and porous (Glass balls, sponge nickel and a glass frit). The porous members are used to prevent the accumulation of plant material in the extractor. After reaching the working temperature of the extractor and separator, the pump begins to provide the desired flow rate and the valves attach to the desired pressure.

CO₂ liquid supplied from CO₂ cylinder (T) with siphon tube is cooled in the cryostat (C) between the cylinder outlet and the pump (P) to prevent CO₂ evaporation. The CO₂ is pumped into the system by liquid metering pump until the required pressure is obtained (Figure 2).

Extraction by CO₂ at 60 bars and 60 °C gives a product comparable to essential oil, but the disadvantages of hydro-distillation are the risk of hydrolysis and thermal reactions [23]. At 300 bars, an extract is obtained near an oleoresin, but without losing the highly volatile compounds in the solvent and with the advantage that the traces of solvent do not affect the product. At 100 bars, the extract is intermediate between the two. The extraction of essential oils can be done by supercritical CO₂ [24–37].

Trabelsi and colleagues [25] have studied the influence of pressure; static time and CO₂ flow rate on the extraction process from *C. aurantium* peel under supercritical CO₂ with ethanol as co-solvent. Results show a significant quadratic effect of both pressure and CO₂ flow rate on extraction yield at $\alpha < 5\%$. The static time did not have a significant effect. The adjusted polynomial model has a maximum (Y = 1.07) reached at P = 170 bar; static time = 53 min and $Q_{CO_2} = 2.87 \text{ kg h}^{-1}$.

According to Glisic and colleagues [28], the most important parameters in the extraction by supercritical CO₂ is that the amount of extract obtained is relative to the amount of CO₂ consumed (kg extract/kgCO₂) and the amount of CO₂ consumed is relative to the amount of plant material processed (kgCO₂/kg plant material).

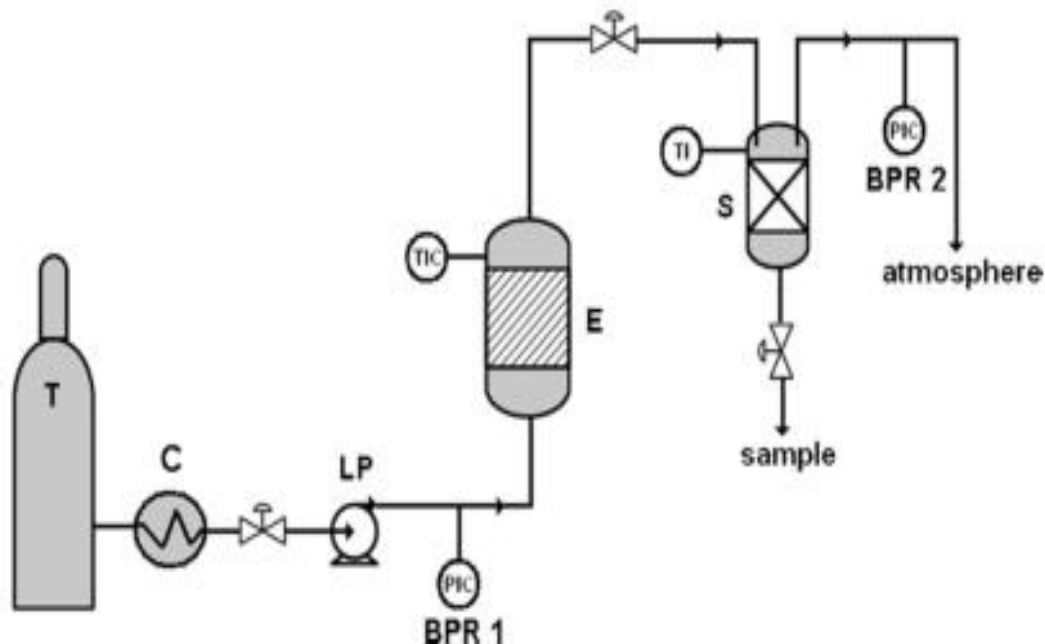


Figure 2. Schematic presentation of the autoclave engineers screening system: T (CO₂ storage tank), C (Cryostat), P (High pressure liquid pump), E (Extractor vessel), S (Separator vessel)

Instantaneous controlled pressure drop process (DIC)

The extraction process by instantaneous controlled pressure drop (*Détente instantanée contrôlée*) was developed by the *Rezzoug* and colleagues [38] for the purpose of drying and texturing various food products to improve their hydration capacity.

In the case of food products such as vegetables, the goal out of this technique is to improve the evaporation of water while preserving the flavor and texture of the “dried honeycomb”. The extraction of essential oil based on this method was used to extract essences from orange zest [39]. This process helps to eliminate any thermal degradation of the compounds of the extract [40]. This increases the overall product diffusivity and improves the transfer of liquid in the plant.

The DIC process was used to study the performance of rosemary leaves essential oil while optimizing the operating parameters of extraction [2]. The method comprises subjecting the rosemary leaves, for a short period of time, to the action of steam at a pressure ranging from 50 to 550 kilo pascal (KPa) (or 0.5 to 5.5 bar) and instantly applying a pressure relief to 50 KPa (0.5 bar).

Firstly, the rosemary leaves are moistened and placed in the DIC reactor at a pressure of 50 KPa (0.5 bar). The pressure provides a better distribution of the heating fluid through the plant and therefore improves heat transfer. Thereafter, it creates steam under pressure in the DIC reactor. The heat treatment is followed by a rapid decompression; it is the fast controlled pressure.

Extraction continues by stripping with steam. In this procedure, we obtain two different phases: The organic phase (Essential oil) and an aqueous phase containing a portion of the essential oil. The hexane is used to separate the organic phase from the aqueous one.

Microwaves assisted extraction (MAE)

The extraction process using microwaves is not an extraction process itself. However, it is coupled or combined with other conventional techniques with the aim of improving and optimizing the extraction process. The microwave heating is widely used in solvent extraction for its many advantages such as speed and efficiency.

The microwave-assisted extraction is an alternative to conventional processes [41–50]. The most important benefits are a reduction in the extraction time and the solvent used. In this method, during the extraction of essential oils of plants, there is no contact with the heat source: which includes other advantages. This gives a number of other benefits: efficient heating, a rapid heat transfer, reduced thermal gradients, selective heating, equipment size reduced, a faster response to the control of the heating process, a quick start, a higher production and disposal of the process steps.

For the purpose of energy conservation, waste water and solvent, the progress of microwave assisted extraction has led to a large number of techniques (Figure 3 and Figure 4) such as: Microwave-assisted ionic liquids treatment followed by hydro-distillation (MILT-MHD), microwave-assisted solvent extraction (MASE), compressed air microwave distillation (CAMD), vacuum microwave hydro-distillation (VMHD), solvent-free microwave extraction (SFME) microwave-accelerated steam distillation (MASD) and microwave hydrodiffusion and gravity (MHG).

It is known that water in the liquid state only, absorbs microwave steam but ice do not absorb it microwave because their gaseous molecules are separated from each other and their solid state molecules are not free to move and rotate the heat. However, the extraction is carried out in the plant material that is continuously heated by microwaves causing a high local temperature and an increase in extraction rate [43]. Several tests were performed: Microwave-assisted extraction (MAE) is an alternative to conventional techniques for various types of samples [44]. The solvent-free microwave extraction (SFME), a combination of microwave heating and dry distillation, is a new process that was developed in recent years [44]. The conventional solvent-free microwave extraction (CSFME) operates under atmospheric conditions without addition of solvent, or water. It is a new idea to

Figure 3. Microwave-accelerated steam distillation (MASD)

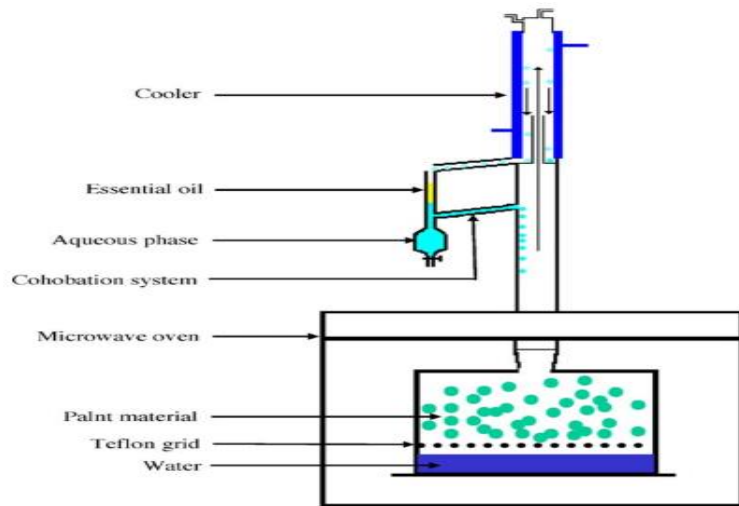
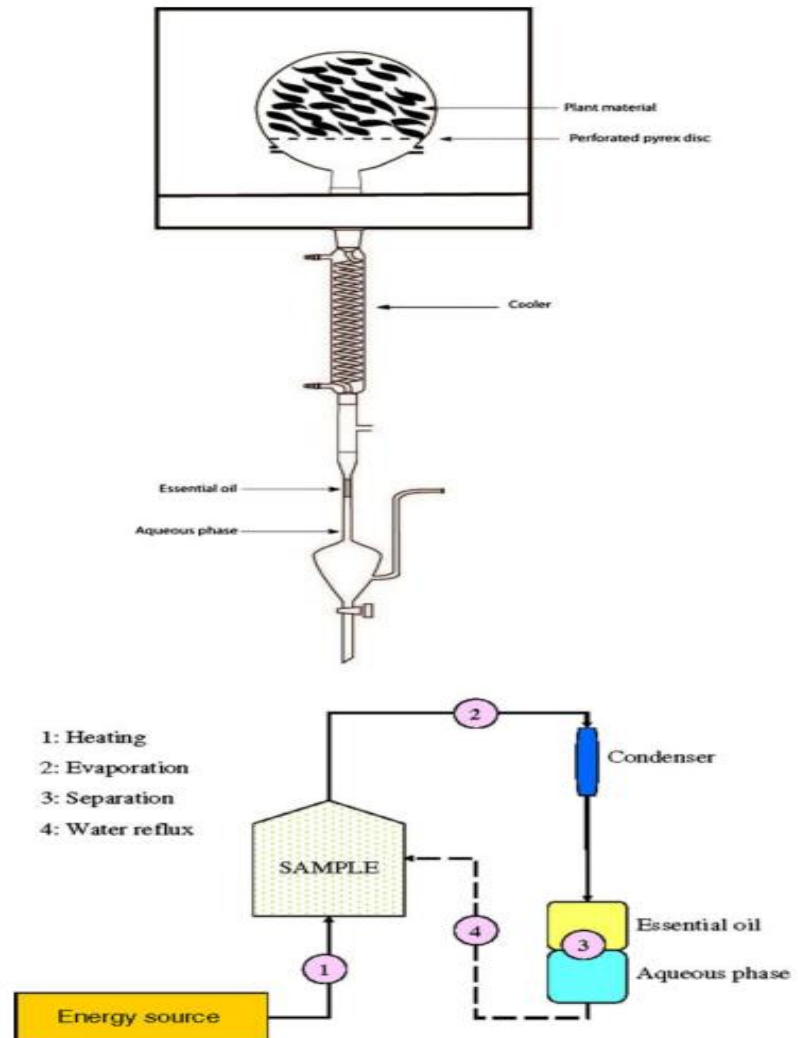


Figure 4. Microwave hydrodiffusion and gravity (MHG)



extract the volatile compounds from the fresh plant material. This technique has been applied in the extraction of essential oil from herbs and spices [45]. It is possible to obtain a selective aroma composition by MAE as a function of the extraction time [51].

Wang et al. [44] improved the CSFME method for the ISFME. The improved solvent-free microwave extraction (ISFME) was compared to CSFME, to microwave assisted hydro-distillation (MAHD), and to hydro-distillation (HD) for the extraction of essential oils (Figure 5 and Figure 6).

Ultra-sound assisted extraction (USAE)

Conventional processes for isolating valuable compounds were dropped because of their low yields and the formation of unwanted by-products due to thermal degradation and hydrolysis as well as the presence of organic solvents which are often toxic. These declines have led us to seek alternative extraction techniques. The supercritical fluid extraction (SFE), particularly with CO₂, has several advantages such as the ability to work at a relatively low temperature in addition to its chemical inertness (Non-toxic). This allows us to announce that the SFE process is an excellent choice for the extraction of compounds from aromatic plants, although CO₂ requires an important purity to avoid contamination of the extracts. The CO₂ also has exclusive affinity with no polar compounds in addition to the relatively high cost. The microwave assisted extraction (MAE) and super-heated liquid extraction (SLE) are recent alternatives. Their returns are better than those of conventional processes.

The ultra-sound assisted extraction (USAE) is a more recent approach that can anticipate declines in conventional techniques and avoid their drawbacks such as the degradation of thermo-labile and volatile compounds. USAE technique is more efficient and faster than conventional techniques. It does not consume much solvent. The main advantages of the technique over other USAE such as MAE, SFE and SLE are: The reduced costs due to the simplicity of the equipment required with similar or better yields. The main drawback of the USAE technique is the potential formation of free radicals during sonolysis of the solvent which can degrade some sensitive compounds by oxidation.

Extraction with ultrasound is an implementation using an extractor consisting of a cylindrical separator chamber in stainless steel. The peristaltic pump is programmed to change the direction of rotation to avoid compacting the plant material and to increase the pressure in the system. The ultrasonic irradiation is applied by means of a digital sonifier equipped with a cylindrical probe immersed in the water basin where the extraction chamber is located, as seen in Figure 7.

The plant material is introduced into the extraction chamber that is connected with the dynamical system and filled with a solvent propelled by the peristaltic pump in the extraction

chamber (Immersed in the water bath at 25 °C). The solvent flows through the plant material (Solid) for 10 min under ultrasonic irradiation. During the extraction, solvent direction changes every 120 s to minimize compaction of plant material, which can cause pressure in the system.

The extraction assisted by ultrasound is widely used to improve the batch transfer between the immiscible phases through good agitation at low frequency [52]. Usually the increase in the use of ultrasound technology is due to the effect of ultrasonic waves on the plant material. These waves have the role of plant cells rupture and release their contents into the extraction medium. It is well known that the ultrasound device disrupts the cells but there is no information about its effect on plant tissues. The passage of soluble constituents from plant material to solvent is performed by diffusion or osmosis [53]. According to *Zhong and Wang* [54], the most important effect of the ultrasound treatment is the destruction of gummy material binding the fibers to facilitate the evacuation of essential oil.

The beneficial effects of ultrasound are essentially the intensification of mass transfer that improves the penetration of the solvent into the plant tissue and the capillary [55]. All these effects facilitate access of the solvent in the cells of the plant. The collapse of cavitation bubbles near the cell walls may cause disruption of the cells accompanied by a good penetration of the solvent inside the latter through the ultrasonic jet. Indeed, there is a clear effect of ultrasonic waves on the plant material. The yield depends on the solvent used and it increases with the polarity of the latter. The plant material contains hydrophilic and hydrophobic compounds, but the content of water-soluble compounds is the most important [53].

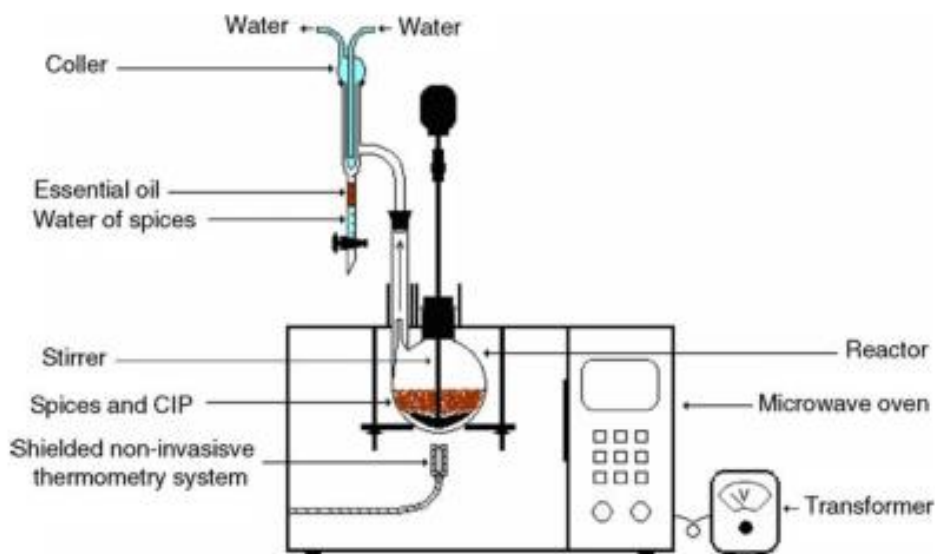


Figure 5. Improved solvent-free microwave extraction (ISFME)

Figure 6. Microwave assisted hydro-distillation (MAHD)

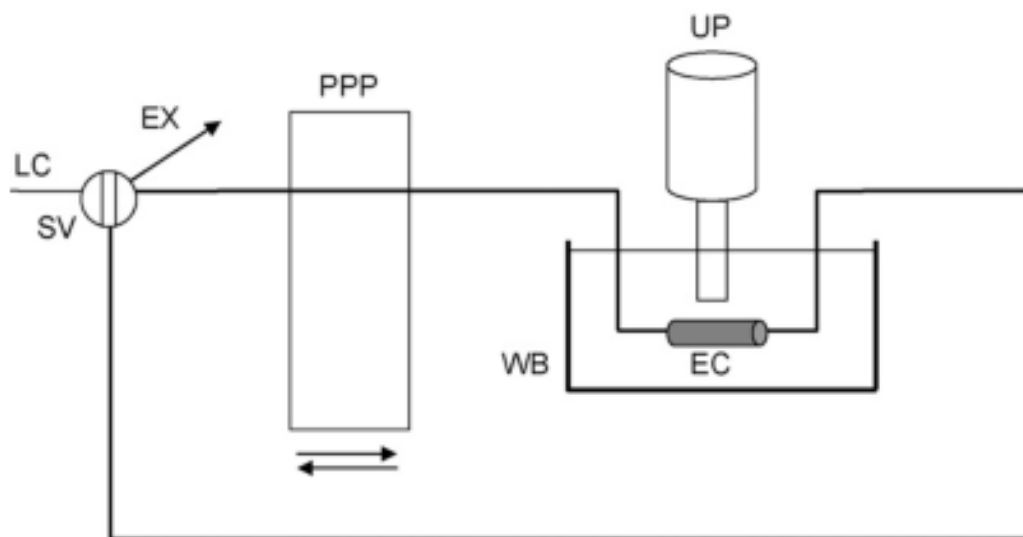
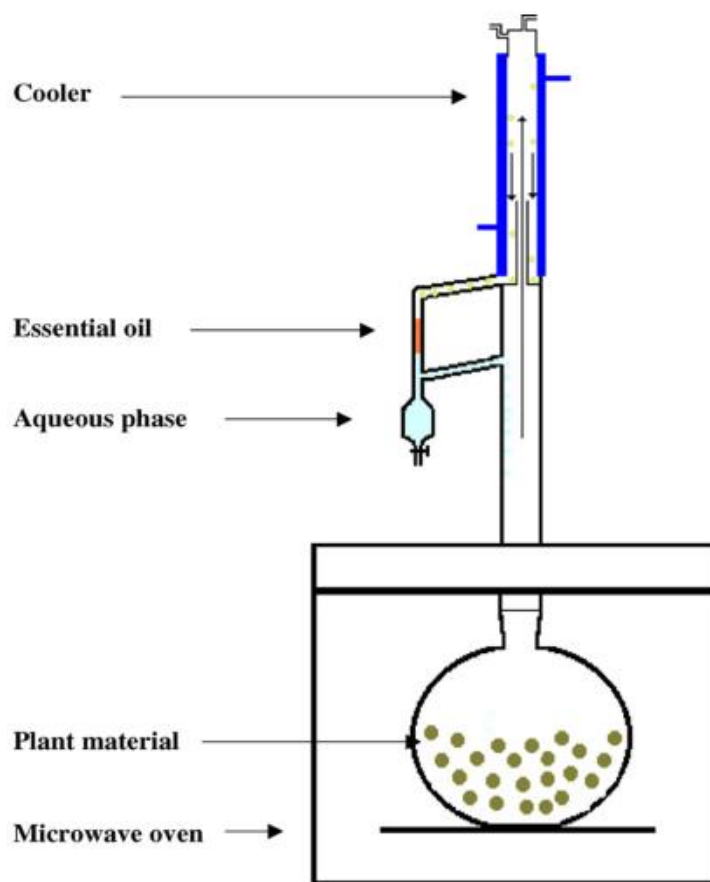


Figure 7. Experimental set-up for the dynamic ultrasound-assisted extraction of essential oils from aromatic plants and flowers. LC (Leaching carrier), EX (Extract), SV (Switching valve), PPP (programmable peristaltic pump), UP (Ultrasonic probe), EC (Extraction chamber), WB (thermostatic water bath)

Comparison of extraction processes performance

Many methods of extraction are available, starting with the oldest (Hydro-distillation) to the recent (Extraction with supercritical CO₂). If we compare the composition of aromatic plant extracts obtained by supercritical fluid extraction (SFE) to that of extracts obtained by steam distillation (SD), no major differences are generally observed. This is the case, for example, of coriander for which the main components of the extracts obtained are linalool (76% and 68%) and, γ -terpinene (5% and 7%) respectively by SFE and SD. The camphor was 3% in both cases [56].

Nevertheless, one of the main differences between oils obtained by SFE and SD is the presence of low percentages of waxes in the extracts obtained by SFE. The presence of small quantities of these compounds in the oils did not appear to affect their quality, since the natural flavor has been maintained. The SFE allows, moreover, through appropriate conditions of temperature and pressure, to extract aromatic oils selectively. Thus, the waxes may be obtained separately and find potential applications in the cosmetic or pharmaceutical industry. Another major difference is based on the relative amount of some biologically active compounds such as thymoquinone, which is present in thyme and lavender oils. In the case of thyme, thymoquinone content of SFE extract may be 15 times higher than in the volatile oil. This oxygenated monoterpene has significant biological activities such as anti-cancer properties, antioxidant, and neuroprotective acting against cerebral Alzheimer's disease [57].

If we compare the two methods of extractions, economically, there are several published works that specifically address the calculation of the cost of extraction with supercritical CO₂. We will assess the costs involved in the extraction process of bioactive compounds of interest. Assessing the costs involves the price of equipment investment, operating and management costs, the purchase of raw materials and their transformations. To conduct a technical study of economic science approaches will be realized. The optimization of the economic evaluation was proposed by *Rosa and Meireles* [58] to determine the manufacturing cost (COM) of extraction using a supercritical fluid. This study was based on a methodology developed by Turton and colleagues [59], which considers the cost of manufacturing based on what he calls, direct costs (Which depend directly on the production and quantities) and indirect, as fixed costs (Equipment, taxes and insurance) as well as the overall costs (Which are part of the administrative costs of different sectors, such as sales, research and development). *Pereira and Meireles* [60] conducted an economic analysis of the essential oil of rosemary, fennel and anise obtained by supercritical fluid extraction (SFE). For this evaluation the extraction was carried out at 300 bars and 40 °C (The yield was 5%).

The economic evaluation of supercritical fluid extraction process plant, were considered along various costs in industrial production, from the initial investment to the cost of utilities (Energy cost) manual labor, raw materials and fixed costs. Usually in industrial unit, it is necessary to take into account the costs of waste treatment, but in extraction of natural compounds, the waste will be regarded as a co-product. In several published works that address the economic aspect, we find that the cost of a Kg of an extracted essential oil is less expensive than a kg got through hydro-distillation simple extraction. The most determining factor for the extraction cost by supercritical fluid extraction processes is the cost of the raw materials. The plant capacity improves significantly the cost of production.

For more effective comparison, advantages and disadvantages of the different distillation processes are detailed as such: Carbon dioxide is generally the most desirable solvent for supercritical fluid extraction (SFE). The critical temperature of carbon dioxide is only 304 °K, which makes it attractive for the extraction of heat-sensitive compounds. In addition, it is an inert, non-flammable, non-explosive, inexpensive, odorless, colorless, clean solvent that leaves no solvent residue in the product, it is also non-toxic and is generally accepted a harmless ingredient in pharmaceuticals and food. In addition, carbon dioxide has a low surface tension and viscosity and high diffusivity which make it attractive as a supercritical solvent. The diffusivity of supercritical carbon dioxide is one to two orders of magnitude higher than for other fluids, which permits rapid mass transfer, resulting in a larger extraction rate than that obtained by conventional liquid extraction [15].

The conventional method (Steam distillation) used for the isolation of essential oils has several disadvantages. High temperatures and water can cause chemical modifications of essential oils. The steam distillation usually results in the loss of the volatile components and some water-soluble constituents. However, these disadvantages can be avoided by using a combination of organic solvent extraction and steam distillation (SE-SD). The SE-SD method may overcome many disadvantages that conventional solvent extraction and hydrodistillation bring about in the extraction of essential oil, such as high remnant solvent and thermal degradation. This combination technology was used in the extraction of essential oil from plant material for high quality, simple technology and low cost [17].

Microwave steam distillation (MSD), microwave hydrodiffusion and gravity (MHG), microwave steam diffusion (MSDf) and solvent-free microwave extraction (SFME) are the advances in microwave extraction. The advantages of microwave extraction process of essential oil are due to their reduced equipment size, ease-of-use, speed, ability to control a process via mild increments in heating and low solvent consumption, all of which contribute to reducing environmental impact

and costs [18]. Results identified the MHG as being the optimal extraction technique. Indeed, it gave the maximum yield (5.4%) in only 15 min (120 min for SD) and consumed 1.3 kWh (Against 8.06 kWh for SD). The MAHD is more selective than conventional hydrodistillation. Furthermore, the MAHD is less tedious and minimizes the risk of compound degradation due to heat. The MAHD also presents some advantages over conventional hydrodistillation such as in the extraction rate. Therefore, microwave is not involved in any deterioration of the extracted components and it can be introduced as a safe method for the extraction of essential oils [19]. The MAHD presents distinct advantages for the fast and reproducible production process of essential oil whilst significantly reducing the energy and solvent consumption related to conventional production methods [20].

Other studies are ongoing and require validation and scale-up such as ohmic-assisted hydrodistillation (OAHD) and ultrasound-enhanced subcritical water extraction (USWE). The OAHD is a new process proposed for the extraction of essential oils in which ohmic heating technology is combined with distillation which was studied by *Gavahian* and colleagues [61]. The results of this study showed that higher applied voltage can speed up OAHD and confirmed this emerging technology as a green technology. OAHD was presented as an “environmentally and friendly” extraction method suitable for essential oil extraction. However, there is a use of electrical energy that comes from fossil fuel. The extraction conditions of essential oil using ultrasound-enhanced subcritical water extraction (USWE) were studied and optimized. The results shows that USWE presents many advantages such as: Time-saving, environment-friendliness and high efficiency compared to conventional extraction methods [61].

Conclusion

The various essential oil extraction processes were reviewed. The conventional methods were compared with the improved process. These improvements focus on optimizing yields of essential oil as well as the operating parameters of the processes. The results showed the benefits of the new processes over the older one in terms of the environmental preservation and energy consumption. However, the costs of the new technologies are still high and are therefore not available to all manufacturers. Toxicological studies should be conducted to determine the effect of the obtained essential oils on human health. Further, biological activities of the obtained extracts must be validated in vivo system.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Abbreviations

<i>SD</i>	<i>Steam distillation</i>
<i>HAD</i>	<i>Hydro-distillation adsorption</i>
<i>SFE</i>	<i>Supercritical fluid extraction</i>
<i>DIC</i>	<i>Instantaneous controlled pressure drop process</i>
<i>MASE</i>	<i>Microwave-assisted solvent extraction</i>
<i>SCO₂</i>	<i>Supercritical carbon dioxide</i>
<i>MAE</i>	<i>Microwaves assisted extraction</i>
<i>MASD</i>	<i>Microwave-accelerated steam distillation</i>
<i>CO₂</i>	<i>Carbon dioxide</i>
<i>MILT-MHD</i>	<i>Hydro-distillation</i>
<i>CAMD</i>	<i>Compressed air microwave distillation</i>
<i>SFEM</i>	<i>Solvent-free microwave extraction</i>
<i>MHG</i>	<i>Microwave hydrodiffusion and gravity</i>
<i>VMHD</i>	<i>Vacuum microwave hydro-distillation</i>
<i>CSFME</i>	<i>Conventional solvent-free microwave extraction</i>
<i>ISFME</i>	<i>Improved solvent-free microwave extraction</i>
<i>MAHD</i>	<i>Microwave assisted hydro-distillation</i>
<i>HD</i>	<i>Hydro-distillation</i>
<i>USAE</i>	<i>Ultra-sound assisted extraction</i>
<i>%</i>	<i>Percentage</i>
<i>USWE</i>	<i>Ultrasound-enhanced subcritical water extraction</i>
<i>SLE</i>	<i>Super-heated liquid extraction</i>
<i>SE-SD</i>	<i>Solvent extraction and steam distillation</i>
<i>MSD</i>	<i>Microwave steam distillation</i>
<i>MSDF</i>	<i>Microwave steam diffusion</i>
<i>OAHD</i>	<i>Ohmic-assisted hydro-distillation</i>

AFNOR	Association française de normalisation
cm	Centimetre
mm	Millimetre
°C	Centigrade
mL	Milliliter
Anhydrous MgSO ₄	Anhydrous magnesium sulphate
EO	Essential oil
T _c	Critical temperature
g/cm ³	Gram per cubic centimetre
α	This is a significant difference of 5%, which means we have a 5% chance of being wrong
Y	Yield of extrcation
P	Pressure
Q _{CO₂}	Flow rate of CO ₂
kg h ⁻¹	Kilogram per hour conversion chart
Kilo Pascal	KPa
kWh	kilowatt hour
s	Second
Kg	kilogram

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