Commercial Extraction of Cannabis – Process Intensification through the Application of Microwaves

Marilena Radoiu [1,2]

[1] Radient Technologies Inc., Edmonton, Canada; [2] Microwave Technologies Consulting, Lyon, France
Contact Email: mradoiu@radientinc.com, mradoiu@microwavetechs.com

This article is a summary of a full paper recently published on this study [1]

1 Introduction

Cannabis is a genus of flowering plants belonging to the cannabaceae family with three main species: *Cannabis sativa* L, *Cannabis indica* L, and *Cannabis ruderalis* L, Figure 1 [2].

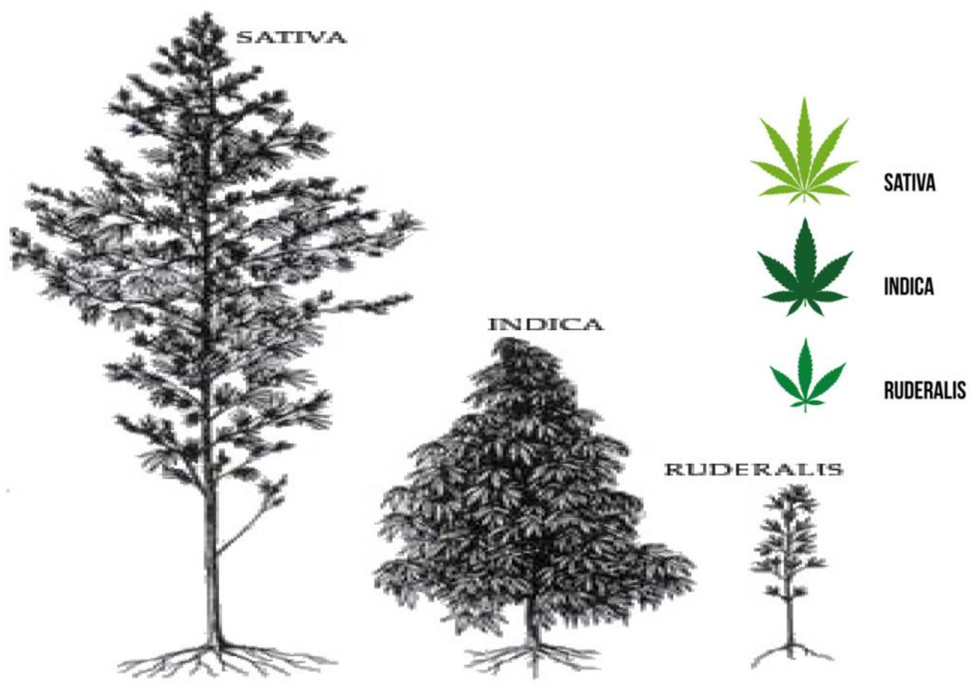

Figure 1: Cannabis plants [2].

Cannabis has a long history of being used for medicinal, therapeutic, and recreational purposes. Cannabis is known, for example, to be capable of relieving nausea (such as that accompanying chemotherapy), pain, vomiting, spasticity in multiple sclerosis, and of increasing appetite. The importance of cannabis in therapeutics is emphasized by the ever-increasing number of research publications related to the use of cannabis and its derived products to treat various indications [3-6].

Cannabis contains more than 500 different compounds, which include terpenes, flavonoids, lipids, sterols, chlorophyll, fatty acids, salts, sugars, and a unique class of terpeno-phenolic compounds known as cannabinoids or phytocannabinoids. More than 100 cannabinoids have been identified in different cannabis plant strains. Examples include Δ9-tetrahydrocannabinolic acid (THCA), cannabinoldiolic acid (CBDA), cannabinolic acid (CBNA), cannabigerolic acid (CBGA) and cannabichromenic acid (CBCA). In fresh plant material all cannabinoids are present in their acidic form. The acidic cannabinoids can be converted into their decarboxylated (neutral) analogues (CBD, THC) under the influence of light, heat, or prolonged storage, by losing the relatively unstable carboxylic group in the form of carbon dioxide. THC and CBD are the most widely studied cannabinoids and have been associated with the therapeutic and medicinal properties of the cannabis plant and its associated products and also with its popularity as a recreational drug. THC is mainly recognized for its psychotropic effects when consumed, but lately has also been found to effectively treat pain, muscle spasticity, glaucoma, insomnia, lack of appetite, nausea, and anxiety while CBD is used to treat migraines, inflammation, seizures, irritable bowel syndrome (IBS), depression, insomnia, and anxiety [3,4]. CBD is non-psychoactive and is the major cannabinoid constituent in hemp cannabis.

The terms hemp and marijuana are classifications of cannabis adopted into culture even though they do not represent legitimate nomenclature for cannabis. Hemp and marijuana are both cannabis; hemp, however, refers to cultivars of cannabis that contain very low concentrations of psychoactive THC (typically less than 0.3% by dry weight). Hemp (sativa) is an industrially grown plant that is cultivated outdoors, better suited for warm climates with a long season. It is mainly used to produce textiles from the fibre, and foods and supplements such as protein and essential fatty acids from the seeds. Hemp seed oil is rich in unsaturated omega-3 and omega-6 fatty acids and is almost entirely devoid of cannabinoids. Marijuana, on the other hand, is often deliberately bred and cultivated in controlled environments in order to optimize the cultivar's characteristics, including the composition of cannabinoids such as THC and CBD. Controlled growing and cultivation is designed to produce female plants that yield budding flowers rich in cannabinoid content. Harvesting of industrial hemp has traditionally avoided collection of flowers to minimize cannabinoid content of industrial products. This practice is however changing as the production of CBD from farmed hemp becomes legalized in more and more jurisdictions world-wide.

North America is experiencing a boom for cannabis-derived products (i.e. packaged foods, edibles and beverages, beauty and personal care, consumer health, pet care, home and garden), made possible by the legalization of recreational cannabis in Canada in 2018 and in 11 U.S. states, two U.S. territories, and the District of Columbia. The global market for cannabis-derived products was ~ 5 trillion USD in 2018 and is expected to grow 1,200% by 2023 [5].

To this end, there are various conventional biomass extraction methods available for the extraction of cannabis. Given the inherent commercial value of CBD and THC, the applied method to extract them is very important in terms of accomplishing the quantity and quality of the product. Moreover, economics of the processes is a very important parameter in its commercialization.

2 General considerations of Cannabis extraction

In general, the most appropriate methodology to obtain an extract from raw biomass must be selected according to the characteristics of the desired product. There are several important factors to consider when choosing an extraction method for cannabis, the most important being as follows:

- Extraction efficiency, the percentage of bioactive compounds recovered through the entire extraction process;
- Extract quality and consistency, including the purity or "potency" of cannabinoids in the extract and also the relative amounts or "profile" of other potentially synergistic compounds such as terpenes;
- Throughput capacity and scalability, assessment of the extraction method and its efficient implementation at commercial scales vs. market demand;
- Environmental control, e.g., carbon footprint and safety, i.e. minimize risks to the consumers and worker safety.

In many cases, additional processing steps, both upstream and downstream of the extraction itself, are required to obtain the final cannabis extract product. The incorporation of these steps with the extraction method and their impact on the overall process efficiency and product quality must also be considered. Some common processing steps discussed further below include:

- Decarboxylation, the process of converting non-active native acidic cannabinoids into their active, neutral forms via a thermal reaction;
- Winterization, the process of removing plant lipids and unwanted waxes by a secondary solvent, freezing and filtration;

- Decolorization, the process of removing chlorophyll and unwanted pigments;
- Secondary purification, the process of further purifying the extract to increase the potency or alter the composition of cannabinoids and other components, via various methods including distillation, chromatography, or crystallization.

There are generally three typical extraction methods currently being used for commercial cannabis extraction, albeit at only modest scale:

- Supercritical CO_2 (SC-CO_2) extraction
- Pressurized gas (hydrocarbon) extraction
- Conventional organic solvent extraction

These are discussed in more detail below.

In addition to these "big three", there are several non-conventional, alternative extraction methods that are being assessed at laboratory scale, including for example ultrasound-assisted extraction, hydrodynamic extraction, pulsed-electric field extraction. Given that none of these has yet been demonstrated at any reasonable commercial scale, they are not further discussed.

2.1 Supercritical CO_2 (SC-CO_2) extraction

Supercritical fluids are a well-documented alternative to traditional organic solvents suitable for various extractions. Any material in its critical state when it is both heated above its critical temperature (T_c) and pressurized above its critical pressure (P_c) and hence there are no distinct liquid and gas phases. The specificity of this technique relies on solvent's physicochemical properties, which can be 'tuned' by an increase of pressure and/or temperature beyond its critical values [6].

Supercritical CO_2 extraction is a common technique for cannabis extraction-separation, which uses supercritical CO_2 (74 bar, 31°C) in a batch process. Although non-toxic and non-flammable, SC-CO_2 requires very high pressures to be employed. In addition, the method is somehow inefficient and, therefore, not conducive to high throughputs, as well as environmentally damaging (e.g., producing large amounts of the greenhouse gas carbon dioxide as a by-product). The resulting extracts are, however, considered to be solvent-free. The decarboxylation must be carried out on the cannabis biomass upstream the extraction process (acidic cannabinoids are poorly soluble in SC-CO_2). This potentially increases overall costs (decarboxylation must be performed in advance on what may be large quantities of cannabis biomass) and leads to the loss of some light volatile terpenes. SC-CO_2 also co-extracts heavy fats and waxes which must be subsequently removed in downstream processing steps (winterization), leading to further cannabinoid losses and reduction in overall efficiency or recovery of available cannabinoids. Finally, the scale up of SC-CO_2 is only possible by addition of multiple machines.

2.2 Pressurized gas (hydrocarbon) extraction

Hydrocarbon extraction is the most popular technique that uses liquified gases such as n-propane and n-butane pressurized into liquids (2-10bar) as solvents for extraction of cannabinoids. An advantage of the method is the possibility of these gases to remain in liquid phase at low pressure and the possibility to remove them from the system at the end of the extraction by gentle heating leading to an extract with low traces of residual solvent. Hydrocarbons such as n-butane and n-propane are good solvents for the low-polarity cannabinoids [6]. In this method, butane or propane is pressurized to a liquid state for extraction and then either depressurized or heated for removal from the obtained extracts. This extraction process is carried out in batch and creates what are known as cannabis "concentrates", e.g., shatter, a viscous material with very high concentration of THC and other cannabis compounds like terpenes, which is popular for recreational users. Decarboxylation can be carried out upstream or downstream of the extraction. Although effective, the process is undesirable for medicinal and consumer products, due to the risk of solvent contamination. Safety is also a major concern given the high flammability/explosivity of the hydrocarbon solvents employed. In principle, the scale-up is only possible by the addition of multiple machines.

2.3 Conventional organic solvent extraction

The most traditional and perhaps the simplest method for extracting active compounds from cannabis involves maceration in organic solvents such as ethanol, ether, chloroform, and methanol. When organic solvents are used for the extraction, the obtained product consists of various compounds, including some undesired substances that dissolve together with the cannabinoids. Also, high boiling or extraction temperatures often lead to the degradation of heat sensitive compounds. This extraction method is operated in either batch or continuous flow and can use decarboxylated biomass or decarboxylation can be performed on the extracted product. The main drawbacks of the method are linked to the high input ratios of biomass-solvent and implicitly to the high quantities of solvent to be separated from the extract and recycled and also to the co-extracted molecules, such as fats, waxes, and pigments, which means more complex downstream processing (separation, purification, etc.)

3 Microwave-Assisted Extraction of Cannabis (MAE) in continuous flow, MAP™

Microwave-Assisted Extraction (MAE) is different from the methods presented above because the extraction occurs as a result of the volumetric heating as opposed to transferring heat from the surface inwards, making the process more efficient and more uniform due to the ability to precisely control temperature and contact time. The very nature of heating through the involvement of the raw material under processing (instead of using fossil fuels or less efficient, indirect electrical heating systems) brings about quality consistency as well as positive environmental impacts.

The carefull design and optimization of all MAE parameters (e.g., solvent type, residence time, extraction temperature, microwave power density) and of the reactor (e.g., microwave frequency, number of microwave inputs along the reactor, precise measurement and control of forward and reflected power) can lead to lesser solvent requirement as compared to conventional methods and the biomass can be exhausted with one extraction only.

The basics of MAP™ [1] continuous flow extraction of cannabis consists of coupling MAE and continuous flow technology and as such creating a very promising way to produce high value-added extracts since unlike batch processing, the continuous flow has been demonstrated to facilitate process intensification and contributes to a safe, efficient and sustainable production. By employing continuous-flow MAP™, it is possible to control extraction time and temperature very precisely, both of which can greatly influence extraction efficiency and the composition of the extract.

A schematic of one process involved in the extraction of the cannabis biomass and decarboxylation of the extracted products is presented in Figure 2. In this method, the raw milled cannabis biomass is mixed with a solvent (e.g., ethanol, IPA, pentane, PEG400) selected based on its dielectric properties vs. type of biomass and its concentration of cannabinoids. The obtained slurry is pumped in the continuous flow microwave-assisted extraction reactor and progressively heated to the desired extraction temperature by using 915 MHz microwaves – Figure 3; the microwave power can be automatically ‘tuned’ to the process conditions as to reach power densities between 0.1 and 10kW/kg of biomass. Downstream the extractor, the spent biomass and the extract are separated from the slurry. The extract is treated to obtain a final product containing the target compounds in sufficiently high yield and high purity. The spent biomass may be processed to yield less than 0.3% concentration of THC naturally produced by plants and disposed of once this condition has been achieved [1].

The extractor/reactor consists of a food grade stainless steel tube within which a mechanical stirrer is placed. Microwaves are provided from a 75kW (max. power), 915MHz microwave generator consisting of a low ripple switch mode power supply, a magnetron head, a circulator and water cooled load with reflected power meter. The microwave generator can be operated from 10kW up to 75kW in continuous wave (CW) mode or controlled pulse. Due to the possibility of working with flammable solvents, the microwave generator is installed in a different, non-ATEX (directives for explosive atmospheres) room. The microwave transmission line, standard WR975 rectangular waveguide, passes the wall between the ATEX and non-ATEX environments through a separation window and then it splits into two inlets delivering equal microwave

[1] MAP™ is a patented microwave-assisted processing by Radient Technologies Inc. (www.radientinc.com), which has been successfully operating a continuous-flow microwave extractor in Canada for over five years at throughputs over 200kg/h of biomass input

power all along the reactor. Within the reactor, the separation between the reaction mixture and the microwave transmission line is done via microwave transparent windows.

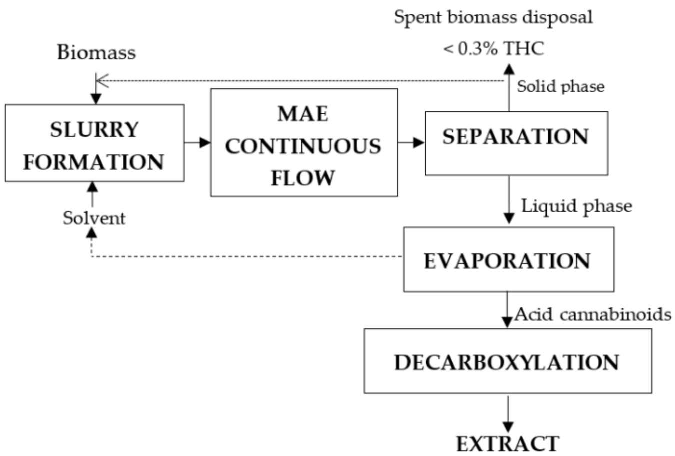

Figure 2: Schematic of the microwave-assisted cannabis extraction and acidic cannabinoids decarboxylation.

Due to the continuous measuring and controlling of the reflected power and the automatic impedance tuner installed immediately after the circulator (in the non-ATEX zone), the microwave forward power is automatically adjusted as to maximize the absorbed energy by the extraction mixture and to minimize energy losses by reflected power. Microwave components located within the ATEX zone are continuously purged with nitrogen; arc detectors are installed within all microwaves components as such as the microwaves are shut down if arcing detected. Wall mounted microwave leakage detectors can shut down the microwaves if leakage levels > 2.3mW/cm^2 are detected around the reactor. As described in Figures 2 and 3, the main advantages of MAP™ related to cannabis biomass are:

- Continuous-flow method at atmospheric pressure which allows for much higher volumes of cannabis biomass to be processed in much less time than existing extraction methods;
- Higher rates of consistency and quality because the process does not require stopping and restarting material flows;
- Scale-up to industrial scale without the need to purchase an endless supply of new machinery and without the use of pressurized batch vessels;
- Eliminates additional steps required in most extraction methods, such as winterization;
- Ability to achieve high extraction efficiency at industrial scale. Typical recovery of active compounds via MAP™ is up to 95%.From a process intensification view, the continuous flow extraction and its heating via microwaves comes with several additional benefits, including significantly increased flexibility and safety with respect to operation:
- The contact time between the biomass and solvent before, during and after microwave treatment can be adjusted much more easily;
- It is fully ATEX or "Hazardous zone" classified, meaning it can be used with any flammable liquid and be completely safe.
- It is possible to precisely control biomass residence time in the microwave zone and - if desired - separate the biomass from the solvent very quickly after treatment, or continue contact for any length of time at any temperature, depending on the desired outcome;
- The use of multiple microwave field deposition points through the use of a split waveguide and a "ridge wave deposition" allowing for non-uniform dispersal of the wave from the inlet to the outlet to account for changing dielectric properties as the material is treated;
- It has an automatic impedance matching unit that allows for constant, automatic adjustment of the field strength and microwave energy absorption maximization;
- It has a built-in mechanical agitator with variable speed control to randomize movement of biomass thus making the field uniform for the materials at all times;
- It is fully automated (operators simply input desired MW parameters on an HMI and it runs itself while connected to the plant PLC systems).

The extractor is also easily scalable. The continuous flow approach eliminates the requirement for having geometric similarity between scales, i.e. the equipment shape and dimensions do not have to scale proportionately. Classically, even geometric similarity does not ensure thermal similarity in scaled systems; for example, heat transfer is an interface-controlled process and so the surface area relative to the volume is critical. As the volumetric scale increases, the area relative to the volume decreases and the overall efficiency of heat transfer can decline considerably. There is no thermal inertia with microwaves, on the other hand. Since penetration depth is not an issue with the continuous flow design, the energy is deposited uniformly throughout the mixture resulting in rapid energy transfer and direct dielectric heating – hence the thermal inertia inherent to classical methods is not an issue.

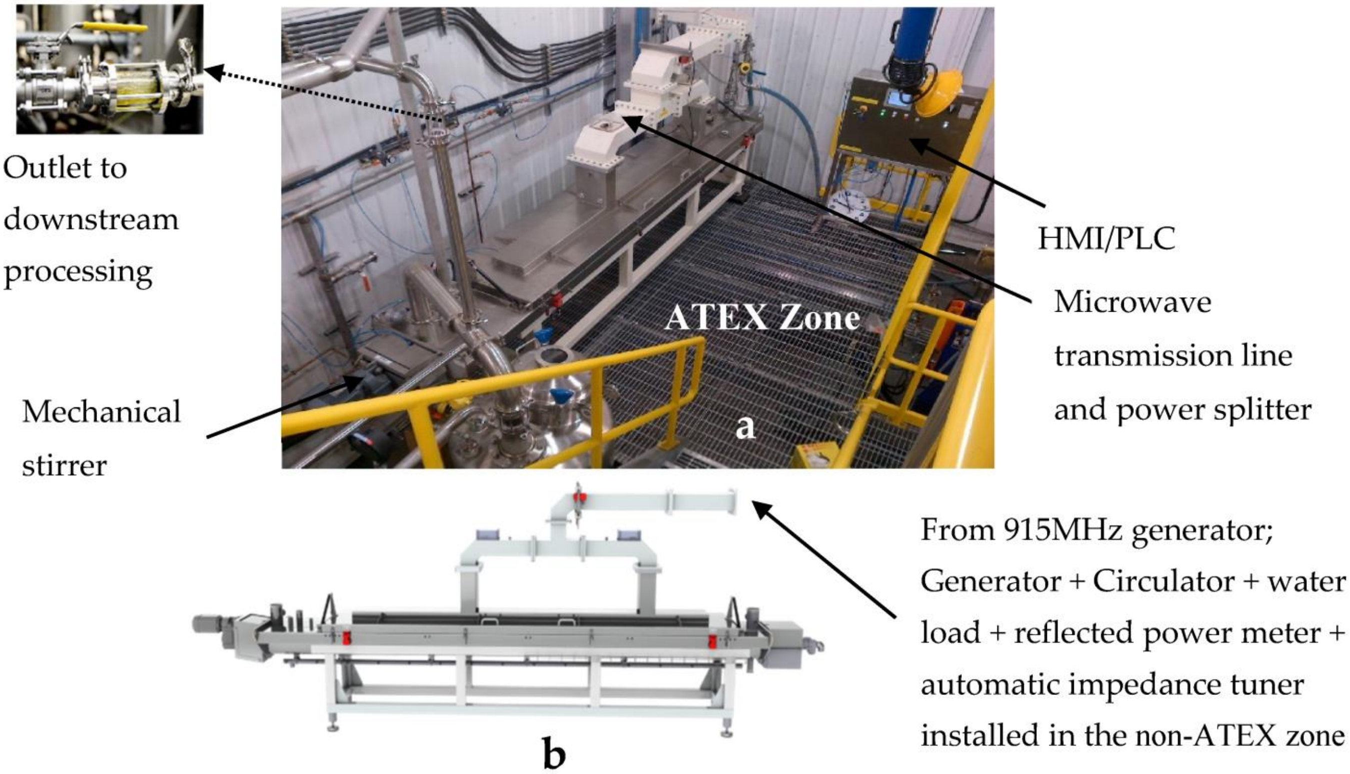

Figure 3: Photo and schematics of the continuous flow microwave extractor in ATEX environment. a) Photo of the continuous flow reactor located in the ATEX production zone; b) schematics of the continuous flow reactor showing the connection with the 915MHz generator installed in a non-ATEX zone

4 Conclusions

While there are various solvent methods for extracting the active compounds out of biomass, e.g., supercritical fluid extraction (SFE), Soxhlet, percolation, agitated tank, countercurrent, when considering cannabis extraction, none of these is optimal in all aspects. Molecules extracted through these processes may differ in the quality (physiochemical properties) and quantity hence altering the chemical composition of the extract; in addition, many of these methods have limitations when it comes to scaling up to suit mass production. In addition, as a result of increased legislation, concerns about the environment and competition within the globalized market, it has become paramount to look for and implement innovative, clean and sustainable ways to obtain natural extracts, i.e. green extraction of natural products. Green extraction refers to looking for, designing and implementing extraction processes that lead to (i) a reduction in energy consumption, (ii) utilization of alternative solvents to obtain products that are natural and renewable, and (iii) extracts that are safe and of high quality.

Microwave continuous flow extraction is a good example of a such technique. In the MAP™ reactor, the process is run in a continuously flowing stream, enabling very tight process control and improved mass heat and mass transfer, consequently achieving higher extraction control and higher product quality. Furthermore, continuous extractors can be easily scaled up by placing multiple cavities in series or in parallel, thereby shortening development time for full-scale production.

For further reading:

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About the author

Dr. Marilena Radoiu is the founder of Microwave Technologies Consulting, France and since January 2018 she has been also acting as the Managing Director of Microwave Innovation at Radient Technologies Inc., Canada. She has more than 15-year experience in the development of microwave-assisted technologies applied to chemical synthesis, biomass extraction, plasma, food etc. Her work has included engineering and development of novel industrial and scientific standard and custom-tailored equipment and processes.

Dr. Radoiu is a Chartered Scientist and fellow member of several professional associations, including the Royal Society of Chemistry and the Association for Microwave Power, Education and Research in Europe (AMPERE).

For more details: www.linkedin.com/in/marilenaradoiu