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REVIEW ARTICLE

Microwave-assisted processes and their applications

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ABSTRACT

Microwave-assisted extraction (MAE) has become a popular way to get rid of toxins in the environment and then study them later. They have benefits like short extraction times, low costs, and the ability to be automated or linked to other analytical processes in real-time. MAE systems have recently added new features or made technological improvements to improve extraction efficiency and make sure that they are used in a greener way. When microwaves are used, there is a lot of heating at the atomic level. As a result, the thing that is being heated gets very hot. When microwaves are used, electromagnetic energy is turned into heat inside the material, which warms it up. The heat moves outward from the center of the material. Changes can be made to both the physical treatment and the way to extract. This can give you bigger yields and a different way to extract the good stuff than if you just macerate. Process optimization often focuses on the overall yield of the whole process. It can be used to add components you want to an extract or to keep out compounds you don't want, like contaminants. It can also be used to figure out what the best-operating conditions are. The main focus of the current review is on international advancements in microwave processing and how they can be used in industry.

KEY WORDS: Environmental application, Extraction efficiency, Factor affecting microwave, Microwave, Optimum operating condition

INTRODUCTION

With today's technology, plants can be extracted from their primary and secondary metabolites using a variety of non-traditional processing methods such as solid-liquid extraction or maceration techniques (which are more commonly used), but the main drawbacks are the high energy consumption and lengthy processing times required. In the face of growing technology and a competitive engineering environment, industries have long demanded microwave-assisted extraction (MAE), enzyme-assisted extraction, high-voltage electrical discharges, pulsed electric fields, ultrasound-assisted extraction, high-pressure processing, pulsed ohmic heating, and supercritical fluid extraction.[1] These methods have been used for a long time because of new technology and a competitive engineering environment method that can be used on a wider range of materials and can make better physical and mechanical qualities than traditional methods. This is because of the physical, mechanical, metallurgical, chemical, and other properties that MAE/radiations can improve the materials. It also saves time, and energy and is better for the environment because of the different intensification mechanisms that can be used.[2] This is why When you use conventional and microwave processing, you get different kinds of heat from the materials. When you use traditional processing methods, you start by heating the outside. Then, you move the heat into the materials by conduction or radiation, and other methods like these, too.[3] A lot of heating happens at

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the atomic level when microwaves are used. This causes a lot of heating in the object that is being heated. When microwaves are used, electromagnetic energy is turned into heat inside the material, which makes it warm.[4] Out of the material's core, the heat moves away from it toward the outside. When this physical treatment is done, it can also change the extraction process, which could lead to higher yields and different extraction selectivity than if you just macerate. It can be used to enrich an extract with target compounds or to avoid unwanted compounds such as pollutants, it can be used to figure out which operating parameters are best, process optimization is often based on the total yield of the whole process.[5]

PRINCIPLE

Submerging material that has been chosen to be extracted in an extraction solution that can dissolve the desired compounds while still being safe for the microwave oven to use is how the process works. As soon as the food is in the water, microwaves are used to heat it.[6,7] There is a lot of material in three dimensions because microwaves can see through the liquid that is used to get it. When it comes to how well a substance can take in microwave radiation, how much moisture it has is a good rule of thumb. Because there are a lot of water molecules in the material, a lot of heat is built up inside of it.[8,9] When the pressure inside the matrix is too high, there is an intermolecular blast. Chemical systems can then move the substances they hold around freely, which means that they can move them around freely.[10,11] Extraction of the solid material can be done by filtration and the resultant solution can be handled like any other extract obtained by classic extraction procedures.[12]

MECHANISM

First, in the microwave region, dipole polarization is the most critical event. They require far more energy than microwave frequencies can supply. People should focus on orientation polarization because it is the most critical factor to consider. Microwave frequencies do not heat the dielectrics since they do not affect them. As soon as you apply microwaves to something, its magnetic and electric properties rapidly change (~2.4×10^9/s at a frequency of 2.45 GHz). When molecules are unable to move swiftly enough when the direction of travel changes, there is friction. This causes the molecules to itch by heating them.[13,14]

Second, microwave heating can also be done with the ionic conduction method. People who use microwaves can move things around in a solution because of the charge they have on their bodies. When two ions come together, they make thermal energy. This energy turns kinetic energy into heat. In a solution, the more ions there are, the faster it gets hot. This is how well it can take in microwave radiation and makes heat. When food is standing, its dielectric loss determines how well it can do this. By dissipation factor (δ) equation, it helps you figure out how much energy a substance can take in it, expressed as follow: -

$$\tan \delta = \varepsilon'' / \varepsilon'$$

Where ε′ denotes Polarization is the ability of molecules to change their shape in the presence of an applied electric field, ε″ denotes the dielectric loss factor that measures the effectiveness of converting microwave irradiation into heat. Meanwhile, this is how thermal energy is created when electricity is converted:

$$P = K.f\ \varepsilon'\ E^2 \tan \delta$$

Where there is a term called the dielectric loss tangent that stands for tan δ, f denotes the frequency employed, ε′ denotes the dielectric constant, and an electric field's strength is called E, People use a lot of microwave power, so P is how much power is used per unit volume and K is a known constant.[14]

HISTORICAL PERSPECTIVE

People in Canada who work for Environment Canada microwave-assisted processes (MAP) use microwaves to speed up physical, chemical, and biological processes. This helps make the world a better place by making less waste, using less solvent, and using less energy, which makes the world a better place to live in. Soluble chemicals are easy to get rid of with an applicator that can be used in a microwave. You can do this with many different types of materials. It's called a MAP because there are many different ways to use them. A lot of them. This one is one of them. Because of new extraction methods, chemicals that would normally need different extraction methods can now be selectively extracted in a fraction of the time it would take to do so with typical extraction methods, which is why new extraction methods are better. If the material hasn't been dried, processed, or otherwise made into something else first, this method can be used to get it, which isn't true for other methods. When you use this technology, you can make progress that is better for the environment because it uses less energy and makes less waste in many cases, which saves money and energy.[15]

FACTORS AFFECTING MICROWAVE

As MAE is made, many things can affect how well it works and how much it makes. Things that might make MAE less effective are the solvent type and concentration, the solvent-feed ratio, the time it takes for the solvent to be extracted, the microwave power, and how the sample moves. These things could make the process less effective.

To understand how these things work together and how they affect the MAE, you should learn about them.

Effect on solvent system and solvent to feed ratio

It is crucial to consider the solvent when using a microwave for extraction. MAE extraction solvents must be able to penetrate, interact, and have a low dielectric constant to be good at extracting MAE. Microwave radiation that is insoluble can be taken up by a solvent that has a higher dielectric constant and loss. This could cause the solvent to heat up at a faster rate than the plant material needs. When several solvents are mixed, the properties of the solvent can change, which can make the solvent more or less effective for different types of molecules. This can be done by using a solvent combination that has reduced dielectric properties while extracting thermolabile compounds. This will allow solutes to cool down once they are released into the solvent. In this case, the plant matrix is preferentially targeted by microwave energy, resulting in an efficient release of plant components into the cooler solvent. A sample's extraction efficiency is determined by how well the analytes dissolve in the sample's extraction fluid.[16]

Effect of microwave power level

Samples that have dielectric materials in them get heated up when microwaves hit them. This gives them the energy they need. They, as well as interactions and equilibrium rates, all depend on this factor. The microwave power can kill compounds that cannot stand the heat, so be careful when you use it. This could lead to a low amount of extract being made, which could be bad. In general, as microwave power rises, extraction yield rises with it until it stops or does not rise at all, then it does not rise at all. In one study when Alfaro and his team looked at what happened to MAE when microwave power was used, they came up with the term "energy density." This term was used to look at what happened to MAE when the microwave power was used. In this case, they reveal that it is how much energy is used per mass for a certain amount of time. Microwave radiation may break down the plant matrix and make the active chemicals come out. There are a lot of experts who think this will happen. It does not work better if the power level goes up. To give you an example: The yield of flavonoid extraction from Radix Astragali increased. when the microwave power was increased from 200 W to 1000 W. Using too much microwave power can make products break down or break apart, and this can happen if the microwave power is too high. This could cut down on the amount of material that can be taken out. There were a lot fewer flavonoid yields even though the power went up.

Effect of temperature

A better solubility means it is possible to get a lot more out of high-temperature extractions. There is a way to get more out of a microwave by increasing the power. More molecules interact with each other inside the solvent, which makes it easier for them to move around and become solubilized.[17] This can cause the cell-matrix to be broken open and more components to be pushed out into the solution as cell pressure rises with temperature. This can happen because the cell temperature rises. Because solvents are easier to move and be dissolved at high temperatures, the efficiency of extracting things like oil goes up. It is not always true that this is the case.[18] Nevertheless, extraction efficiency has been found to climb with temperature in some cases until an optimal temperature and solvent to solid ratio are attained. After that, extraction efficiency tends to fall with increasing temperature. Extraction temperatures are set based on how stable and how much of the active chemical can be taken out of the plant. For example, in one study Xiao *et al*. reveal that when 1000W microwaves can be used to get the flavonoids out of the roots of Radix Astragali. They found that extracting flavonoids from the roots of Radix Astragali at higher extraction temperatures than 110°C caused flavonoids to become unstable. A lot of microwave radiation could break down flavonoids, which could cause them to lose their health benefits.[19] Furthermore, in another study, Tsubaki and other researchers found that the phenolic content of the extract from Oolong tea rose with the temperature of the water used to make the tea extract. 170°C was found to be the best temperature to work with. In this case, higher extraction temperatures led to less yield. To make sure that the active ingredient is extracted in the best way possible, plant extraction needs to be done at the right temperature.[20]

Effect of extraction time application and cycle

This is only true for solvent-free MAE, which needs a longer extraction time of 1 h to get all of the essential oil out. This is because the extraction time of MAE ranges from a few minutes to about 30 min.[21] This is why. It is possible to avoid heat damage by increasing the time it takes to remove the waste. Because this can help if the extraction time needs to be a little bit longer. To solve this, you could try again with more solvent, but that might not work either. Furthermore, microwave power has been found to have a big effect in a lot of studies. During low power and low temperature, too much microwave radiation changed the chemical structure of active compounds, which made them less active. This led to a very low yield. Radix Astragali were exposed to light for 25 min, and the amount of flavonoids that were extracted went up, as well. After that, the amount of flavonoids that were taken fell.[22]

Effect of contact surface area

If the plant has a lot of surface area, it is better at getting rid of it three sample preparation steps help get as much of the biological cellular matrix into contact with solvent as possible. Milling, grinding, and homogenization are three of them.[23] For example, in one study Xiao *et al*. reported that from Radix Astragali the flavonoids can be extracted with a good MAE method. The best way to get flavonoids was to use this method: An oven with 1000 watts at a temperature of 110°C for 25 min of exposure with 90% of it is ethanol give 25 ml of solvent for every gram of the substance that needs to be cleaned up if you want to get more flavonoids out of a plant without hurting it, the MAE method is better than other methods. This could be good for the economy in the next few years.[24]

APPLICATIONS

Plastic waste

At 500°C and 600°C, significant density polyethylene was microwave pyrolyzed with a stirred carbon bed that worked very well. A lot of oil and wax were made (80%). Polymer laminates that have been coated with aluminum can be heated to get rid of the aluminum. This is how you can remove aluminum from laminates such as toothpaste tubes and drink cartons that have been de-pulped (e.g., Tetra packs). A good way to separate things was found to be able to get almost all of the aluminum back.[25]

Biomass

Getting rid of the sludge that comes from sewage plants is a big problem for the environment in the world we live in now. In the last few years, people have been recycling and composting more and more to get rid of their waste. Sewage sludge contaminants are linked to pollution in the environment and high costs to clean up. You should use microwaves when you want to get rid of waste from the sewage system.[26] That does ot mean that it cannot also be used to clean up and recycle sewage waste. There was a small amount of char from previous cycles that were used in this study. Microwaves were used to break down the sewage sludge in this case, and they worked. When you start the pyrolysis process, you can use microwave heating to dry the sludge well. There are a lot of ways to do this. When it was done, it could be used to make gas from the pyrolysis products.[27-29] In this case, the steam that comes out of the microwave drying process could be used to do it. Microwave pyrolysis is better than other methods at making syngas (up to 66 vol percent) and small amounts of oil with low PAHs concentrations from sewage sludge. Drying and pyrolysis can all be done at the same time. They used it to make bio-oil from sewage waste in their study. As a biofuel, it is thought that microwave power of 400 or 600 W could make a lot of bio-oil that could be used.[30]

Waste automotive engine oil

Incondensable gas was one of the things that came out of microwave pyrolysis. This gas can be used as a gaseous fuel and to make chemicals. Use water to make second-generation fuel or chemicals, and then heat CO to make even more hydrogen, which will make even more hydrogen. Turn the light hydrocarbons C2-C6 into hydrogen, or make something else with them to get hydrogen, but you have to do both to get hydrogen from them.[31] Fischer–Tropsch is a process that can be used to make hydrogen and synthetic fuel instead of just burning the gas that comes out of the ground.[32] Most of us do this. The use of microwaves to break down used cooking oil has shown a lot of promise in the last few years. This is a good thing. To make hydrocarbons and hydrogen, you can use pyrolysis in many different ways around the world. These things can be used to make energy or to do other things like that. If you have a custom-made microwave oven that is made for this, you can get this. The bed of particulate carbon is used as the microwave absorber. To get the waste oil to heat up, you need materials that are better at taking in microwaves than the waste oil itself is.[33,34]

MAE for microalgae from biofuels to biorefinery

Current extraction methods are hard to scale up because they take a long time, use too much solvent, require a lot of energy, and are expensive to make. Microalgae can be stripped of their lipids, pigments, proteins, and carbohydrates using microwaves, which have been studied a lot since 2008. Some of the benefits of microwaves over other ways of heating are fast heating, selective energy loss, and heat and mass moving in the same direction.[35] The benefits of microwave extraction are shorter work days, higher yields, and cleaner products. Overall, MAE seems to be a good way to get bioactive out, and it does so in a way that is good for the environment and uses fewer solvents.[36]

Microwave-vacuum conditions for food processing

In the past 10 years, adding microwave radiation to vacuum processing has become more popular, especially for heating-sensitive foods. Because it does not use air, the combination technique does not cause unwanted reactions such as oxidation. Hence, important sensory qualities such as taste, look, and feel are well preserved in the product.[37] When used with regular heating, a vacuum can slow down production, cause technical problems, and make operating costs go up. In the food industry, these problems have been solved by putting together microwave irradiation and vacuuming.[38]

Drying of food materials

This method of drying food is expected to consume less energy and dry it more quickly because of the way the food vapors are heated during microwave-assisted ultrasonic drying procedures. This prevents the food from shrinking by creating a pressure gradient within it. Aside from the fact that it is possible to dry food items at lower temperatures than other methods, it can be predicted that the combined application of diverse energy sources is beneficial for effective drying.[39]

Microwave-powered cold plasma

Plasma is used for a wide range of tasks in the food industry, such as getting rid of bacteria and making something sterile. Some of the energetic, active particles that can break covalent bonds and start reactions are electrons, ions, radicals, and exciting species. Using microwave energy, it is possible to make plasma, which has a number of important benefits, such as being very good at making reactive species, having a higher density of electrons, and not causing contamination. This study found that when the etched surface of spores was treated with high microwave penetration and cold plasma therapy, the number of spores was reduced more. This may have broken disulfide bonds in the protein coats of spore cells, making them easier for excited molecules to attack.[40]

CONCLUSION

MAEs processes are either better or comparable with conventional solvent extraction methods. Optimization of process parameters and the use of modern technologies can significantly improve extraction efficiencies. Microwaves are used to selectively heat certain chemical species. Non-homogeneous structures in the bulk of materials, whether they derive from plants, animals, earth, or man-made sources, allow for direct heating of specific parts or regions. Water can be used to solubilize and cool the needed components of the materials being extracted because free water absorbs microwave energy more than the bulk of organic solvents do. To improve existing or new food processing operations, the use of microwave energy is a viable solution with high process efficiency and few modifications to food quality characteristics. These benefits may pave the way for the development of highly sought-after food products for consumers and for the expansion of microwave technology's commercial application. Using a microwave to aid in food processing has numerous advantages. Food bioactive can be more efficiently extracted using the microwave-aided method, which utilizes less solvent than other extraction methods. Nutraceutical chemicals that are more easily oxidized can be extracted from samples that have been microwaved prior to extraction. Other microwave-assisted applications, such as tempering, frying, roasting, and freezing can better preserve the nutritional and sensory profile of the treated goods. In addition, MAP gas-phase extractions benefit from selective heating of particular chemical species over others and selective heating of the liquid or solid phase over the gas phase for a specific sample matrix. Traditional liquid and gas-phase extractions can be replaced by MAP, a valuable and frequently upgraded alternative. For food reviews international's current concerns about food quality and safety, this technology presents an intriguing opportunity.

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