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Microwave Technology in Pharmaceuticals and Natural Product

Tejas .S. Shinde*, Dr.Savita. Sonawane, Dr .Sanjay. K. Bais
Fabtech College of Pharamcy, Sangola-413307
Maharashtra, India

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ABSTRACT
The technology of High-frequency radiation offers garnered considerable interest acting as quick, productive as well as eco-friendly way to separate bioactive substances from pharmaceutical matrices and natural sources. A thorough summary of the fundamental ideas and workings of MAE is given in this article, along with an emphasis on its benefits over traditional extraction techniques, minimizing isolation times, reduced use of solvents along with increased separation yields .The article covers new developments in instrumentation and process optimisation, as well as important elements influencing microwave functionality, including solvation medium type, temperature, processing period , and dielectric heating energy. Along with its use in pharmaceutical analysis and drug development, MAE's utilization during derivation in different phytochemicals, including alkaloids, flavonoids, along with essential oils to be examined. The limitations and difficulties of MAE, such as its scalability and the heat deterioration of sensitive chemicals, are also covered in the review. Lastly, new developments and potential paths for MAE research are explored, establishing it as a key instrument in environmentally friendly extraction processes for pharmaceutical and natural goods.

KEYWORDS: Microwave, Bioactive substance, Phytochemicals, Thermal degradation, Sensitive compounds

I. INTRODUCTION

A relatively recent extraction method called microwave-assisted extraction (MAE) blends conventional extraction of solvent with microwave technology. In several disciplines, including environmental evaluation, dietary and farming analysis, pharmaceutical medications, and medicinal products, solvent extraction is extensively used to enhance qualitative and quantitative examination as well as separating of significant molecules. In MAE, however, extracting happens because electromagnetic waves alter the cellular makeup of the cells. It has been suggested that the transmission of mass and thermal differences acting in a similar direction could be the cause of the extraction accelerate seen in MAE.[1]

Since the synthesis of unprocessed plant material serves as the foundation with regard to separation as well as pharmaceutical cleanup compounds found throughout flora, extraction constitutes are first fundamental stage in research investigation for therapeutic herbs. The proper selection concerning solutions also application by thermal energy or agitation to enhance massive movement in addition to soluble state to target molecule are main tenets for standard solvent-based extraction methods of plant materials. The majority of the phyto-constituents are at serious danger of thermal deterioration because the conventional method often takes more time to extract them.[2]

Although the force generated between mobilised cells and the manner in that particular temperature acts on bonds that are polar while by product exposure to light promote the formation of certain compounds and chemical reactions like oxidation, dehydration, alterations in structure, and esterification will occur, transforming secondary metabolic products in plant medicine into different structures, microwave radiation can minimise nutrition degradation and preserve appearance. Food is frequently heated in microwaves to dry it out.[3]

Particularly for heat-sensitive chemicals, traditional extraction technique is frequently ineffective also time spending. Despite being in business since 1879, Soxhlet has several disadvantages, such as lengthy durations , significant energy consumption, and incompatibility with thermolabile substances.[4]

In 1945, Percy Spencer made the discovery of microwaves' heating capabilities during World War II while doing radar experiments. In fact, bent over the heating device. while holding a sweet piece in his pocket, and the bar instantly melted. After World War II, microwave ovens were created as a result of the obvious heating capabilities of microwaves . [5]

The decrease of extraction time while employing microwaves is one of the primary benefits of adopting MAE. This is mostly due to the fact that traditional heating and the microwave approach have different thermal capabilities. These appliances Warm it up thoroughly. whereas conventional heating requires a certain amount of time to heat the vessel before the heat is delivered to the solution. This speeds up the heated process and reduces the heat difference. Furthermore, MAE makes it possible to run many samples and significantly reduces the amount of chemical solution used.

Fig no: 1 microwave oven

The current article provides summarized overview for thermal treatment also fundamentals in extracting energy by microwaves. There is discussion of the impact of variables such matrix properties, temperature, time, solvent volume, and solvent selection. Commercial microwave heating systems for analytical laboratories come in two varieties: open-vessel and closed-vessel systems. [6]

PRINCIPAL

Theory :

With wavelengths ranging from 0.01 to 1 meter and operating frequencies between 0.3 to 300GHz.When compared to traditional heating, electromagnetic heating enhances the procedure also conserves significant amount of power. This is mainly because microwaves consume less energy, as they heat only the sample and not the equipment. Electromagnetic warmth effectiveness is possible up to 50% greater compared to effect in conventional intensity techniques. A microwave photon's energy incredibly less when compared with usual power demanded to separate a chemical linkage. Consequently, the interaction is solely kinetic, and atomic framework of an carbon-containing compound are unaffected by microwave stimulation of molecules. Microwaves are a cleaner and more environmentally friendly way to conduct reactions than traditional heating techniques. [7]

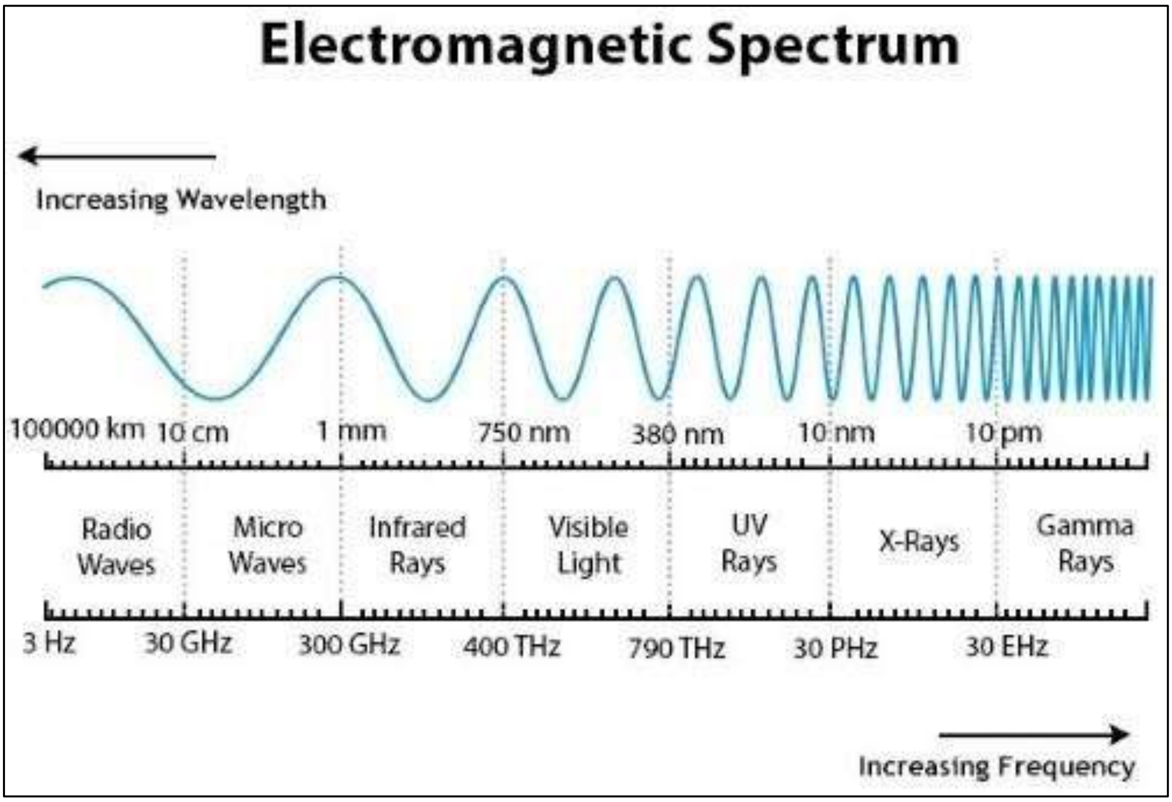

Fig no: 2 Electromagnetic spectrum

Energy will be transferred by microwaves in 10^{-9} seconds for every electromagnetic energy cycle. As a result, interaction rates and product yields are increased because energy moves more quickly than molecules can relax . [2,8]

The sample can be directly exposed to microwave radiation, which improves heat efficiency and homogeneity. Microwave-assisted extraction (MAE) provides quick energy delivery to the solvent's complete volume, and reproducibility is significantly increased . [9]

Oven design :

At a set frequency, microwaves are produced by the magnetron tube. Its components include a vacuum tube with a very negative potential cathode in the centre that emits electrons and a structured anode that creates cavities around it. The fringing fields couple them, and their microwave resonance frequency is the desired one. Either the tube current or the strength of the magnetic field can regulate the magnetron's power output. From the source, the microwave is sent to the cavity via the wave guide. When the corresponding load terminates the waveguide and the material is introduced by wall slots, it can be employed in non-conventional thermal treatment. This arrangement is known as moving vibration apparatus as its peaks positions vary over time. After the sample has been added to a special extraction vessel (reactor), it is put into the cavity, and the circulator is used to reflect and homogenise the radiation.

Mechanism:

Since electromagnetic waves alter the structure of cells, the underlying principles of the high-frequency electromagnetic procedure as compared with traditional techniques. It has high separation yield and process acceleration in MAE could be the consequence of two transport processes functioning in mass gradients and heat gradients. In contrast, heat transfer in typical extractions happens from the outside of the substrate to the interior, whereas material migration happens within interior to the exterior.

Additionally, MAE dissipates thermal energy volumetrically inside irradiation medium, whereas traditional extraction transfers heat from the heating media to the sample's interior.

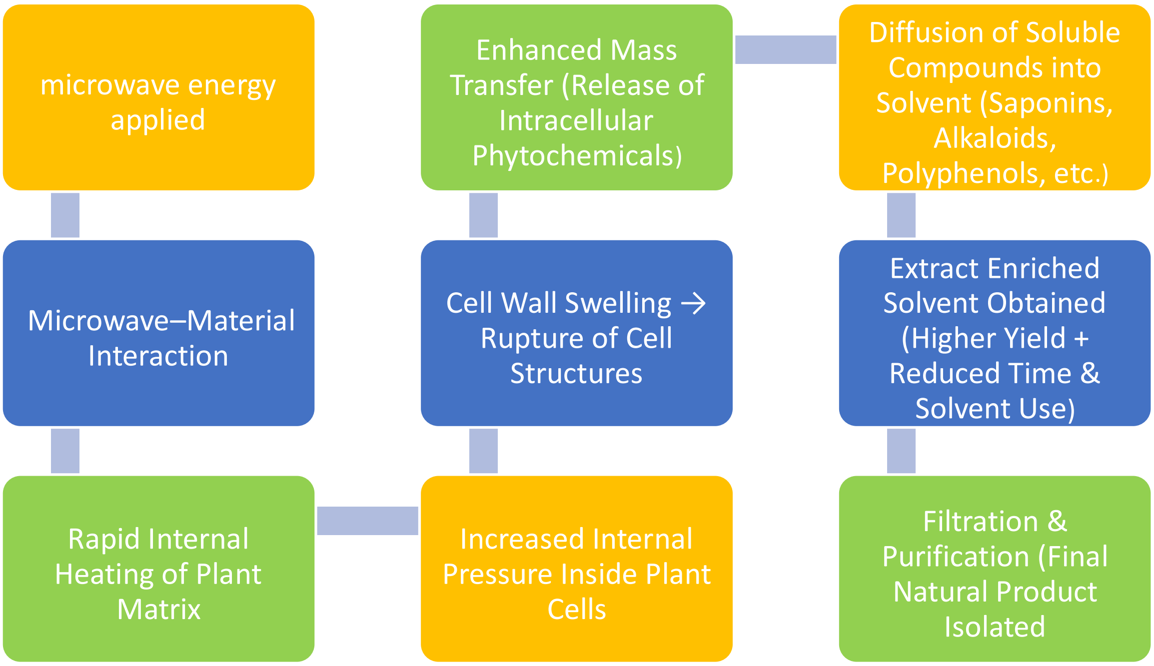

Fig no: 3 Mechanism

The rate at which the extract is recovered during the extraction process does not vary linearly with duration because dissolved component levels within the solid material fluctuates, creating non-equilibrium condition. When particulate containing firm substance and fluid interact to produce the separation, a number of phenomenological processes must take place, such as

1] Fluid penetration in firm material structure.
2] Component breakdown and solubilisation.
3] Solute transport from the solid matrix.
4] Migration of the extracted solute into the bulk from the solid's exterior solvent.
5] The movement of the concentrate relative for material
6] Essence together with solid are separated and released. [10]

INSTRUMENTATION

The varieties of systems that are sold commercially: open and closed system with regulated Thermal state also Compression.[6,11]

Closed Type System :

These are typically employed to isolate in extreme circumstances, like high extraction temperatures. These days, MAE equipment made for lab use is safe to operate and gives the operator multiple options for managing the extraction process. It is commercial systems include a Microwave emitter, Heating chamber with separation Container placed on Rotating platform, temperature and pressure Instruments, and several electrical power components. The sample is first loaded into isolation container, after which After adding the solution to the container was sealed closed to begin the extraction process. The solvent is heated to the predetermined levels using microwave radiation and a pre-extraction procedure. Typically, the heating process takes less than two minutes.

In the static extraction step, Material are exposed for further energy as well as recovered during a specified amount of duration .Following the isolation process, material are left to cool to a manageable temperature. Standard compound has been required before analysis.[12]

Open extraction system :

Designed to address the drawbacks of closed systems, including safety concerns, the open system is thought to be more suited for extracting chemicals that are thermolabile. Higher yields of samples and the ability to add more solvent at any point during the procedure are two advantages of this technology. Open systems essentially function

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in milder environments. The Open MAE system is frequently employed in analytical chemistry as well as in the extraction of active chemicals. This system only exposes a portion of the vessel to the direct transmission of microwave radiation while operating under air conditions.[13]

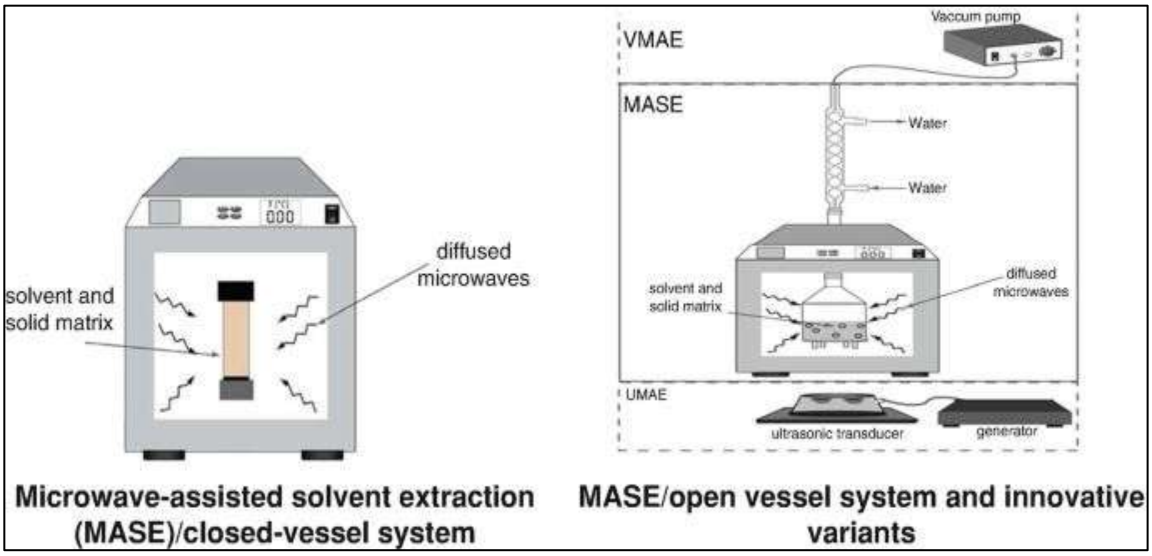

Fig no: 4Openvessel and closed vessel system

INFLUENCING CONDITIONS IN MICROWAVE TECHNOLOGY

When using microwave assisted extraction, effectiveness of the procedure might raised with taking into account for kind of fluid, the microwaves' isolation energy ,the final thermal state, the separation period, and the characteristics Belonging to Botanical tissue framework and the Intended Chemical species. Only by taking the aforementioned aspects into account while using microwave-assisted extraction can we achieve meaningful results.[14]

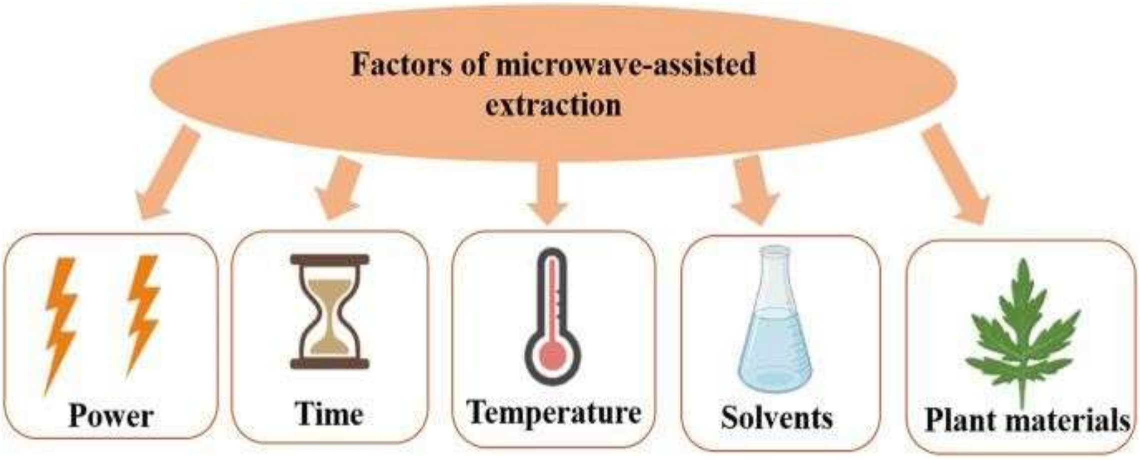

Fig no :5 factors

Solvent nature and volume :

Making the right solvent selection is essential to achieving the best extraction results. Dissolution properties of Specified Compound ,fluid-plant matrix Correlation, and also solvent's microwave-absorbing capabilities all influence the solvent selection for MAE.[15] The plant matrix can be heated more effectively when small fraction of water in separation fluidis able to readily enter its cells. Consequently, the active ingredients' mass transfer into the extracting solvent is increased. The best isolation for geniposidic and chlorogenic compound conducted with such circumstances ,was determined to be 80% (v/v) aqueous methanol.[16] chemicals reports several other uses of high microwave absorption solvent composition.[17,18]

Extraction time :

An important factor in achieving a high-quality product is extraction time. Despite the possibility of deterioration, The yield of substance isolatedis typically enhanced with lengthening separation period. Various natural product separation investigations Use different durations ranges. This technique aided separation can sometimes take 15 to 20 minutes, and in some cases, as little as 30 seconds has been shown to produce the most metabolites.[19]

Microwave power :

Microwave radiation application raised the monomolecular layer of moisture's Thermal energy Incorporation , which raised sample's Liquid surface energy also enhanced moisture absorption.[20] A material's breaking point Elevated temperatures and power levels will harm the materials' microstructure throughout the drying process.[21] Microwaves with low power encourage plant growth and reproduction. The amount of soluble protein in the roots of Sequoia plants rose and their metabolism was stimulated following a brief exposure to low power microwave radiation.[22] Without an adequate power source, the sample's temperature has little effect on moisture, which can rise quickly and harm the sample's structure.[23]

Temperature :

The consequent increase in solubility makes high-temperature extraction potentially viable. This is because greater temperatures lead to more interactions between molecules in the solvent, which in turn promotes more molecular motion and improved solubility. The temperature rise may also result in an accumulation of cellular pressure, which might rupture cells and cause the cell matrix to open. This would increase in availability of components for extraction into the solution. Additionally, the solvent's viscosity drops at high temperatures, enhancing its mobility and solubility and boosting extraction efficiency. Nonetheless, in certain instances, it has been noted that extraction efficiency rises as temperature rises until an ideal warmth where the quantity of liquids over material were reached, after which will begins to fall while temperature rises further.

The kind of compounds that need to be extracted also affects this because each compound has a unique decomposition temperature. Higher temperatures or extended high temperature applications brought on by extended high power levels might cause degradation, which can subsequently result in a drop in yield and quality.[24]

Plant Matrix Attributes :

Numerous bioactive substances, including flavonoids, phenols, sterols, and essential oils, have been extracted from a variety of plants. Before beginning an extraction procedure, it is advised to understand how the plant's cellular structure is generated. Because the manufacture, Movement as well as storage of natural product occur for particular locations .

Essential oils are one example of a substance that is found in specific Cell components found Inside, surrounding, or beneath plant cells of plants. Another illustration are the lipid rafts, or microdomains, that are found in the plant plasma membrane and include sterile glycosides and sterile acyl glycosides. [25]

MICROWAVE TECHNOLOGY IN PHARMACEUTICALS

In pharmaceutical chemistry, Organic Production via microwaves has become a potent instrument which enables quick, clean, and energy-efficient transformations. Microwaves speed a variety of chemical processes, especially those involving polar compounds or transitions between states, by delivering fast and homogeneous heating . Microwave-assisted synthesis and extraction are commonly used to the pharmaceutical field to generate and isolate heterocyclic compounds, natural molecules that are bioactive, and active ingredients in medicines (APIs).

Microwave technology in Synthesis of Heterocyclic Compounds

Condensation and cyclisation reactions, those are essential for creating heterocyclic scaffolds commonly seen in pharmaceuticals, have been shown to be greatly aided by microwave irradiation.

1] Synthesis of Imidazoles

Imidazoles are a class of heterocyclic compounds with five members that have two nitrogen atoms in non-adjacent locations. These are significant chemicals present in many physiologically active compounds, including ketoconazole (antifungal), metronidazole (antimicrobial), and cimetidine (antiulcer). Long reaction durations, high temperatures, and the use of dangerous solvents are frequently necessary for the conventional synthesis of imidazoles.

Microwave-Assisted Debus–Radziszewski Pathway for Imidazole Formation. In this reaction, formaldehyde, ammonia, and glyoxal are cyclocondensed under microwave radiation to produce imidazole. [26,27]

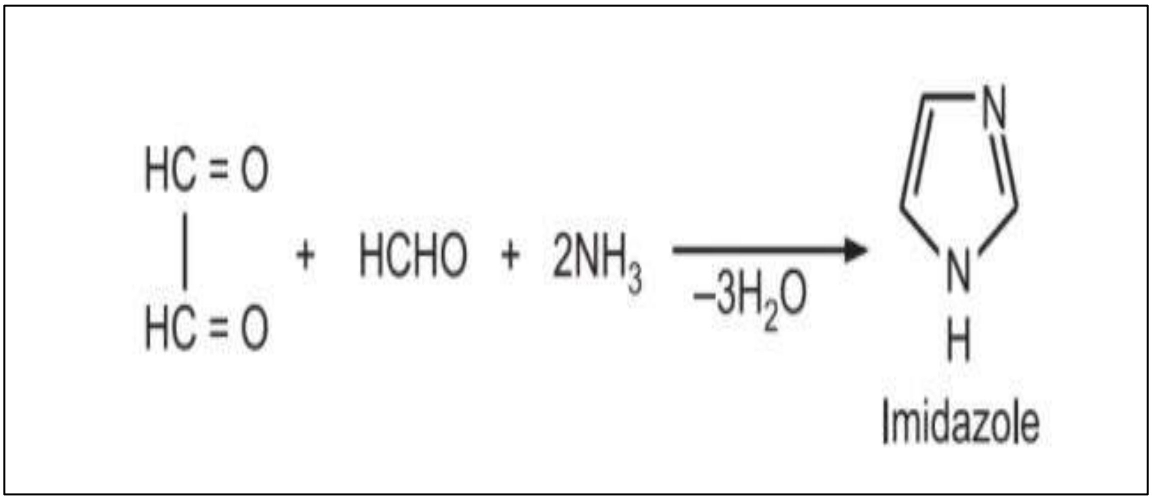

Fig no :6 synthesis of Imidazole

2] Synthesis of Benzimidazole Derivatives

Nitrogen-based heterocyclic molecules known as benzimidazoles have a variety of medicinal uses, including antiinflammatory, antiviral, antibacterial, and anticancer actions.Three primary processes are involved in the microwave-based synthesis of benzimidazoles: condensation, cyclisation, and oxidation. initial ophenylenediamine interacts with a compound called aldehyde (like benzaldehyde) when exposed to microwave radiation. With the removal of a water molecule, the amino acid group (–NH_2) of the o-phenylenediamine derivative reacts with the carbonyl compound (C=O) of the aldehyde to generate an imine intermediate (Schiff base). The core benzimidazole ring system is established in the second step when the residual amino group on the o-phenylenediamine contacts the imine carbon (C=N) intramolecularly, resulting in cyclisation and the creation of a dihydrobenzimidazole intermediate. In order to get the completely aromatic benzimidazole derivative, this intermediate is finally oxidised (aromatised), usually by air or moderate oxidising agents like hydrogen peroxide or ferric chloride. Compared to conventional heating techniques, these changes happen quickly under microwave conditions, yielding high yields in a matter of minutes. [28,29]

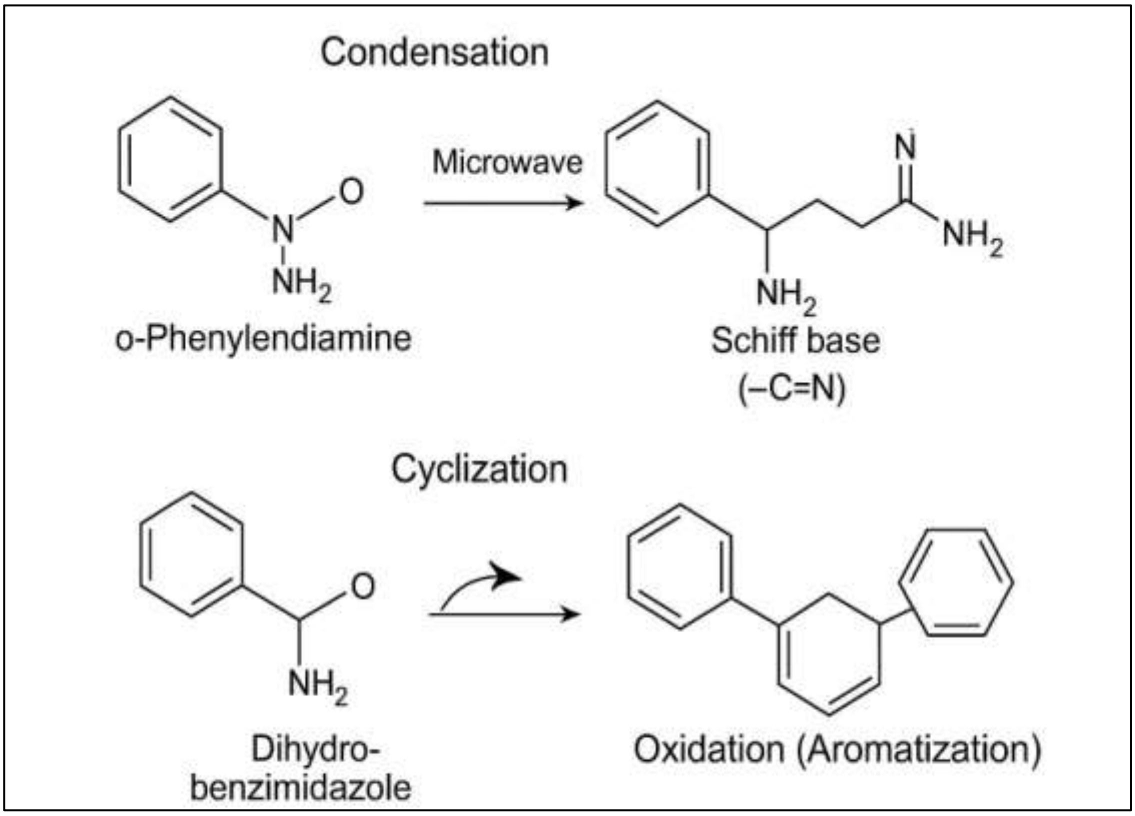

Fig no: 7 Reaction in Benzimidazole

Microwave Technology in Esterification

Strong acid catalysts (such as H2SO4) and extended reflux heating for some time are often needed for this reaction. On the other hand, esterification can happen quickly and effectively via microwave irradiation, frequently in a matter of minutes, with greater yields and lower energy usage.Acid catalysis and microwave irradiation improve four essential mechanistic processes in the electromagnetic-assisted esterification of a carboxylic acid with an alcohol.

R–COOH compound atom is acidified in first stage (protonation of the carbonyl oxygen) by an Concentrated H_2SO_4. It activating C=O group while carboxylic acid is targeted Valence electron pair on the alcohol's oxygen atom in the second phase, known as the nucleophilic attack by alcohol. A tetrahedral precursor with both –OH and –OR groups bonded to the identical carbon atom is created as a result. An intramolecular proton transfer occurs within the intermediate during the third stage (the removal of water), changing one -OH group into a better release group. A water molecule (H2O) is then removed, creating a charged ester intermediate. In order to replenish the acid catalyst, the protonated ester finally loses a proton in the fourth stage (deprotonation), producing the neutral ester product.[30,31,32]

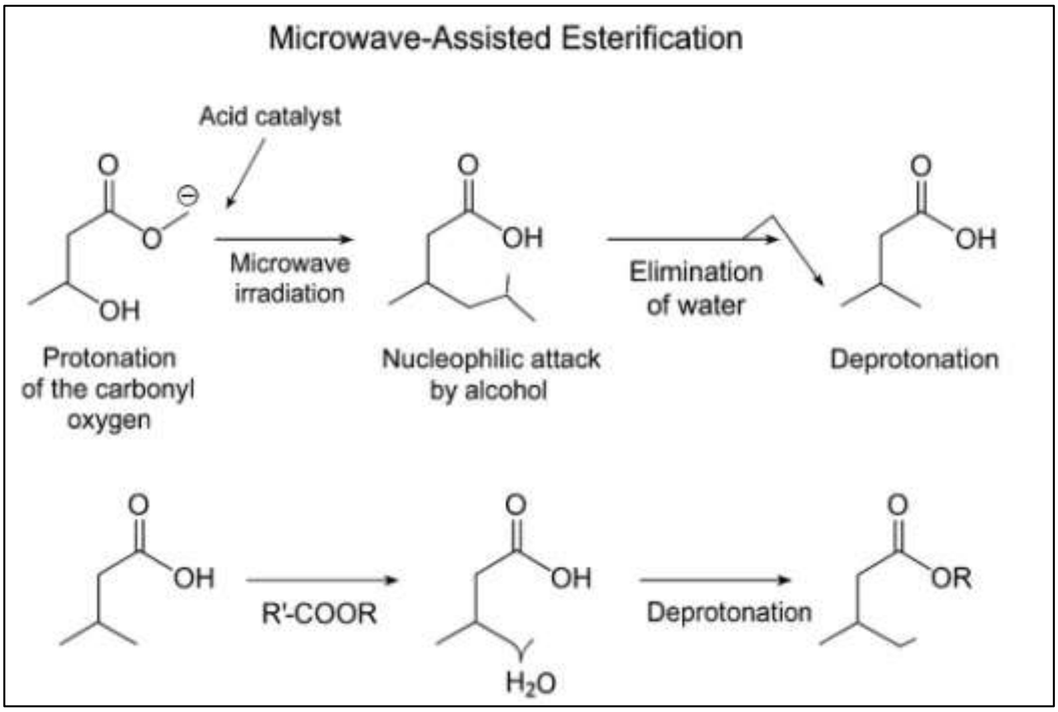

Fig no : 8 Reaction in Esterification

Microwave technology in Amidation

The creation of an amide bond (–CONH–), one of the most important connections in medicines, peptides, natural compounds, and polymers, is a basic organic transition known as amidation. Long reaction periods, high temperatures, and catalysts like coupling reagents (such DCC and EDC) are typically needed for amidation.However, the application of microwave irradiation has transformed this procedure by offering a quick, solvent-free, and energy-efficient pathway to amide synthesis.

By using Waves of the Resonating 2.45×10^9 Hz, microwave-assisted amidation (MAA) directly heats polar molecules and reaction intermediates. This causes rapid, even heating and increased molecular collisions, which drastically shortens reaction times and increases yields.

Acid catalysis and microwave activation both significantly improve the three essential phases of the microwave assisted amidation method. The carboxylic acid is first activated by protonating its carbonyl oxygen using an acidic catalyst like sulphuric acid (H_2SO_4) or p-toluenesulfonic acid (p-TsOH).The presence of these protons makes the carbonyl carbon more electrophilic, thereby facilitating nucleophilic attack. Sp³-hybridized Transient structureis created in the second step when the amine, which has a lone pair of electrons on the nitrogen atom, hits the activated carbonyl carbon as a nucleophile. Under microwave irradiation, which improves molecular collisions and reaction kinetics through equal and quick warming, this stage is greatly expedited. The quadrilateral intermediates finally experiences proton transfer in the third stage, which is followed by the removal of a water molecule and the creation of the intended amide bond (-CONH–). The catalytic cycle is finished when the acid catalyst is renewed. All things considered, microwave irradiation not only expedites every mechanistic stage but also enhances yield and selectivity, enabling amide synthesis to take place effectively in a matter of minutes under moderate and eco-friendly settings.[31,33,34]

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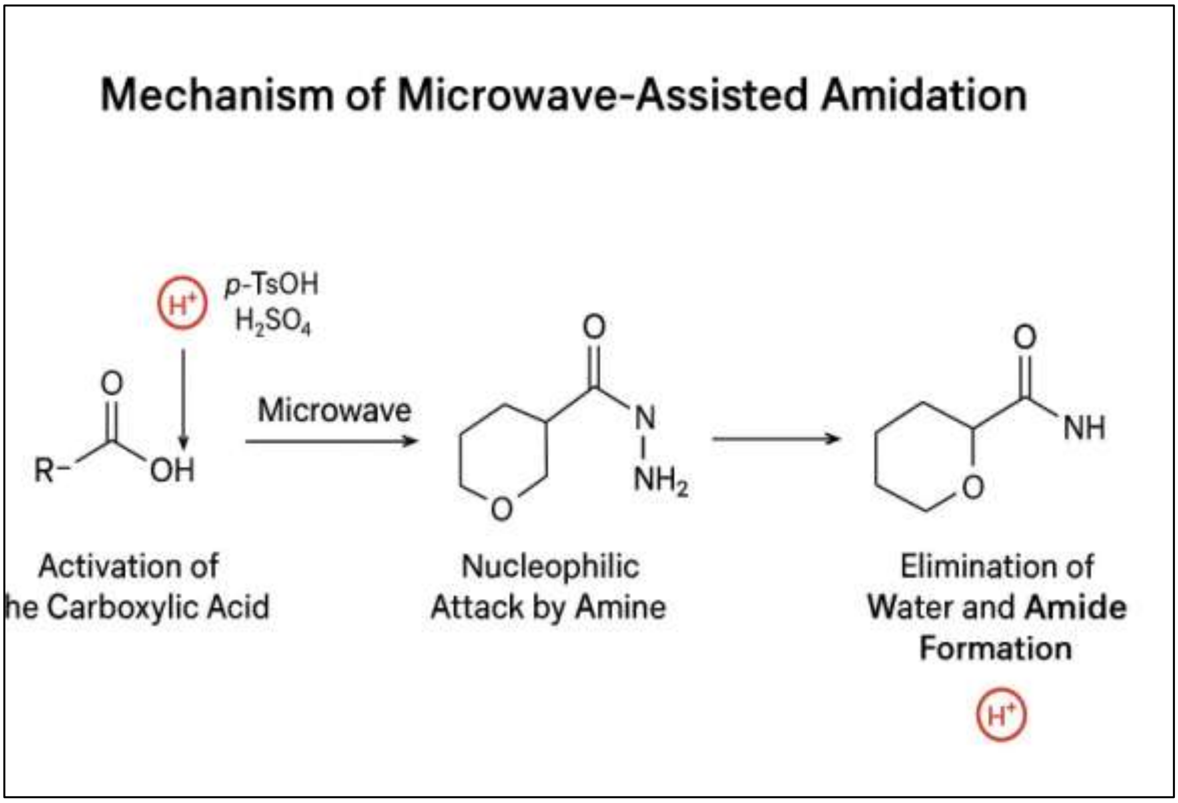

Fig no :9 Reaction inAmidation

ROLE OF MICROWAVES IN ISOLATING NATURAL PRODUCT

Alkaloids :

Alkaloids are an important type that naturally occurring bioactive compounds that are used extensively to provide cancer prevention, antibacterial, and anti-inflammatory properties. Alkaloids can be isolated using conventional solvent extraction techniques, which are frequently ineffective, time-consuming, and solvent-intensive.it is environmentally friendly and effective substitute method for separating alkaloids along with additional plantbased constituents from plant parts in the past decade.[35]

Microwave Extraction of Lotus Plumule Alkaloids

Fig no :10 Lotus Plumule

Green embryo of lotus seeds, known as lotus plumule, is used as a traditional medicine and is commonly consumed as a tea in China to treat hypertension and restlessness. The Multiwave 3000 Reaction System was used to extract the lotus plumule powder. The 64-position rotor of this microwave system may deliver dependable quality and outstanding performance. This extraction was performed for five minutes using two millilitres of a 60% (v/v) methanol aqueous solution at a power

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of 200 W. It allowed to reach room temperature prior to centrifuged then transferred

to flask and brought up to the mark with methanol then it is filtered through 450 nm membrane .The method known as MAE is appealing for the quantitative extraction of alkaloids from lotus already employed to isolate alkaloids of different botanical source

According to the findings, one of the key elements in the extraction process is the solvent. The output of alkaloids growth peaked at 60% methanol consumption and thereafter declined as the methanol concentration rose from 0% to 100%. Nonetheless, the yield of alkaloids decreases as the methanol concentration surpasses 80%. This could be because of the weaker endothermic capability and decreased absorption of microwave radiation. Following the two considerations, 60% methanol was chosen.

It is also crucial to consider how microwave power affects alkaloids production. Around 200 W produced the maximum yield, and when the energy raised, it shows no discernible difference with power, so 200 W was selected. In a similar way, the yield remained steady when the extraction time exceeded 4 minutes. Furthermore, the target components structure may be harmed by the higher power and longer extraction time; for this reason, 4 minutes was chosen as the extraction duration. As the quantity of liquid to solid grew, so did the production of alkaloids.[36]

Saponins :

In the genus of plants, saponins are a broad class of organically formed glycosides. They are distinguished by their amphiphilic structure, which contains both hydrophilic (sugar) and hydrophobic (sapogenin) moieties, which enables them to form durable soap-type bubbles in water-based solutions.[37]

Reetha

Fig no : 11 Sapindus mukorossi

Known as Sapindus mukorossi. It is a well-known, attractivebroad-leaved as well as commercially significant forest varieties of Sapindaceae family. Native to the hilly regions of of 1000 meters, it is extensively grown in North India. Rich in important saponins with exceptional Adsorption behavior, this is a environmentally benign substitute biosurfactant material for used inPersonal care items. Metal contaminants and Petrochemicalscan be eliminated within contaminatedSubstrate or wastewater by using S. mukorossi saponins, which can also improve oil recovery, dye solubilisation, and nanoparticle formation.

The purpose of the initial single-factor trials was to determine the proper ranges for the six parameters used in the future experimental procedure. After mixing a certain volume of solvent with 1 g of pericarps sample, MAE was performed. Polyamide filter was used for filtration after the solution allowed to come in room temperature then separated by centrifugation for ten mintues

According to HPLC-MS data, the primary constituent of total saponins from S. mukorossi pericarps is oleanolic acid, which was consistently used as the benchmark in earlier research to ascertain the saponin content of S. mukorossi. In this case, we also used oleanolic-type compounds as the primary compounds to determine the amount of saponins present in S. mukorossi pericarps. According to the third determination result, the proportion of oleanolic-type triterpenoid saponins in the acquired saponins in our study was 76.05% ± 1.52. By using HPLC analysis, the 3e content of S. mukorossi saponins was ascertained.[38]

Flavonoids :

A vast class of organically produced polyphenolic chemicals, flavonoids are Abundantly spread across Fruiting bodies ,Vegetation as well as Category in Herbal remedies. These are secondary substances that are essential for agricultural physiology, namely defence against bacteria, fungal nitrogen fixation, UV extraction, and colouration.

In terms of structure, flavonoids are triple-carbon linkage (C6– C3– C6) and a fifteen- carbon structure.[39]

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Pomegranate

Fig no : 12 Pomegranate peel

In tropical and subtropical regions, pomegranates (Punica granatum L.) are commonly found as shrubs or small trees. Its antimutagenic, anticancer, and antioxidant properties are among its health and nutritional advantages.

Microwave aided extraction was performed in a modified microwave oven. A temperature sensor was built inside the system to track and control the extraction vessels' internal temperature. Solvent was introduced to 50 mL beaker extraction containers containing 1 g of dry materials. The mechanism was started up once the container was sealed.

The sensor picked up the precise temperature. The heating unit would automatically turn off till the temperature decreased after reaching the appropriate level. Depending on the situation, the extraction temperature and duration were adjusted to varying degrees. Following extraction, the containers are left to reach room conditions for a few minutes.

Microwave aided extraction (MAE) of antioxidant chemicals, particularly flavonoids, from pomegranate peels was optimised by evaluating the solvent quantity , Alcohol content (40–80%), and MAE time (1–5 min) separately. By combining the findings of the single factor analysis with orthogonal tests, the extraction process was optimised for flavonoid yield and antioxidant activity..[40]

COMPARISON WITH CONVENTIONAL METHOD

The chemical compounds from plant material May obtained using different traditional extraction techniques . it is lengthy extraction process and substantial volume leading to the loss of Chemical solution and costly to get get rid of but also has the potential to pollute the ecosystem, are two major disadvantages of the traditional extraction method. Furthermore, it is difficult to automate the traditional equipment**.**

When applying microwaves, MAE reduces the extraction time. The primary cause of this is the variation in heating efficiency between the microwave and traditional heating methods. Microwaves warm the fluid directly, whereas With conventional method , time is needed to warm the container prior to transferring heat to the liquid .it speeds up heating process also reduces heat gradient. Furthermore, MAE makes it possible to run several samples and significantly reduce the amount of organic fluid used.[41]

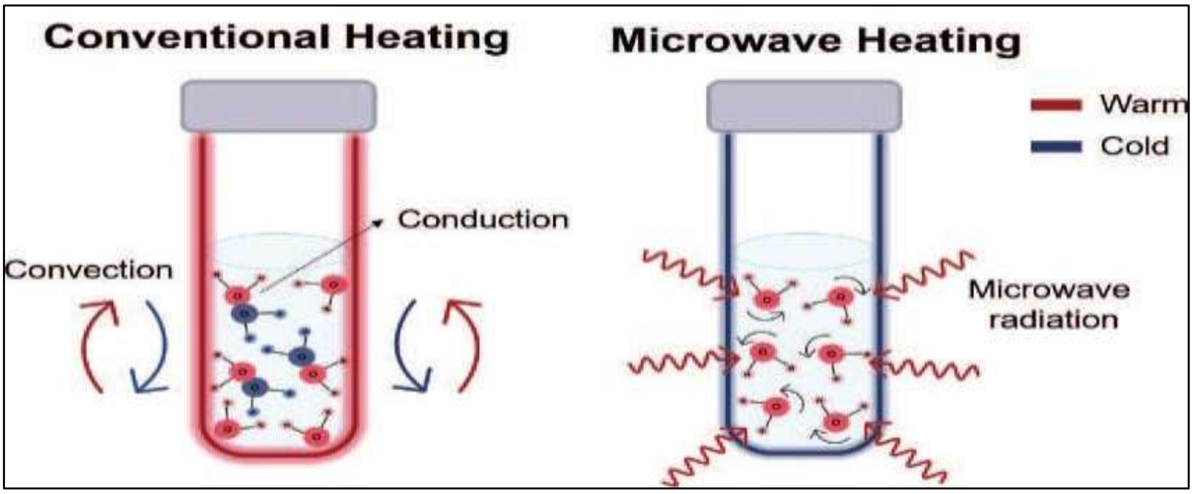

Fig no :13 conventional and microwave heating

Advantages

1] This Dielectric heating is acknowledged like flexible or effective technique for separating secondary metabolites utilized to recover different chemicals.

2] Microwave aided extraction typically exhibits clear benefits over traditional reflux and Soxhlet extraction, including reduced isolation interval, increased extraction yield, improved selectivity, and higher-quality target extracts.

3] Because microwave aided separation is inexpensive and easy to use.

Disadvantages

1] The instruments used in this technology aided isolation are of costly so in many situations highly complex to operate than those used in ultrasonic assisted extraction**.**

2] Compared to supercritical CO2 extraction, microwave aided extraction typically uses the amount of organic fluid, such as methanol, which is likely less environmentally friendly. Furthermore, when the solvent's viscosity is very high or the target chemicals are nonpolar, the microwave technique's extraction effectiveness may be quite low.

3] It is not appropriate to use microwave aided extraction to extract thermally labile substances.[42]

PHARMACEUTICALS APPLICATION Of MICROWAVE TECHNOLOGY

1]Microwave-Mediated Chemical Synthesis

It offers quick, consistent heating that speeds up reactions and increases yields. It is frequently used in the creation of heterocycles and condensation processes.[43]

2] Microwave-Enhanced Drying Method

In the pharmaceutical field, using microwaves is a sophisticated drying method that effectively removes wetness from powdery substances, granules, and herbal extracts. This technique preserves the stability as well as quality of temperature- and thermally sensitive substances while offering quick and consistent drying. Microwave drying enables shorter processing times, more energy efficiency, and higher-quality products when compared to traditional drying techniques. [44]

3] Sterilization Using Microwave Energy

In the health care industry, microwave sterilisation are a quick and effective method for sterilising goods, lab equipment, and packaging materials. It ensures sterility without requiring extended exposure to high temperatures by using microwave energy to eradicate living things such as bacteria, spores, and fungi. When in comparison with traditional thermal sterilisation, this technique shortens processing times while preserving the chemical and physical stability of pharmaceuticals that are sensitive to temperature. For applications where product integrity and sterility assurance are crucial, microwave sterilisation is regarded as an energy-efficient and environmentally beneficial method.[45]

4] Microwave-Based Approach for Formulation Optimization

A contemporary method for improving the physicochemical characteristics of medications and dosage forms in medicinal development processes is via microwave formulating. Drug solubility, dissolving rates, and solid dispersions' homogeneity are all improved by the use of microwave energy. Additionally, it is used in the creation of nanotechnology systems, polymeric matrices, and extended-release formulations. Benefits from this method include shorter processing times, consistent heating, and better active component dispersion in carrier materials. All things considered, microwave-assisted formulation aids in the creation of medical products with improved bioavailability that are more reliable and successful.[46]

5] Microwave-Enhanced Analytical Methods

In the pharmaceutical industry, microwave-assisted sample preparation is a crucial analytical technology that is mostly utilised for the digestion of complicated drug samples prior to elemental and trace metal analysis. In order to accurately quantify metals and contaminants and also this method enables it possible to absorb both organic and inorganic matrices quickly, uniformly, and efficiently. Smaller procedures, lower reagent use, and increased uniformity are just a few of its many advantages over traditional wet digestion, guaranteeing accurate and trustworthy scientific outputs for medical testing and studies.[47]

RECENT ADVANCES AND FUTURE PERSPECTIVES

- A rising Attention of combining traditional technique and microwave technology in order for get around drawbacks for using only one method and achieve a good extraction efficiency.[48]

- A new isolation method was designed for separate lycopene within tomatoes by combining ultrasonic and microwave technology. The findings indicated that the novel method's extraction rate is more compared to extraction induced by ultrasonic waves.[49]
- Additionally, combining squeezing extraction with Electromagnetic-induced isolation were investigated for increase the separation Performance in Persea americana oil. [50]
- Given its clear benefits, significant work should be put into figuring out how to best optimise both technique in conjunction ,figuring out how it works, and then scaling up the good laboratory results for industrial use. creation of an extraction method using microwave assistance without the need of solvents Most recently, research on other methods of extracting bioactive compounds obtained by herbs in absence chemical solution has been prompted by worries about resource depletion, environmental harm, and food safety.[51]
- Using non-pressurized solvents, a microwave-assisted extraction (MAE) technique was created to separate antioxidants from Hippophae rhamnoides berries. In contrast to traditional methods like pressurised hot water extraction, maceration, and pressing extraction, the MAE approach produced crude extracts with the highest antioxidant activity.[52]

II. CONCLUSION:

The capacity of microwave technology to provide quick, consistent heating through the direct interaction of electromagnetic waves with materials has made it a potent tool in pharmaceutical and natural-product research. Achieving reliable and effective outcomes requires mastery of its fundamental concepts—dielectric heating, dipolar rotation, and ionic conduction—as well as proper control of variables such as power, temperature, pressure, and solvent selection.

Microwave irradiation accelerates important organic transformations in pharmaceutical production, including amidation, esterification, and heterocycle formation. Reactions that often take a long time or require harsh conditions can frequently be completed in a matter of minutes, with higher selectivity, clearer reaction profiles, and increased yields. In natural-product chemistry, alkaloids, flavonoids, saponins, and other bioactive substances can be quickly and effectively isolated using microwave-assisted extraction. By disrupting plant cell structures and increasing mass transfer, microwaves shorten processing times, reduce solvent consumption, and improve extraction efficiency compared with conventional techniques such as Soxhlet or reflux extraction.

Limitations such as cost, scaling issues, and possible thermal degradation of heat-sensitive materials must be taken into account, despite advantages like energy savings, increased purity, and environmental benefits. Nevertheless, microwave-based technologies represent a significant step toward more efficient and environmentally friendly pharmaceutical synthesis and natural-product extraction, and continued advancements are expected to enhance their commercial application.

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