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MICROWAVE IN RESEARCH-MORE MIRACLES

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Abstract:
Microwave has created a tremendous impact on chemical research. The diversity of microwaves in chemistry has proven to be highly effective. This perspective describes the future possible trends in microwave research. As an example, future trends in organic and inorganic chemistry, material science, biochemistry, flow chemistry, communication, earth science, the food industry, and medicinal chemistry are considered. This trend in microwave-assisted science is identified considering the success and failure of current knowledge in this area.
Keywords: Portable Microwave, Medicinal Chemistry, Space Shuttles, Material Science, Organic and Inorganic chemistry, Earth Science

1. Introduction:

Many studies have shown the applications of microwaves in various disciplines. For instance, microwave chemistry is used in different fields such as biotechnology, pharmaceuticals, petroleum, plastics, and chemicals. Our research group has been conducting microwave-assisted reactions for the past many years. Mostly, microwave-assisted methods are fast, economical, green, high yielding, and selective on most occasions. The details of future trends in microwave technology are discussed here in the following sections. Our hypothesis in this matter is derived from current knowledge considering microwave-assisted research and extending the concepts as described in several hundred publications. This article will be valuable to many researchers who like to conduct microwave-assisted science in new directions.

2. Current Trends in Microwave Technology:

Applications of microwaves in various disciplines were reported by many researchers. As an example, microwave chemistry is used in different areas such as biotechnology, pharmaceuticals, petroleum, plastics, and chemicals. Generally, microwave-assisted protocols are fast, economical, selective, and high-yielding in most situations. In chemical laboratories, household microwave ovens were used extensively for synthesis in the early days. Later on, dedicated automated instruments with numerous features were considered for synthesis purposes. However, for the scientific purpose scientists still apply kitchen microwave ovens. There are serious practical and scientific reasons to prefer dedicated instrumentation. Many scientists have induced alterations in the domestic microwave ovens for various purposes. Likewise, for large-scale applications, several commercial microwave reactors are available in the market. Besides, to improve the performance of the device several modifications were made in different parts of the instrument such as in microwave generators, isolators, high-frequency power supplies, power monitors, waveguides, and applicators.

The microwave technology stays dominant over conventional heating methods in most cases because of the significant features it offers. It includes the possibility of solvent-free reactions, reaction time reduction for the chemical/pharmaceutical reaction, instantaneous and uniform heating, and the possibility of the parallel chemical reaction. It was observed that the scientists involved in drug development and discovery studies like medicinal chemistry and high-speed combinatorial generally adopt and choose microwave technology. Besides, microwave technology has inspired scholars to begin novel undiscovered fields of complex processes both in organic and inorganic chemistry.

Microwave-induced catalytic and non-catalytic synthesis of N-heterocycles, such as five-membered N-heterocycles, six-membered N-heterocycles, fused N-heterocycles, and polycyclic N-heterocycles is a crucial breakthrough. Due to the broad range of pharmaceutical and material science applications, heterocyclic compounds are an important family of compounds. Among the heterocyclic compounds, due to the diverse applications in different areas, nitrogen-containing heterocyclic (N-heterocyclic) compounds have achieved the peculiar interest of scientists. Thus, in synthetic chemistry, the synthesis of N-heterocyclic compounds has always been among the most important research areas due to widespread interest in these compounds. For the synthesis of N-heterocycles, a large number of studies were reported under diverse reaction conditions such as catalytic reaction conditions, solvent-free conditions, one-pot synthetic conditions, reactions under solid support, and microwave irradiation conditions. Considering the reactions under microwave irradiation, researchers have successfully conducted a wide range of organic reactions under microwave irradiation conditions. It includes Diels–Alder reaction [1], Ene reaction [2], Mannich reaction [3], Heck reaction [4], Suzuki reaction [5], esterification [6], hydrogenation of lactam [7], hydrolysis [8], dehydration [9], cycloaddition [10], epoxidation [11], reduction [12], condensation [13], and cyclization [14] reactions. Besides, using these microwave-assisted synthesis methods synthesis of several pharmacologically significant compounds such as pyrimidines, steroidal derivatives, thiazoles, imines, tetrazoles, triazoles, quinolines, indolizine, β-lactams, pyrroles, and quinoxalines were possible.

Same like N-heterocyclic compounds, the sulfur-containing heterocyclic (S-heterocycles) and oxygen-containing heterocyclic (O-heterocycles) compounds are also important classes of compounds in chemistry because of their broad scope of applications. Microwave-assisted synthesis of S-heterocyclic compounds, O-heterocyclic compounds, and related complex compounds was also presented by several researchers.

Other than synthesis microwave-assisted methods can be used for other purposes. For example, microwave-assisted reduction and oxidation reactions are highly efficient, clean, fast, economical, high yielding, and selective procedure in most cases. It is a safer alternative to conventional reduction and oxidation methods and it was described by several researchers. The advantages of the microwave-assisted environmentally benign and safe protocol include the application of commercially available catalysts, simple reaction setup, high product yields, elimination of side products, short reaction times, and low chemical waste.

In enzymatic reactions, microwave technology is important. It is reported that enzymatic catalysis and microwave irradiation synergistically enhance the rate of reaction significantly. Biodegradation of toxic organic pollutants using enzymes from several microorganisms or plants was reported. As it is controlled by microbial enzymes, bioremediation is a cost-effective and environmentally friendly biotechnology branch. The works in this field aim to reduce the toxicity of the pollutants and also to get novel practicable products. Microwave technology, in conjunction with enzymatic catalysis and solvent-free chemical synthesis, is a nature-friendly method. Low wastage of solvent and good yield of the products were reported during this protocol. Enzymes from various microorganisms are involved in the biochemical synthesis of various important compounds assisted by microwave irradiation. Reports depicted that, by microwave heating, the stability, activity, and selectivity of the enzyme can be improved. However, due to the high temperatures associated with microwave heating, the use of microwave irradiation in enzymatic synthesis remains limited still as enzymes are very sensitive to temperature. By maintaining the temperature as low as 40 °C and by precise power inputs several studies are proceeding.

The pathogenic Gram-positive bacteria, as well as Gram-negative bacteria, can cause several infections and it still stays as a significant public health-threatening issue [15–17]. The infections can also be produced by viruses and fungi. A good air purification system is necessary at places where people gather, such as in schools, offices, hospitals, assembly halls, theaters, and restaurants as the viruses are airborne. Inactivation of microorganisms can be possible with the sterilization process. Nowadays, sterilization is employed extensively in several areas such as in the food industry, material manufacturing industry, medical-care industry, and in hospitals [18]. The inactivation of harmful microorganisms can be attained by using different methods. For example, physical or chemical methods, such as heat, radiation, and chemical solutions or gases are available for sterilization.

Heat sterilization [19], ozone gas sterilization [20], plasma sterilization [21], Microwave sterilization [22], and ultraviolet light sterilization [23] are the widely used sterilization methods. The full interior of the system should be heated during the heat sterilization process. Because of that, the process needs much time and energy. Ozone gas sterilization requires some chemical or physical reactions and it poses problems such as toxicity. Considering the plasma sterilization method, it is one of the important sterilization methods, but the stabilization of the electric discharge of the airflow system is difficult. Ultraviolet sterilization is widely employed in hospitals and laboratories. It is very compact, easy to use, and possesses a high sterilization effect. However ultraviolet irradiation can sterilize only the irradiated area. Considering different sterilization methods, microwave sterilization has a lot of advantages. and for several applications microwave sterilization is the most feasible method. During this sterilization process, the object can be heated directly, rapidly, and selectively and it leads to the reduction of power consumption. During the microwave sterilization process, it sterilizes the surface of material as well as the interior of the material. Microorganisms can be sterilized effectively and homogeneously as microwaves are irradiated from all angles. Microwave sterilization is widely used in many fields such as in the food industry, medical field, and material processing field owing to the above mentioned advantages. Combined microwave systems methods such as microwave-assisted plasma sterilization methods were also shown significant outcomes.

For the synthesis of diamond, microwave enhanced chemical vapour deposition is an appropriate approach. It provides diamonds in shapes and sizes and with composition and quality control unattainable using synthesis at high pressure. This technology permits the exploitation of diamond's exceptional properties in a range of technologies outside its traditional role in grinding, cutting, and dressing operations.

Last several years, we have been using a domestic and automated microwave oven for our research. Diverse compounds were synthesized using this method [7,24–32]. For example, the reaction of the acid chloride with imine in the presence of a tertiary-based produced beta-lactams under microwave irradiation. The ratios of the beta-lactams varied from *cis* and *trans* in different proportions. Hydrogenolysis of the benzyloxy group to the hydroxy group was performed with ammonium formate and PD/C. No hydrogen gas was necessary during this process. The N-C4 bond cleavage was done and open-chain amides were prepared by this reagent combination. Other than this, several polycyclic beta-lactam rings were prepared using suitable functionality at C-3, C-4, and N-1 in microwave following carbocation, carbanion, and radical chemistry. Heterocycles such as imidazoles, quinazolines, dihydropyrimidine, pyrazine, indole, thiophene, pyrrole, isoquinoline, quinoline, acridine, glycoside, and dihydropyridine were also prepared following microwave-induced reactions in an automated microwave oven within a few minutes.

3. Future Trends in Microwave Technology:

With the available data as described above and extending their concepts, some future applications of microwave technology in science become obvious. Analyzing the available methods, microwave-related chemistry mainly depends on heating, the temperature of the system, concentration of the materials, polar and non-polar effects, the dielectric constant of all the reactive partners, hot-spot, activation of the initial materials, non-thermal effects, the appearance of the vessels, and time adjustments. These parameters obviously are adjustable and therefore, a large number of research problems in science areas can be easily explored. The experimental scientists, in general, publish papers in journals based upon the results and facts. These experiments open up additional possibilities to pursue. This is exactly a similar matter between microwave technology and available science. But, there is a difference in terms of technology. For example, in microwave-induced science, it is the radiation exerted by the oven controls the overall process. In classical science, experiments are performed manually. The expecting trends in near future in microwave technology are described in the following sections.

3.1 Organic and Inorganic Chemistry:

The developments in microwave technology have allowed for its broader employment in further areas of research and production. It is expected that a decade from now, in a chemistry laboratory microwave reactor will not be unique or uncommon. Microwave technology can open up new synthetic pathways in a chemical reaction. Besides, it can allow the application of many environmentally friendly solvents and catalysts. This will effect in cleaner products that will not need as much purification. Later on, microwaves will be simply a tool in the standard chemistry toolkit, the same as thin-layer chromatography.

It is anticipated that the introduction of new materials, for example, semiconductor-based generators for replacing TWT and magnetrons for power supplies in small scale and large scale microwave reactors or domestic microwave can enhance the device's efficiency. To increase the operational parameters of devices, it also will be useful and the further disseminating of effective methods for the production of important materials. It will also offer shorter heating times than that are currently available.

The employment of an automatic communication system in a microwave reactor will make more advantages on laboratory experiments and also in cooking. For example, the operation using internet/Bluetooth connections. It will allow users to operate the machines from any place. Besides, while the reaction is running, the system will do also some calculations for the user.

For properly using power and managing the time of the chemical process, efficient sensors will be very useful. Specialized sensors with the capability to detect the non-heating regions will form microwave technology more useful. Accuracy in calculating the temperature inside the reactor is important, it is expected that replacing the standard sensor with a semiconductor-based temperature sensor having high thermal stability can overcome the drawback in temperature measurements of the reactor.

To increase the lifetime of the device, it is important to design a new microwave reactor with stronger materials having bigger penetration depth or having better resistance to high-temperature materials.

3.2 Material Science:

In the field of materials synthesis, microwave technology provides some advantages and distinct features. The growth of the particle of the corresponding materials will be much more controlled and uniform, as the microwaves can act directly with the sample and turn on and off speedily. It will heads to an enhancement in the desired property and features of the materials. Using microwave synthesizers, notable results have been reported in the field of materials synthesis. Over the next few years, we are expecting an increased adoption rate of microwave technology in the material science field.

3.3 Biochemistry:

In the biochemistry field also new important trends are happening with the application of microwave technology. As most of the biomolecules are sensitive to temperature, the molecules lose its biological activity if it is exposed for longer periods of time to an elevated temperature. Besides, several of the biochemical reactions are very slow or difficult to take place. Several of the reports depicted that microwave technology can cover some of the challenges in this field. For instance, microwave technology can push biochemical interactions to occur without the high bulk temperatures which can head to activity loss or degradation. Compared with the conventional method that rapidly heats a solution to raised temperatures, the greatest advantage of microwave technology is the efficient energy transfer. Considering these significant properties, a tremendous number of acceptance in areas including peptides and proteomics is taking place.

3.4 Flow chemistry:

Flow chemistry (continuous flow or plug flow chemistry) is an emerging field. Flow chemistry provides the potential for the effective manufacture of chemical products. Flow chemistry can be coupled with microwave technology for the better execution of a reaction. In a flow microwave, better chemical interactions are expected. By applying stop-flow, continuous flow, or large batch modes, the microwave reaction's efficiency can be improved.

3.5 Communication:

Compared to microwave ovens, the wireless routers works in microwave frequencies with lower power. The working of a Wi-Fi device can interfere with other microwaves with high power. For example, microwaves from a microwave oven can affect the working of the Wi-Fi device. To get over these problems, the newly designed Wi-Fi devices send and receive data at a higher frequency of 5GHz.

Electromagnetic radiation effects in the environment increased due to the wide use of electronic equipment like computers, cell phones, communication devices, and wireless facilities. It can also cause cancer and several other diseases. In addition, it is necessary to take out the interferences in the aircraft and other important instruments in the military. There are possible methods to minimize and attenuate electromagnetic waves. For example, two-dimensional microwave-absorbing and shielding materials can get over these issues. Studies demonstrated that two-dimensional materials and structures are promising for use in microwave devices. Conventional materials with two-dimensional structures, graphene-like materials, such as two-dimensional transition metal dichalcogenides and black phosphorus can be used for this purpose. In the future, these two-dimensional materials will likely play an important role in electromagnetic wave absorption and cancellation, as these materials also have beneficial shielding and absorbing properties.

Microwave photonics is an emerging new technology. This technology integrates both the merits of radio wave propagation and optical-fiber cable transmission. It may give a practical solution to realizing broadband and low-cost subscriber networks.

3.6 Earth Science:

Researchers examined scientifically the critical technologies for formulating advanced microwave radiometers suitable for earth science applications. The emerging technology enables microwave measurements with adequate spatial resolutions for a number of earth science parameters. For example, the parameters like sea ice, snow, soil moisture, sea surface temperature, precipitation, vegetation, and ocean winds. High spatial resolution microwave sensing from space with sensible swath widths and revisit times aids large real aperture radiometer systems. The efficiency of the measurement systems can be improved by using the aperture radiometer systems with new lightweight compact-packaging technology. For a passive microwave airborne imager, the airborne earth science microwave imaging radiometer is a suitable example. The system can cover the 6-100 GHz bands which are essential for detecting key earth system elements.

3.7 Food Industry:

Also in the food industry, microwave technology can bring lots of improvements. As an example, IR scanning of the universal product code of frozen or nonprepared food will make microwaves read the information written on the food pack. Along with that, it will make the reactor use automatically the same time and power instructed in the food packet by the manufactures. This can also be employed in laboratory reactors using a code reader and UPC codes.

3.8 Medicinal Chemistry:

There is the highest demand for new drugs with a high degree of potency, unique targets of action, and low toxicity in normal cells, as most of the currently useable drugs are cytotoxic to normal and infected cells. For the prediction of the medicinal activity of a molecule, the physicochemical parameters play an important role. It helps to design more potent drugs [33–39]. Microwave-assisted synthesis along with theoretical analysis will aid scholars to design and synthesis more active drugs.

Other than the synthesis of drugs, sterilization is also an important process in the medical field. With new microwave technology, sterilization methods can be improved. For example, new devices such as semiconductor sources can be used to generate plasma in microwave-induced plasma sterilization systems to improve the sterilization process.

3.9 Space Shuttles:

It is also anticipated that space shuttles could shortly be launched into space by beaming' power to them employing microwaves. Utilizing this microwave technology craft can be built far lighter at launch since it is not having to bear fuel. It is expected that the space shuttles powered by beamed high power microwave energy can perform markedly and it can surpass the limit of chemical combustion rockets. Thus, instead of chemical combustion, the planned space shuttles will be propelled by ejecting hydrogen, heated with microwave technology. Later on, the space shuttle arrives at the destination and circulates the payload, it will glide back to the original position, refuel, and will be set up for its next journey. It will be possible to bring to market the low-cost, reusable, single-stage-to-orbit spaceplanes with this microwave technology.

3.10 Portable Microwave:

An exciting element called “Portable microwave” with high efficiency can be provided by using the emerging microwave oven technology. By using the portable microwave, the researcher doesn’t necessitate to keep the microwave set up in a fixed position or on a counter.

Some companies already have demonstrated mini portable microwaves for a car, as an initial step. People working in several areas can benefit from it. For instance, workers who spend more hours in the car per week because of their work duties or who like to travel or camping in RVs or who don't have time to return for a lunch to their home or who are staying in caravans and mobile homes can use the portable car microwave oven.

These mini microwaves are much cheaper compared to larger units. Mini microwave ovens take only far less space because of their compact size. Also, it uses a ridiculously small amount of power resources. In spite of the small size, a mini microwave can warm or cook between 140 ºF and 170 ºF. For more convenient transportation, it is easy to grip handles. The mini microwave also has all the basic features of a standard microwave oven. For example, it can heat pizza slices, sandwiches, fast food, popcorn, leftovers, liquid food, baby bottles, food jars, etc. Besides, mini microwaves are very practicable in the case of unexpected power outages and other related emergency occasions where a normal microwave oven can't work.

Conclusion:

This perspective depicted the current and expected trends in microwave technology. Future trends in diverse fields such as organic and inorganic chemistry, material science, biochemistry, flow chemistry, communication, earth science, the food industry, and medicinal chemistry are discussed in brief. Based on this current contribution, we expect that many more miracles will appear in this field.

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