MICROWAVES REACTION : A NEW TREND OF EMERGING GREEN TECHNOLOGY

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Abstract:-

Green Chemistry with its twelve principles would like to see changes in the conventional chemical synthesis and the use of less toxic starting materials. Green Chemistry would like to increases the efficiency of synthetic methods, to use less toxic solvents, reduce the stages of the synthetic routes and minimize waste as far as practically possible. In this way, chemical synthesis will be part of the effort for sustainable development. Microwave assisted synthesis has revolutionized chemical synthesis. Small molecules can be built in a fraction of the time required by conventional methods. In conventional heating methods oil bath or hot plate are used as a source of heat to a chemical reaction. Microwave irradiation is widely used as a source of heating in chemical synthesis. The basic mechanisms observed in microwave assisted synthesis are dipolar polarization and conduction. Microwave- assisted synthesis provides clean synthesis with the advantage of enhanced reaction rates, higher yields, greater selectivity, and economic for the synthesis of a large number of organic molecules, have provided the momentum for many chemists to switch from conventional heating method to microwave assisted chemistry. Microwave-assisted synthesis is rapidly becoming the method of choice in modern chemical synthesis and drug discovery. The present article will highlight the applications of microwave- assisted synthesis in organic synthesis, inorganic synthesis, polymer synthesis, nanotechnology, peptide synthesis and discuss the basic mechanism involved in microwave heating.

Key words: Microwave heating, Green chemistry, Microwave synthesis, Microwaves.

INTRODUCTION

The term Green Chemistry is becoming the worldwide term used to describe the design of chemical products and processes that reduce or eliminate the use or generation of substances hazardous to human health.[1] The term was coined by the US Environmental Protection Agency and has been defined as: the utilization of a set of principles that reduce or eliminate the use or generation of hazardous substances in the design, manufacture and application of chemical products.[2] This goal can be achieved by use of twelve principles of Green Chemistry which are as follows.

(1) It is better to prevent waste than to treat or clean up waste after it has been created.
(2) Synthetic methods should be designed to maximize the incorporation of all materials used in the process, into the final product.
(3) Synthetic methods should be designed to use and generate less hazardous/toxic chemicals.
(4) Chemical products should be designed to affect their desired function while minimizing their toxicity.
(5) The use of solvents and auxiliary substances should be made unnecessary wherever possible and innocuous when used.

(6) Energy requirements of chemical processes should be minimized, and synthetic methods should be conducted at ambient temperature and pressure if possible.
(7) A raw material should be renewable rather than depleting whenever practicable. (8) Unnecessary derivatization should be minimized or avoided if possible.
(9) Catalytic reagents are superior to stoichiometric reagents.
(10) Chemical products should be designed so that at the end of their function they break down into innocuous degradation products that do not persist in the environment.
(11) Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
(12) Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents.[2-4]

Organic synthesis on a large scale involves the use of basic chemical ingredients from the petrochemical sector and catalysts; and after the end of the reaction, separation, purification, storage, packaging, distribution etc. Conventional methods of organic synthesis usually need longer heating time, tedious apparatus setup, which result in higher cost of process and the excessive use of solvents/reagents. During these processes there are many problems of health and safety for workers in addition to the environmental problems caused by their use and disposition as waste. Green Chemistry would like to increases the efficiency of synthetic methods, to use less toxic solvents, reduce the stages of the synthetic routes and minimize waste as far as practically possible.[5] Microwave synthesis is considered as an important approach toward green chemistry, because this technique is eco-friendlier. Due to its ability to couple directly with the reaction molecule and by passing thermal conductivity leading to a rapid rise in the temperature, microwave irradiation has been used to improve many organic syntheses.[6,7] Microwave chemistry is the science of applying microwave radiation to chemical reactions. Microwave synthesis represents a major breakthrough in synthetic chemistry methodology; a dramatic change in the way chemical

synthesis is performed. Conventional heating, long known to be inefficient and time consuming, has been recognized to be creatively limiting too. Microwave synthesis gives the chemists more time to expand their creativity, test new theories and develop new processes. Instead of spending hours or even days synthesizing a single compound, chemists can now perform the same reaction in minutes. The problem associated with waste disposal of solvents has been overcome by performing reactions without a solvent under microwave irradiation. Coupling of microwave irradiation with the use of mineral-supported catalyzed reactions, under solvent-free conditions, provides clean chemical processes with the advantage of enhanced reaction rates, higher yields, greater selectivity, and greater ease of manipulation. Thus microwave synthesis acts as a potential tool for green chemistry.[6, 8]

Microwave irradiation provides an alternative to the conventional methods, for heating or introducing energy into the system. It utilizes the ability of mobile electric charges present in liquid or conducting ions in solid to transform electromagnetic energy into heat. Microwave radiations are electromagnetic waves. In the electromagnetic spectrum, the microwave radiation region is located between infrared radiation and radio waves. Microwaves have wavelength of 1 mm to 1 m corresponding to frequencies between 0.3 and
300 GHz. Telecommunication and microwave radar equipment occupy many of the band frequencies in this region. Microwave dielectric heating; uses the ability of some liquids and solids to transform electromagnetic radiation into heat to drive chemical reactions. This

technology opens up new opportunities to the synthetic chemist in the form of new reactions that are not possible using conventional heating.[7,9]

MECHANISM OF MICROWAVE HEATING

All the materials are not susceptible to microwave heating as response of various materials to microwave radiation is diverse. Based on their response to microwaves, materials can be broadly classified as follows:

(1) Materials that are transparent to microwaves, e.g. Sulphur
(2) Materials that reflect microwaves, e.g. copper
(3) Materials that absorb microwaves, e.g. water Microwave absorbing materials are of utmost important for microwave chemistry and three main different mechanisms are involved for their heating namely: Dipolar polarization, Conduction mechanism and Interfacial polarization.[10]

Dipolar polarization:

For a substance to generate heat when irradiated with microwaves it must possess a dipole-moment. It is the electric field component of the microwave radiation, rather than magnetic field component that is responsible for heating, when a dipole tries to reorient itself with respect to an alternating electric field; it loses energy in the form of heat, by molecular friction. Dipolar polarization can generate heat by either interaction between polar solvent molecules such as water, methanol and ethanol; or interaction between polar solute molecules such as ammonia and formic acid. The key requirement for dipolar polarization is that the frequency range of the oscillating field should be appropriate to enable adequate inter-particle interaction. If the frequency range is very high, inter-molecular forces will stop the motion of a polar molecule before it tries to follow the field, resulting in inadequate inter-particle interaction. On the other hand, if the frequency range is low, the polar molecule gets sufficient time to align itself in phase with the field. Microwave radiation has the appropriate frequency (0.3-30 GHz) to oscillate polar particles and enable enough inter-particle interaction. This makes it an ideal choice for heating polar solutions.[11, 12]

Conduction mechanism:

The conduction mechanism generates heat through resistance to an electric current. The oscillating electromagnetic field generates an oscillation of electrons or ions in a conductor, resulting in an electric current. This current faces internal resistance, which heats the conductor. A solution containing ions, or even a single isolated ion with a hydrogen bonded cluster, in the sample the ions will move through the solution under the influence of an electric field, resulting in expenditure of energy due to able to believe that the more polar the solvent, the more readily the microwave irradiation is absorbed and the higher the temperature obtained. Where the irradiated sample is an electrical conductor, the charge carriers (electrons, ions, etc.) are moved through the material under the influence of the electric field, resulting in a polarization. These induced currents will cause heating in the sample due to any electrical resistance. Major limitation of the method is that it is not applicable for materials with high conductivity, since such materials reflect most of the energy that falls on them.[11]

Interfacial polarization:

The interfacial polarization method can be considered as a combination of both the conduction and dipolar polarization mechanisms. It is important for heating systems that comprise a conducting material dispersed in a non- conducting material. For example, consider the dispersion of metal particles in Sulphur. Sulphur does not respond to microwaves and metals reflect most of the microwave energy they are exposed to, but combining the two makes them a good microwave-absorbing material. However, for this to take place, metals have to be used in powder form. This is because, unlike a metal surface, metal powder is a good absorber of microwave radiation. It absorbs radiation and is heated by a mechanism that is similar to dipolar polarization. The environment of the metal powder acts as a solvent for polar molecules and restricts the motion of ions by forces that are equivalent to inter-particle interactions in polar solvents. These restricting forces under the effect of an oscillating field induce a phase lag in the motion of ions, resulting in random motion of ions, and ultimately heating of the system.[13-15]

MICROWAVE VERSUS CONVENTIONAL SYNTHESIS

Conventional synthesis usually involves the use of a furnace or oil bath which heats the walls of the reactors by convection or conduction (Figure 1). The core of the sample takes much longer to achieve the target temperature. This is a slow and inefficient method for transferring energy into the reacting system. On the other hand, in microwave assisted synthesis microwave penetrates inside the material and heat is generated through direct microwave-material interaction (**Figure 1**). Microwave-assisted synthesis has several advantages over conventional reactions in that the microwave allows for an increase in reaction rate, rapid reaction optimization, and rapid analogue synthesis. It also uses both less energy and solvent, and it enables difficult compound synthesis. Specifically, microwave synthesis has the potential to impact upon medicinal chemistry efforts in at least three major phases of the drug discovery process: lead generation, hit-to-lead efforts, and lead optimization. Microwave chemistry can be carried out very efficiently in a parallel format using dedicated rotors or micro liter plate systems. Several hundred reactions can be performed in a single microwave experiment using multimode microwave devices. Researchers have shown the benefits gained by employing microwave heating in tandem with combinatorial chemistry.[16, 17]

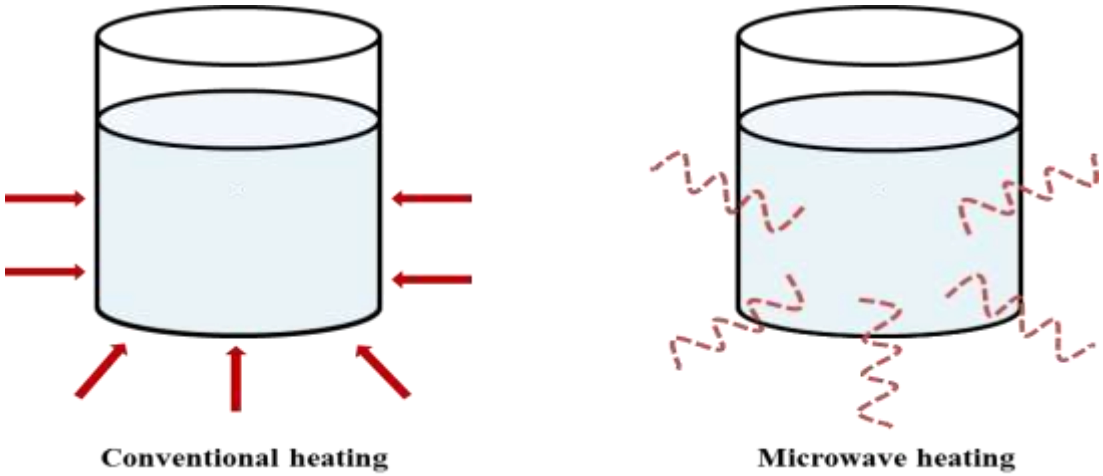


Figure 1: Comparison of microwave heating versus conventional heating[18]

A few reactions which were carried out using microwave heating and compared with conventional heating indicating time and energy efficiency of the technique are compiled in **Table 1**.

Table 1: Comparison of reaction times using microwave versus conventional heating[19]

Compound synthesized	Reaction time: Microwave	Reaction time: Conventional
Methyl benzoate	5 minutes	8 hours
4-nitrobenzyl ester	2 minutes	1.5 hours
Zeolite synthesis	30 seconds	60 minutes
Cubanite	3 minutes	3 days
$NaAlH_4$	2 hours	8 hours
$CuBi_2O_4$	5 minutes	18 hours
Ag_3In	2 minutes	48 hours

MICROWAVE SYNTHESIS APPARATUS

The apparatus for microwave assisted synthesis include; single-mode microwave ovens, and multi-mode microwave ovens.[9]

Single-mode microwave apparatus:

The differentiating feature of a single-mode apparatus is its ability to create a standing wave pattern. This interface generates an array of nodes where microwave energy intensity is zero, and an array of antinodes where the magnitude of microwave energy is at its highest. One of the limitations of single-mode apparatus is that only one vessel can be irradiated at a time. However, the apparatus is user- friendly. An advantage of single-mode apparatus is their high rate of heating. This is because the sample is always placed at the antinodes of the field, where the intensity of microwave radiation is the highest. These apparatuses can process volumes ranging from 0.2 to about 50 ml under sealed-vessel conditions, and volumes around 150 ml under open-vessel conditions. Single-mode microwave ovens are currently used for small-scale drug discovery, automation and combinatorial chemical applications.

Multi-mode microwave apparatus:

An essential feature of a multi-mode apparatus is the deliberate avoidance of generating a standing wave pattern inside it. The goal is to generate as much chaos as possible inside the apparatus. The greater the chaos, the higher is the dispersion of radiation, which increases the area that can cause effective heating inside the apparatus. As a result, a multi-mode microwave heating apparatus can accommodate a number of samples simultaneously for heating, unlike single-mode apparatus where only one sample can be irradiated at a time. Owing to this characteristic, a multi- mode heating apparatus is used for bulk heating and carrying out chemical analysis processes such as ashing, extraction, etc. In large multi-mode apparatus, several litres of reaction mixture can be processed in both open and closed-vessel conditions. A major limitation of multi-mode apparatus is that, heating samples cannot be controlled efficiently because of lack of temperature uniformity.[20-24]

BENEFITS OF MICROWAVE ASSISTED SYNTHESIS

Microwaves can accelerate the rate of reaction, provide better yields and higher purity, uniform and selective heating with lower energy usage, achieve greater reproducibility of reactions and help in developing convenient and cleaner synthetic routes. The main

advantages of microwave assisted organic synthesis are:

Faster reaction: Based on experimental data it has been found that microwave-enhanced chemical reaction rates can be faster than those of conventional heating methods by as much as 1,000-fold. The microwave can use higher temperatures than conventional heating system, and consequently the reactions are completed in few minutes instead of hours, for instance, synthesis of fluorescein, which usually takes about 10 hours by conventional heating methods, can be conducted in only 35 minutes by means of microwave heating.

Better yield and higher purity: Less formation of side products are observed using microwave irradiation, and the product is recovered in higher yield. Consequently, also the purification step is faster and easier. For example, microwave synthesis of aspirin results in an increase in the yield of the reaction, from 85 % to 97 %.

Energy saving: Heating by means of microwave radiation is a highly efficient process and results in significant energy saving. This is primarily because microwaves heat up just the sample and not the apparatus, and therefore energy consumption is less.

Uniform and selective heating: In conventional heating, the walls of the oil bath get heated first, and then the solvent. As a result of this distributed heating in an oil bath, there is always a temperature difference between the walls and the solvent. In the case of microwave heating, only the solvent and the solute particles are excited, which results in uniform heating of the solvent. Selective heating is based on the principle that different materials respond differently to microwaves. Some materials are transparent whereas others absorb microwaves.

Green synthesis: Reactions conducted using microwaves are cleaner and eco-friendlier than conventional heating methods. Microwaves heat the compounds directly; therefore, usage of solvents in the chemical reaction can be reduced or eliminated. Synthesis without solvent, in which reagents are absorbed on mineral support, has a great potential as it offers an eco-friendly green protocol in synthesis. The use of microwaves has also reduced the amount of purification required for the end products of chemical reactions involving toxic-reagents.

Reproducibility: Reactions with microwave heating are more reproducible compared to the conventional heating because of uniform heating and better control of process parameters. The temperature of chemical reactions can also be easily monitored.[25-31]

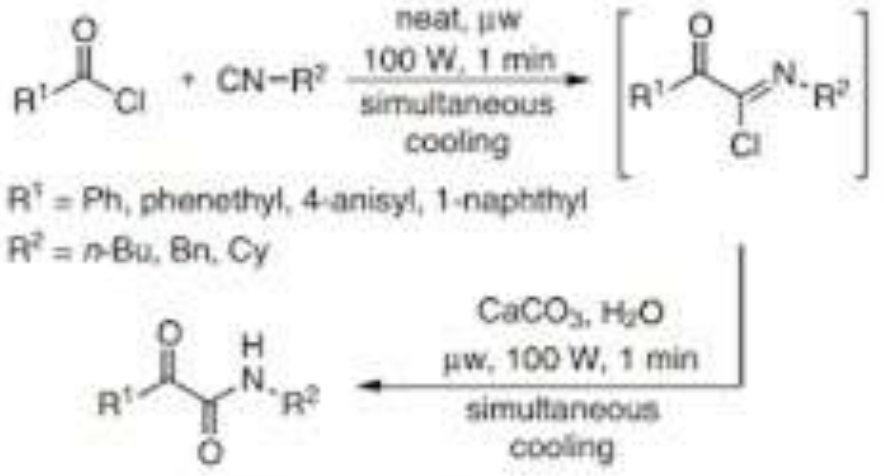
LIMITATIONS OF MICROWAVE ASSISTED SYNTHESIS

The yield obtained by using microwave apparatus available in the market is limited to a few grams. Although there have been developments in the recent past, relating to the scalability15 of microwave equipment, there is still a gap that needs to be spanned to make the technology scalable. The use of microwaves as a source of heating has limited applicability for materials that absorb them. Microwaves cannot heat materials such as Sulphur, which are transparent to their radiation. Improper use of microwave heating for rate enhancement of chemical reactions involving radioisotopes may result in uncontrolled radioactive decay. Certain problems, with dangerous end results, have also been observed while conducting polar acid-based reactions, for example, microwave irradiation of are action involving concentrated sulphuric acid may damage the polymer vessel used for heating. Conducting microwave reactions at high- pressure conditions may also result in uncontrolled reactions and cause explosions. Health hazards related to microwaves are caused by the penetration of microwaves. While microwaves operating at a low frequency

range are only able to penetrate the human skin, higher frequency-range microwaves can reach body organs. Research has proven that on prolonged exposure microwaves may result in the complete degeneration of body tissues and cells. It has also been established that constant exposure of DNA to high- frequency microwaves during a biochemical reaction may result in complete degeneration of the DNA strand.[19, 32, 33]

ENHANCED MICROWAVE SYNTHESIS

Recently, an alternative method for performing microwave- assisted organic reactions, termed Enhanced Microwave Synthesis (EMS), has been examined. By externally cooling the reaction vessel with compressed air, while simultaneously administering microwave irradiation, more energy can be directly applied to the reaction mixture. EMS ensures that a high, constant level of microwave energy is applied. Simultaneous cooling enables a greater amount of microwave energy to be introduced into a reaction, while keeping the reaction temperature low. This results in significantly greater yields and cleaner chemistries. EMS was employed in the synthesis of a variety of α-keto amides (Scheme 1) to support a protease inhibitor discovery project. This may eventually lead to improved treatments for stroke, Alzheimer's disease, and muscular dystrophy. Under conventional heating conditions, this took between 2 to 6 hours for completion; whereas under optimized EMS conditions, the two steps were completed in 2 min and in 21- 74% yields.[34, 35]



Scheme 1: Improved Synthesis of α – Keto Amides by Enhanced Microwave Synthesis

APPLICATIONS OF MICROWAVE ASSISTED SYNTHESIS

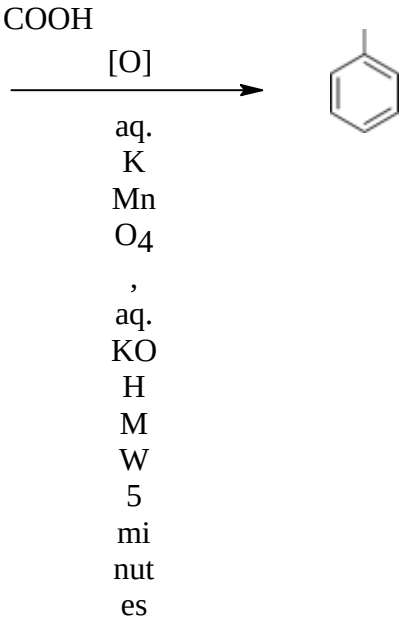
Application of microwave irradiation in chemical synthesis involves its use in the acceleration of chemical synthesis. Microwave-enhanced synthesis results in faster reactions, higher yields, and increased product purity. In addition, due to the availability of high-capacity microwave apparatus, the yields of the experiments have now easily scaled up from milligrams to kilograms, without the need to alter reaction parameters. Microwave-assisted synthesis can be suitably applied to the drug discovery process.[33]

Organic synthesis:

Microwave-assisted organic synthesis has been the foremost and one of the most researched applications of microwaves in chemical reactions. Literature survey reveals that scientists have successfully conducted a large range of organic reactions. These include Diels-Alder reaction, Eni reaction, Heck reaction, Suzuki reaction, Mannish reaction, Hydrogenation of [beta]-lactams, Hydrolysis, Dehydration, Esterification, Cycloaddition

reaction, Epoxidation, Reductions, Condensations, Cyclisation reactions, Protection and deprotection, etc.[34] Microwave-assisted organic synthesis is being widely applied in the pharmaceuticals industry, particularly for developing compounds in the lead optimization phase of drug discovery and development. In this phase, chemists use diverse synthetic techniques to develop candidate drugs from lead compounds. Based on reaction conditions, organic synthesis reactions can be conducted in the following techniques.

(1) **Microwave-assisted organic synthesis at atmospheric pressure:** Microwave-assisted organic synthesis can be most conveniently conducted at atmospheric pressure in reflux conditions, for example, oxidation of toluene to benzoic acid (**Scheme 2**) with $KMnO_4$ under normal conditions of refluxing takes 10-12 hours compared to reaction in microwave conditions, which takes only 5 minutes. **Table 2** shows an increased yield of 200 % for the oxidation of hexane nitrile and 150 % for the hydrolysis of cyclohexene when the reaction is conducted in the microwave batch reactor.[36, 37]



Scheme 2: Oxidation of toluene to benzoic acid with $KMnO_4$

Table 2: Heterogeneous reactions under microwave and classical heating[36]

Chemical reaction	Time (minutes)		MW Yield (%)
		Classical Yield (%)	
Hydrolysis of hexane nitrile	60	40	26
Oxidation of cyclohexene	60	26	12

(2) **Microwave-assisted organic synthesis at elevated pressure:** Microwaves can be used to directly heat the solvents in sealed microwave-transparent containers. The sealed container helps in increasing the pressure in the reactor, which facilitates the reaction that will take place at much higher temperatures. This results in a substantial increase in the reaction rate of microwave- assisted organic synthesis.[12]

(3) **Microwave-assisted organic synthesis under solvent- free conditions:** Microwave-assisted solvent-free organic synthesis has been developed as an environmentally

friendly process as it combines the selectivity associated with most reactions carried out under microwaves with solvent and waste-free procedures in which organic solvents are avoided throughout all stages. The solvent-free organic syntheses are of three types: (i) reactions using neat reactants; (ii) reactions using solid-liquid phase transfer catalysis (PTC); and (iii) reactions using solid mineral supports. The microwave-assisted reaction could be completed within two to three minutes, compared to conventional oil-bath heating at 75 °C for 40 hours.[12, 38]

Inorganic synthesis:

A variety of materials such as carbides, nitrides, complex oxides, silicide's, zeolites, apatite, etc. have been synthesized using microwaves. A series of A_3B and A_4 type mesoporphyrinic complexes were synthesized with superior yields using microwave irradiation under solvent-free conditions. Solvent-free synthesis by microwave irradiation has been successfully applied to obtaining mesoporphyrinic compounds because the absence of solvent from the reaction environment has the effect of decreased interaction time between reactant molecules and improves the reaction yield. Two new iso-structural coordination polymers with novel anionic metal-organic frameworks were synthesized using microwave-assisted technique. Microwave-assisted synthesis of pinacol boronates from aryl chlorides catalysed by a palladium/imidazolium salt system was reported.[39-43]

Synthesis of nanotechnology products:

Amongst the several methods that exist for synthesizing of nanoparticles, the use of microwave assisted synthesis has shown promise. Synthesis of silver nanoparticles from silver nitrate employing starch as the reductant as well as stabilizing agent has been carried out under direct heating, controlled heating and microwave irradiation. The microwave irradiation was considered as better for reduction of silver ions to silver nanoparticles. It also afforded smaller particle sizes and particle size distribution. Compared to conventional methods, microwave assisted synthesis was faster and provided particles with an average particle size of 12 nm. Nanostructures with smaller sizes, narrower size distributions, and a higher degree of crystallization were obtained under microwave heating than those in conventional oil-bath heating. The gold nanoparticles have been prepared by microwave high-pressure procedure with alcohol as the reducing agent. A method has been reported for microwave-assisted non-aqueous synthesis of zinc oxide nanoparticles. Particularly the fast reaction rates, better product yields and the possibility to automatically combine different experimental parameters makes microwave- assisted synthesis suitable for the studies of the influences of the reaction conditions on the morphology and sizes of zinc oxide nanoparticles particles, which determine its properties and applications. Pt/C and $PtCo_3O_4$/C nano catalysts were prepared using microwave assisted methods. The results of XRD and TEM revealed that the prepared catalysts have small and uniform shapes with high dispersion ability. The developed approach is a useful method for preparing platinum and platinum supported electro catalysts, which can be used in the field of fuel cells and other related fields. Strontium stannate ($SrSnO_3$) nanostructures were obtained by microwave-assisted calcination of a $SrSn(OH)_6$ precursor powder. Compared to other conventional calcination methods mentioned in the literature, this procedure led to a remarkable decrease of the reaction time and the synthesis temperature owing to direct interaction of radiation with the material.[9, 44-50]

Polymer synthesis:

Polymer chemistry, including ceramic processing, forms the single-largest application area of microwave chemistry. The use of polar reactants in polymerization reaction results in controlled synthesis and a combination of this with direct heating of reactants makes microwave heating an economically viable option. Using microwave radiation in curing has greatly increased the rate of the reactions. It has been found that the rate of a curing reaction, using microwaves, is not dependent on the power applied but on the way the pulse is applied. Controlled solvent-free synthesis and modification in polymer materials can be rapidly and effectively done with the help of microwave heating using large scale reactors The first microwave assisted organic synthesis of Poly Lactic Acid was carried out with SnOct as catalyst by using toluene as a solvent.[51, 52]

Peptide synthesis:

A microwave-assisted, rapid solid phase peptide synthesis procedure has been reported. The synthesis protocol is based on the use of cycles of pulsed microwave irradiation with intermittent cooling of the reaction during the removal of the Fmoc protecting group and during the coupling. The desired nono peptide was obtained in highest yield and purity by employing Micro Kan technology. The protocols for the synthesis of cystine-rich peptides in the presence of microwave radiation with solid phase peptide synthesis have been reported. The method is broadly applicable for a wide range of peptides using Boc-SPPS, especially for SPPS of large peptides via native chemical ligation. Microwave radiation produces peptides in high yield and with high purity, and the time for the assembly of approximately 30 amino acids peptide chains was reduced to an overnight reaction in the automated microwave-assisted synthesis. The applications of microwaves in the field of peptides and glycol peptides have been reported.[53-56]

Synthesis of radiopharmaceuticals:

Microwave-assisted organic synthesis at an elevated pressure has been used in pharmaceutical industry for the synthesis of radiopharmaceuticals. During pre-clinical trials, these radiopharmaceuticals are used as tracers to generate a nuclear medical image. A multi-mode microwave oven was used in the first trial of this kind and it was observed that the rate of reaction increased substantially. This has resulted in the enhanced use of microwaves to produce radiopharmaceuticals. Advantages of microwaves include the fast reaction rates and high yield of the reaction. This can be attributed to the short half-life of reactants, for example, saving five minutes in a synthesis with carbon-11 resulted in an enhanced production rate of 15%. It has also been observed that several reactions could only be achieved by using microwaves.[57-60]

CONCLUSION

Microwave-assisted synthesis is a convenient way toward the goal of green chemistry. Microwaves irradiation can be used to in chemical synthesis as a heat source; it is very efficient and can be used to significantly reduce reaction times of numerous synthetically useful chemical transformations. Thus, microwave-assisted synthesis has advantages over conventional technology: it is more energy efficient and it can lead to improved isolated yields of products with green synthesis. The advantages of this enabling technology have, more recently, been exploited in the context of multistep total synthesis and medicinal chemistry/drug discovery, and have additionally penetrated related fields such as polymer synthesis, material sciences, nanotechnology and biochemical processes. In order to achieve further development in this field, novel instruments, which give rise to reproducible performances and that constitute a minimal hazard should be used instead of the domestic microwave ovens.

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