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Green Chemistry and Microwave Irradiation Technique: A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Green Chemistry is a term used for the process of making chemical substances in a sustainable way. The aim of green chemistry is to minimize the hazardous footprint on the environment produced by manufacturing and production of various chemical compounds. Green chemistry focuses on using less toxic materials in synthesis of chemicals by increasing efficacy of chemical synthesis and minimizing waste production. The way forward with green chemistry includes use of various potent techniques like microwave irradiation technique. The use of microwave assisted technique has brought a revolution in the field of chemical study and manufacturing. Through this technique even minute compounds and molecules can be synthesized in a fraction of time. The microwave is primarily used in heating the chemical material by conduction and dipolar polarization. The use of microwave irradiation technique is regarded as a crucial element of green chemistry because it produces clean compounds without any residual toxins. The compounds produced are very efficient as they have higher yields and better reactivity and selectivity. The microwave irradiation technique is widely used in the field of nanotechnology as well.

Keywords: Green chemistry; microwave; irradiation; nanotechnology.

1. INTRODUCTION

Green chemistry is the process of making chemical compounds that decrease or dispose of the utilization or emission of unsafe substances. Green chemistry is applicable throughout the steps of manufacturing the chemical substance, including its plan, assembling, use, and finally

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disposal. Another name for green chemistry is sustainable chemistry [1-3]. The basic proponents by Green chemistry are as follows:

- Green chemistry aims at preventing pollution at molecular level.
- The principles of Green Chemistry are applicable on all the streams and domains of chemistry.
- Aims at solving environmental and ecological issues in a clean and sustainable way.
- It focuses on enhancing the overall quality of the chemical substance by increasing efficacy at all levels of production and minimizing pollution and waste disposal as well.
- Primarily the idea of sustainability is used to reduce the hazardous effect of chemicals on human and environmental health.
- It aims at tackling even the hazardous impact of existing chemical products by revising their manufacturing and production processes.
- Green chemistry focuses on designing the chemical synthesis in such a way that the produced material is efficient and non toxic and non hazardous by using 12 basic principles that will be discussed later in the paper.

1.1 Historical View of Green Chemistry

Green chemistry arose out of an assortment of existing thoughts and exploration endeavors (like atom economy and catalysis) in the period till 1990s, with regards to expanding attention regarding issues of chemical contamination and depletion of resources [4-7]. The improvement of green chemistry in Europe and the United States was connected to a change in ecological critical thinking systems: a development from order and control guideline and commanded decrease of modern emission toward the "finish of the line," around the dynamic prevention of pollution through the inventive plan of production technologies themselves [8-10]. The arrangement of ideas currently perceived as green chemistry mixed in the mid-to late-1990s, alongside more extensive reception of the term (which beat contending terms, for example, "clean" and "sustainable" chemistry).In the United States, the Environmental Protection Agency assumed a critical early part in cultivating green chemistry through its pollution counteraction projects, subsidizing, and proficient coordination. Simultaneously in the United Kingdom, research scholars at the University of York added to the foundation of the Green Chemistry Network inside the Royal Society of Chemistry, and the send off of the journal Green Chemistry [11-15].

1.2 12 Principles of Green Chemistry

Paul Anastas and John C. Warner published a set of few principles to guide the practice of green chemistry in the year 1998. They proposed a total of twelve principles. These principles elaborated a variety of methods to decrease the environmental and health impacts of chemical production. Moreover, they also highlight various aspects of research priorities for further development of green chemistry technologies.

Prevention of waste: Formulate such methods that lead to zero wastage. Prevention of waste during any process.

Maximization of atom economy: Formulate the syntheses in such a manner that no atoms are wasted. In other words, the final product must have the maximum proportion of the starting material.

Design less hazardous chemical methods: Formulate such syntheses that produce less toxic materials. No harm to the environment as well as to human beings must be ensured.

Design safe products and chemicals: Formulate such methods that lead to the production of chemicals and products that have negligible toxicity and yet effective.

Usage of safe solvents and reaction conditions: It should be made sure that safe solvents must be used. Moreover, there should be a reduction in the usage of solvents, separation agents, and other auxiliary chemicals.

Enhance energy efficiency: While production, there should be minimal usage of pressure and ensure chemical reactions at room temperature.

Usage of renewable feedstocks: Use initiator (feedstocks) which are renewable rather than exhaustible. The sources of renewable feedstock are plant-based products or leftovers from other processes; on the other hand, for depleted feedstocks it is often fossil fuels (i.e., petroleum, natural gas).

Avoiding the use of chemical derivatives: Keep away from blocking or protecting groups for best results as the usage of chemical Derivatives uses additional reagents and generates waste.

Use catalysts, not stoichiometric reagents: The usage of catalytic reactions leads to Minimum wastage as it can carry out a single reaction many times. They are better than stoichiometric reagents, which are used in large amounts as compared to the catalyst and carry out a reaction only once.

Design degradable chemicals: Design chemical products in a way that it breaks down to smaller particles after use so there is no accumulation.

Real time analysis: Constant monitoring and control during syntheses leads to minimum or complete elimination of side products.

Minimize the potential for accidents: In order to minimize the potential for chemical accidents like fires, explosions; chemicals and their physical forms (i.e. solid, liquid, gas) should be designed accordingly.

1.3 Applications of Green Chemistry

Green Chemistry finds usage in many fields, 2 of the major ones are discussed as follows:

1. **In Synthesis of novel environment friendly chemical compounds**: New innovative chemical technologies like nanotechnology can provide improved environmental performance and enable better adherence to the principles of green chemistry. An example of these type of innovation is the metathesis method in organic synthesis which employs the idea of green chemistry and is known for smarter and better production. The pioneers of this method were Yves Chauvin, Robert H. Grubbs and Richard R. Schrock who were awarded the 2005 Nobel Prize for Chemistry. Their work also talked about three key developments in green chemistry in the field of organic synthesis: 1. use of supercritical carbon dioxide as green solvent 2. aqueous hydrogen peroxide for clean oxidations 3. the use of hydrogen in asymmetric synthesis.
2. **In synthesis of Green solvents:** The use of green chemistry is widely seen in production of green solvents which are majorly used in paint and coatings industries as a solvent to mix paint. The green solvents are also used in making cleaning liquids, degreasing materials, adhesives, and various other chemical compounds. The earlier used solvents were usually heavily chlorinated and were toxic for the health of people and the environment as well.

Through this it can be summarized that green chemistry gives a new and better perspective to how chemicals can also be environment friendly and instead of posing harm to nature these compounds can actually add value to the people and environs that use them. The sustainability element of green chemistry has been discussed by scientists for decades and they are coming up with innovative ideas to design, develop and implement a working model in the field of green chemistry. All the 12 principles of green chemistry are equipping the scientists and engineers to protect and benefit the economy, people and the planet by finding creative and innovative ways to reduce waste, conserve energy, and discover replacements for hazardous substances.

2. MICROWAVE IRRADIATION TECHNIQUE

Microwave chemistry is the technique that uses the microwave radiation for certain chemical reactions. The microwave synthesis has brought about a breakthrough change in the conventional chemical synthesis process. Synthetic chemistry has its vast application. Conventional methods of synthetic chemistry result in excess of time consumption and are also less effective. This limits the entire process and hence results in wastage of time, resources and efforts. There are many benefits of using microwave synthesis, like, researchers can work on innovative ideas, have better exposure to test theories and hence develop new improved processes. The microwave irradiation technique is highly time effective, which means that the processes which took days or hours of working can be accomplished in just a few minutes by using this technique. Moreover, with the help of this technique, reactions can be done without the presence of a solvent and hence, it results in zero wastage of solvents or other harmful chemicals. In order to make the best use of this technique, this technique can be jointly used with mineral-supported catalyzed reactions. If these two methods are effectively implemented by

using solvent-free conditions then they produce multiple advantages of clean and safe chemical processes. Other advantages of this combination are ease in manipulation of compounds, improved reaction rates, enhanced yields and better selectivity. Hence, it can be observed that microwave irradiation technique is a potent tool for achieving green chemistry.

Microwave irradiation technique has altered the conventional methods of heating and improved the overall energy systems. This technique converts the electromagnetic energy into heat. This is possible because here the movable conducting ions that are in liquid form are converted into solid form. The microwave radiations are located between the spectrum of infrared radiation and radio waves in the electromagnetic spectrum. The frequency of microwaves lies between 0.3 to 300 GHz and its wavelength is between 1 mm to 1 m. This frequency of microwaves is common with many microwave radar equipment as well as the telecommunication processes. The electromagnetic radiation heat can be used for enabling reactions through microwave dielectric heating which converts the radiation heat into reaction heat using some mobile solids and liquids. Hence, this technology is highly useful for synthetic chemistry where conventional methods fail to perform effectively.

In the process of organic synthesis there has been wide applicability of microwave-assisted organic reactions. There has been numerous benefits of microwave irradiation, which are as follows: (i) shorter reaction times (ii) enhanced productivity (iii) simple workup (iv) follows green chemistry guidelines (v) improves region and stereo selectivity of reactions (vi) enhanced efficiency of various organic transformations and synthesis. Many industries and other research institutions have used high-speed microwave-assisted chemistry in the fields of synthetic organic chemistry, proteins, peptides, drug innovation and discovery as well as green chemistry. There are various benefits of microwave processing when compared to the conventional methods of heating. These benefits include - energy efficiency, well-defined microstructure, reduced cycle time, eco-friendly, improvised mechanical properties.

2.1 Advantages of Microwave Irradiation Technique

Microwaves have been widely used for various organic synthesis because it allows faster reaction, enhances yields, ensures purity. It also allows efficient usage of energy by providing selective heat uniformly in the reaction. Hence, there is a greater chance of reaction reproduction as well as overall cleaner synthetic routes for any reaction. The main advantages of microwave assisted organic synthesis are as follows:

1. **Faster reaction:** On the basis of various studies it has been discovered that the rate of microwave enabled chemical reactions is 1000 times faster than conventional heating methods. Since the reaction rate is fast and the temperatures achieved is quite high therefore any reaction takes only a few hours as compared to conventional heating that takes longer hours or even days sometimes. For example - fluorescein synthesis can be completed in just thirty five minutes through microwave heating whereas conventional heating takes almost ten hours to do the same process.
2. **Better yield and higher purity**: Microwave irradiation technique leads to higher yield and also ensures low side product formation during any reaction. Moreover, this technique also ensures a higher purity level which is easier and faster to conduct. For instance, the synthesis of aspirin via microwave irradiation technique leads to more than 85% of the existing yield of the reaction.
3. **Energy saving:** The microwave irradiation technique is energy efficient and helps in significant amounts of energy savings. This is possible due to the characteristic of microwave heating which enables only the sample to be heated and not the apparatus, thereby consuming less energy than conventional heating.
4. **Uniform and selective heating:** The microwave heating works on the principle that only the solvent and the solute present in any reaction gets heated so that there remain a uniformity in the amount of heat received by each component in the reaction. Contrarily, the conventional heating technique uses an oil bath to heat the solvents therefore there is a difference in the level of heat on the walls of the oil bath and the solvent present there. Another aspect of microwave irradiation is that it allows selective heating in which different compounds respond differently to microwaves like, few materials are

transparent and few can absorb the microwaves.

5. **Green synthesis:** The microwave irradiation technique follows the guidelines of green chemistry and hence it is safe for human beings as well as eco-friendly. AS already discussed, the microwave heating heats the reaction directly and does not require a solvent therefore it eradicates the use of harmful solvents. Using such safe methods for reactions leads to better application of green synthesis protocols. Moreover, the resultant of such technique is so pure that no further purification using harmful reagents is required.
6. **Reproducibility:** Microwave heating allows the reactions to be more reproducible when compared to the conventional heating methods. This is so because microwave heating allows uniform heating of the reactions and also it provides enhanced control over other parameters of the process. Moreover, this technique also enables constant temperature monitoring of any chemical reactions.

2.2 Disadvantage of Microwave Irradiation Technique

Along with many advantages, there are certain drawbacks of using the microwave irradiation technique. These disadvantages as discussed below in detail:

1. **Unavailability of Apparatus:** The apparatus for using microwave technique is not universally available which makes its applicability limited. However, developments have been made to enhance the scalability of these equipment still there is a long way to go to make this technology more accessible.
2. **Cannot be universally applied:** As mentioned earlier, not all compounds absorb the microwaves for heating and hence this technique cannot be useful with each and every element. Those elements that are transparent like sulfur will have no effect of the microwave heat on them as they do not absorb that heat.
3. **Environmental Threats:** Microwave heating can lead to radioactive decay when it is used excessively for rate enhancement of chemical reactions. In some cases, the end result of any reaction after using this technique is dangerous, especially if it is a polar acid-based reaction. For example - when microwave irradiation is used in a reaction having concentrated sulphuric acid can damage the polymer vessel used for heating. Moreover, the microwave reactions can go out of control if they are done at very high pressure which might also lead to explosion.
4. **Health Hazard to Humans:** There can be health hazards while using the microwaves irradiation technique because they are capable of penetrating into the human skin. Consequently, a much higher frequency of microwaves can also penetrate deep into the human organs. Many researchers have found that a prolonged exposure to these microwaves can lead to body tissues and cell damage. Moreover, a complete DNA strand can be damaged due to excess exposure of DNA to higher frequency of microwave irradiations.

In order to bring down these negative aspects of microwave irradiation technique, green chemistry guidelines can be followed. The use of green chemistry can enhance the efficiency of synthetic methods, enable lesser usage of toxic solvents, reduce the synthetic route process and minimize waste. Chemical synthesis can be revolutionarised by using microwave techniques and hence can be a part of sustainable development. When compared to the traditional heating methods, this technique can do the same task in a fraction of seconds thereby saving the time, cost, resources and also reducing wastage. Microwave irradiation is extensively used in various industries and research organizations as it allows clean synthesis of the compounds along with benefits like higher reaction rates, better yield, uniformity and selectivity. Due to these advantages many chemists have started adopting this technique and replaced it for the conventional one. Microwave-assisted synthesis is increasingly becoming the most applicable technique in modern chemical synthesis and drug discovery.

3. CONCLUSION

Through this paper it can be concluded that for a better environment green chemistry is the way of the future. The chemical compounds if not produced sustainably and in a clean way the environmental impact of these compounds will be very toxic and hazardous for the environment. Endeavors are being made not exclusively to

measure the greenness of a synthetic cycle yet in addition to factor in different factors, for example, compound yield, the cost of response parts, security in dealing with synthetic substances, equipment requests, energy profile and simplicity of manufacturing. One of the many techniques used under the umbrella term of green chemistry is microwave irradiation technique which is primarily used in heating the chemical compound while manufacturing. This technique is used because it is not only sustainable but also produces more efficient compounds and less waste. Compounds made using this technique are also more efficient in reactivity and selectivity. The microwave irradiation technique finds usage in various aspects like chemical compound synthesis, biochemical studies, peptide synthesis and nanotechnology. The scope of microwave irradiation technique is very wide within the domain of green chemistry and more extensive research in this area can potentially develop more sustainable chemical products.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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