Chapter 4
Sonochemical Applications in Plant-Based Extraction and Green Synthesis

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ABSTRACT

This chapter explores sonochemical processes in plant-based extraction and green nanomaterial synthesis. Acoustic cavitation—the formation, growth and collapse of microbubbles—enhances mass transfer in extraction and provides controlled conditions for nanomaterial synthesis using plant extracts as reducing agents. These applications demonstrate significant advantages over conventional methods, including reduced processing time, lower solvent consumption, and decreased energy requirements. The chapter details reactor designs, optimization strategies, scale-up considerations, and sustainability assessments, providing comprehensive implementation guidelines for researchers and industry practitioners seeking to develop environmentally sustainable sonochemical processes.

INTRODUCTION

Such integration of sonochemical processes into green chemistry and bioprocessing technologies is a major development. In the past two decades, ultrasound assisted extraction (UAE) has been proven as a potential extraction alternative to traditional methods for bioactive compounds of plant materials (Chemat et al., 2017). Also, the development of green synthesis routes for the formation of nanomaterials using

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plant extracts has become a major focus as an environmentally benign method for nanomaterials synthesis (Iravani, 2020). It is demonstrated here that, the convergence of these two applications via sonochemistry provides novel opportunities for industrial sustainability and process intensification.

This is the fundamental basis of sonochemistry based on acoustic cavitation which increases mass transfer and kinetics of reactions to improve extraction efficiency as well as control synthesis by several orders of magnitude (Ashokkumar, 2016). When ultrasonic waves travel through a liquid medium, they cause vibrating compression and rarefaction cycles leading to the development, growth, and explosively collapse of microbubbles. During this cavitation process, these cavities produce highly localized extreme condition temperatures (approaching 5000 K), pressures (>1000 atmospheres), cooling rates (>10^10 K/s) and drive both physical and chemical transformation (Suslick & Price, 1999). The specific conditions offered by these are conducive for cell disruption in plant materials, therefore enhancing solvent penetration and mass transfer of bioactive compounds as well as providing the energy needed for reduction and stabilization of metal ions from the synthesis of nanomaterials (Tiwari, 2015).

These applications are of industrial importance because they fulfill several principles of green chemistry. Generally, milder conditions, shorter processing times, lower solvent use are common for most of sonochemical processes when compared to conventional methods (Chemat et al., 2020). Furthermore, the utilization of plant extracts as reducing and capping agents in nanomaterial synthesis removes the use of hazardous chemicals that are incorporated in traditional synthesis routes (Rana et al., 2021). The advantages of sonochemistry place this technology as a valuable tool for industry to impact product quality and process efficiency with less impact on the environment.

This chapter details the application of sonochemical process in plant based extraction and green synthesis of nanomaterial in both fundamental understanding and practical implementation perspectives. The discussion should bridge the gap between laboratory research and industrial application by systematic analysis of reactor designs, process parameters, optimization strategies and scale up challenges. Quality assurance protocols, sustainability assessments and emerging trends that sell the development of these technologies are given special attention. This chapter provides theoretical knowledge with practical implementation guidelines integrated in such a way that the material will be of particular value to the researchers and process engineers as well as industrial practitioners who are contemplating sustainable sonochemical process.

Thermal-Perception-Driven Adaptive Design for Wellbeing in Outdoor Public Spaces: Case Studies in Naples

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