



TRANSFORMING FOOD ANALYSIS AND CONTROL:

NON-DESTRUCTIVE TECHNOLOGIES AND INNOVATIONS

K. Prasad, S. Shekhar, M. K. Paswan and R. Ahuja



Advancing Food Quality, Safety and Sustainability with
Smart, Innovative and Non-Destructive Technologies



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Insights of Microwave: Analytical and Food Processing Applications

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Abstract. Dielectric properties form a bridge between material and material characterisation. Low-power microwaves are non-destructive, and dielectric measurements have made this an emerging method in material characterisation. Compilation of various aspects of microwave, their categorisation, and the generation of microwaves are covered. Open-ended coaxial probe method, waveguide-as-transmission-line method, cavity perturbation method, time-domain spectroscopy method, impulse time-domain transmission method, free-space transmission method, and parallel-plate method as measurement techniques are reviewed, along with instrumentation, including Vector Network Analyser and Impedance Analyser. The applications of high-power microwaves in various thermal processing unit operations, such as blanching, pasteurisation, sterilisation, thawing and tempering, drying, and baking, may be revolutionised by integrating microwaves with conventional thermal approaches to enable efficient food processing. A thorough effort to consolidate all aspects of dielectric measurements and encompassing diverse applications in food engineering under the canopy of microwaves may thus prove to be the future tool for researchers and industrialists to fulfil the need.

Keywords: Microwave, Dielectric constant; Dielectric loss; Analytical tool; Processing methods; Frequency; Microwave heating.

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1. Introduction

Gamma rays to radio waves in the electromagnetic spectrum surround the universe in various forms and play a crucial role in research. The electromagnetic spectrum includes radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays (Fig. 1). A varied range of spectrum over frequencies, electromagnetic radiations can be used to study a system of different sizes from a size much smaller than nanoscale to a size in kilometres. Electromagnetic radiation has both electric and magnetic fields oscillating in perpendicular directions, travelling at a speed of 3×10^8 m/s through space (Fig. 2). The behaviour of electromagnetic radiation is mainly governed by Maxwell's equations (Griffiths, 2023; Jackson, 2021).

Both low and high power microwaves have been widely used for research purposes, such as in astrophysics, where radio- telescopes use microwaves for the study of cosmic background; for drying materials in textile and paper industries; for medical purposes in the treatment of cancer, etc.; in microwave spectroscopy to analyse molecular structure; as well as in daily life, microwave ovens for food processing applications, wireless communication such as WiFi, radar systems for military defence, and air traffic (Pozar, 2021). Further, the applications of microwaves can be extended to the knowledge of dielectric properties. Several other properties of a material can be determined using dielectric properties, which describe the material's response to electromagnetic radiation. A Vector Network Analyser (VNA) is employed for this purpose. Depending on factors affecting the dielectric and the state of the dielectric (solid, semi-solid, or liquid), there are various approaches to finding the dielectric constant, such as Transmission / Reflection Line Method, the Cavity Perturbation Method, the Coaxial Probe Method, Time-Domain Spectroscopy, the Impulse Time Domain Transmission technique, the Free Space Transmission technique, and the Parallel Plate technique. Further details, along with advantages and disadvantages, are summarised in the upcoming sections.

The device described to heat food utilising electromagnetic waves with a wavelength of 10 cm, a microwave, is a major revolution in food heating and cooking, and was patented in 1945 (Tang, 2015). As the name suggests, microwave ovens utilise microwaves for heating purposes (Ohlsson and Bengtsson, 2001). Heat generation throughout the entire volume of food material occurs due to the interaction of microwaves with polar molecules, mainly water and charged ions. Therefore, discussing the mechanisms of

10. Conclusion

A comprehensive progression from the fundamentals of microwaves, including the electromagnetic spectrum, to their impact on a material's dielectric properties, covering both physics and food engineering standpoints. The methods for generating microwave, its transmission, and its applications, along with its classification and importance in the food industry, are discussed. The Physics angle includes understanding electromagnetic theory and knowledge of polarisation and its types, i.e., electronic, ionic, dipolar, and spatial polarisation. Microwaves, due to their ability to interact with dipolar polarisation, are an exceptional tool to investigate the dielectric properties of a material. All the formulations of dielectric properties, that is, dielectric constant, dielectric loss and loss tangent, discussed before, are based on the fact that the dielectric property has a complex nature. The various approaches to dielectric constant, such as Debye Model, Parallel Plate Capacitor Method, the Clausius-Mossotti relation, and the Optical Method have been outlined thoroughly in the previous sections under theoretical approaches. Experimentally, both the impedance analyser and the VNA have their grounds. Despite being sensitive to surrounding noise and expense, operating in the frequency domain is the only main drawback of the impedance analyser. VNA is in the spotlight because of its operation in both the time and frequency domains. The open-ended coaxial probe method, Waveguide method, and cavity perturbation method are widely used to determine the dielectric properties of a material. The direct application of microwave in the food industry is microwave heating in the 915 MHz and 2450 MHz bands, as specified by the FCC ISM bands.

The integration of microwaves in the food industry has led to a revolution in processing and preservation methods, with several benefits, including reduced processing time, nutrient retention, effective control of microbial growth, improved quality and texture, cost efficiency, and energy efficiency. Microwave technology is an emerging tool for developing new products and processes while ensuring compliance with product quality and safety regulations. The major concern with the use of microwaves in food is non-uniform heat distribution due to several factors, including shape, size, moisture content, and fat content. Thus, it has been observed that combined microwave heating methods, compared with separate ones, offer greater benefits.

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