

# Microwave Irradiation and its Application in Textile Industries

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National Research Center, Dokki, Cairo, Egypt

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## Introduction

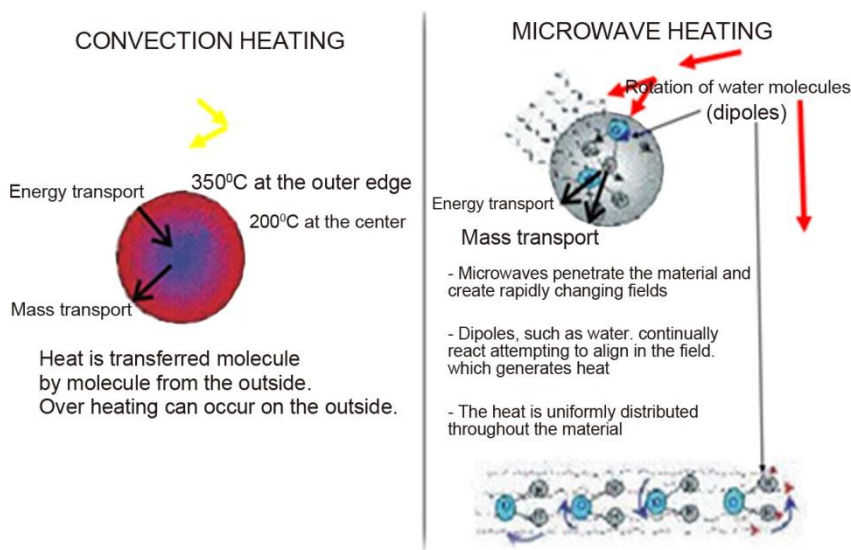
Textile processing consumes huge amount of energy as in dye fixation and heat setting. Heat can be transferred to material by radiation, conduction and convection. These three ways of heat transfer can be used either separately or in combination. Saving time and energy is of immediate interest to textile industry. The introduction of new techniques which will allow less energy to be used is a highly important area of activity to consider. A relatively short section of properly designed microwave heating can increase production speeds.

In microwave processing, energy is supplied by an electromagnetic field directly to the material. This results in rapid heating throughout the material thickness with reduced thermal gradients. Volumetric heating can also reduce processing times and save energy. The microwave field and the dielectric response of a material govern its ability to heat with microwave energy. Knowledge of electromagnetic theory and dielectric response is essential to optimize the processing of materials through microwave heating.

This review addresses major basic and practical aspects of microwave irradiation as means of heat generation. Emphasis is placed on electromagnetic field dielectric response as well as application of microwave heating to textile coloration, processing equipment, and microwave/materials interactions. A future outlook is also reported within the increasing importance of microwave irradiation in textile coloration and other domains of application.

In the last three decades, the microwave oven has become an essential appliance in most kitchens. Faster cooking times and energy savings over conventional cooking methods are the primary benefits. Although the use of microwaves for cooking food is widespread, the application of this technology to the processing of materials is a relatively new development. The use of microwave energy for processing materials has the potential to offer similar advantages in reduced processing times and energy savings. In conventional thermal processing, energy is transferred to the material through convection, conduction, and radiation of heat from the surfaces of the material. In contrast, microwave energy is delivered directly to materials through molecular interaction with the electromagnetic field. In heat transfer, energy is transferred due to thermal gradients, but microwave heating is the transfer of electromagnetic energy to thermal energy and is energy conversion, rather than heat transfer. This difference in the way energy is delivered can result in many

potential advantages to using microwaves for processing of materials. Because microwaves can penetrate materials and deposit energy, heat can be generated throughout the volume of the material. The transfer of energy does not rely on diffusion of heat from the surfaces, and it is possible to achieve rapid and uniform heating of thick materials. In traditional heating, the cycle time is often dominated by slow heating rates that are chosen to minimize steep thermal gradients that result in process-induced stresses. For polymers and ceramics, which are materials with low thermal conductivities, this can result in significantly reduced processing times. Thus, there often is a balance between processing time and product quality in conventional processing. As microwaves can transfer energy throughout the volume of the material, the potential exists to reduce processing time and enhance overall quality.



**Fig. 1.** Energy transfer comparison.

In addition to volumetric heating, energy transfer at a molecular level can have some additional advantages. Microwaves can be utilized for selective heating of materials. The molecular structure affects the ability of the microwaves to interact with materials and transfer energy. When materials in contact have different dielectric properties, microwaves will selectively couple with the higher loss material. This phenomenon of selective heating can be used for a number of purposes. In conventional joining of ceramics or polymers, considerable time and energy is wasted in heating up the interface by conduction through the substrates. With microwaves, the joint interface can be heated in-situ by incorporating a higher loss material at the interface [1]. In

multiple phase materials, some phases may couple more readily with microwaves. Thus, it may be possible to process materials with new or unique microstructures by selectively heating distinct phases. Microwaves may also be able to initiate chemical reactions not possible in conventional processing through selective heating of reactants. Thus, new materials may be created.

In recent literature, many researchers report non-thermal phenomena that have been broadly termed “microwave effects”. Examples of the microwave effect include enhanced reaction rates of thermosetting resins during microwave curing [2] and faster densification rates in ceramics sintering [3]. Although there is considerable debate over the existence of microwave effects, many papers present unexpected results that do not seem to be a consequence of reduced thermal gradients possible within microwave processed materials. Critics of the microwave effect often claim that differences can be attributed to poor temperature measurement and control of experimental conditions that result in systematic error. Although direct heating by microwaves can offer advantages over conventional heat transfer, the different mechanism of energy transfer in microwave heating has also resulted in several new processing challenges. Because energy is transferred by the electromagnetic field, non uniformity within the electromagnetic field will result in non-uniform heating. As materials are processed, they often undergo physical and structural transformations that affect the dielectric properties. Thus, the ability of microwaves to generate heat varies during the process. Sharp transformations in the ability of microwaves to generate heat can cause difficulties with process modeling and control. Understanding the generation, propagation, and interaction of microwaves with materials is critical. Because the processing equipment determines the electromagnetic field, the design of microwave equipment is particularly important. The properties of the electromagnetic field, chemical composition of the material being processed, structural changes that occur during processing, size and shape of the object being heated, and the physics of the microwave/materials interactions all complicate microwave process [4–12].





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