About Some Applications of Microwave Energy

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Abstract ***– Microwave energy is an alternative energy source and the fundamentally different method of transferring energy from the source to the sample is the main benefit of utilizing microwave energy. Furthermore, the penetrating capacity of microwave allows volumetric heating of samples. These attributes of microwave energy make utilizing it very attractive for industrial applications as an alternative to conventional processing methods. The utilization of microwave energy has produced improved results compared to conventional methods with reduced heating times or reaction temperature ,so this article provides a general overview of reported applications of microwave energy.***

Keywords: ***microwave, applications of microwaves, microwave drying , microwave processes.***

I. INTRODUCTION

In the last decades the applications of microwave energy have been extended to a broad spectrum of fields, majority of the experiments carried out with microwave energy were primarily focused on its heating capabilities as an alternative to conventional heating methods; the direct energy transfer to the specimen allows rapid and volumetric heating of the sample while avoiding complications such as establishing thermal gradients on the container or sample surface associated with conventional heating methods. The volumetric heating of samples is further enhanced by the ability of microwave energy to penetrate the sample surface to induce heating deeper in the specimen. Furthermore, the sample heating induced by microwave fields is strictly influenced by the ability of the material to absorb microwave energy; this allows specimens to be selectively heated, which improves the efficiency of the energy introduced into the system.

The ability of materials to respond to the microwave fields depends on its dielectric constant; this property of the material becomes increasingly important in heterogeneous samples as the phenomenon of selective heating would influence the heating kinetics.

The scope of this article is to provide a general overview on common applications of microwave energy as an alternative heating source and reports on the results obttained by researchers for various applications and don’t coveraged of all publications dealing with industrial applications.

II. INDUSTRIAL APPLICATIONS

The nature of microwave energy to heat dielectric materials selectively makes its use in drying materials evident. The most commonly studied foodstuffs are pasta, fruits, vegetables and snacks. Conventional methods for drying utilize solar or hot air-drying and for utilizing solar drying some concerns include the potential for unhygienic conditions such as insect infections, contamination from handling, and bacterial growth. solar drying requires large amounts of space and long drying periods – the effectiveness and drying period is dependent on environmental conditions such as the intensity of sunlight available and the air humidity [1, 2].

With hot air-drying methods, the primary limiting factor in the drying efficiency is the permeability of the sample to diffuse moisture to the surface for evaporation; when the diffusion rate is slow, the sample will have significantly higher surface temperatures than the sample’s bulk. To overcome the limitations of hot air-drying, methods combining microwave energy with conventional hot air-drying technology have been proposed. The nature of microwave energy to volumetrically heat samples decreases the temperature gradient between the surface and the bulk of the sample. As a result, moisture content is able to diffuse to the surface quicker – allowing a shorter drying time compared to conventional hot air-drying – and reported to improve the dried product quality [3,4].

Microwave-assisted drying of pasta provides advantages over conventional hot air driers such as shorter drying times, higher energy efficiencies, and the potential of miniaturizing the required drying equipment [1,5]. The most effective drying method was a combination of a hot air drier assisted by microwave energy. The dielectric heating of foodstuff creates a pressure gradient within the sample and encourages moisture diffusion to the surface, which is normally a significant limiting factor of conventional drying. By using this hybrid method, the pasta studied dried to satisfactory moisture level in a fraction of the time required by conventional drying; dried short-cut pasta with a duration that was thirteen times shorter than conventional methods. Fissure formation on the drying pasta was reported for some test cases in microwave-assisted hot air drying methods; this phenomenon was attributed to the power of microwave energy used and the airflow rate into the drying chamber.

The dehydration of fruits and vegetables is a highly desirable process for optimizing the shelf life while maintaining the nutritional value and quality. Characteristics commonly chosen to criticize microwave assisted dried fruits and vegetables are generally the drying time and quality of the dried product: texture, hardness, surface colour, vitamin concentration, rehydration ability, and most taste. Was attributed colour changes while drying cherry tomatoes conventionally to the degradation of pigments such as carotenoids and browning reactions , changes in the pH of the fruit, and the processing temperature and time[4,5].

The concentration in vitamin C is monitored during drying as it is heat sensitive while desirable to maintain a high level of concentration in the dried product [12]. In the microwave-assisted drying of spinach, was reported drying 50 g spinach samples from 9.01 to 0.1 dry weight basis; the drying process took between 290 and 4005 s when using a microwave power of 1000 and 90 W respectively. The optimal concentrations of ascorbic acid in the dried product were reported using a microwave power of 750 W (43.09 mg / 100 g) and 650 W (43.57 mg / 100 g) during the drying process while the lowest concentrations were reported at 160 W and 350 W. Also the optimal colour measurement values were reported at 750, 650 while the lowest colour measurement values were reported at 1000 W. So the optimal microwave power level to be used would be 750 W. In [3] was compared the drying abilities of infrared and microwave energy. They reported that the overall drying times of ripe and near-ripe apricots were lower when using a microwave drier, and that concentrations of vitamins in microwave-dried apricots were higher than in infrared driers[3,5].

Research on the potential use of microwave-assisted drying of snacks studied the efficiency of the process and quality of the product as opposed to conventional methods. Many researchers found that using pre-dehydrated samples improved the overall efficiency of the process, indicating that initial moisture content is an influential factor in microwave-assisted drying processes and can affect the quality of the dried product [16,22]. Was tested the application of microwave-assisted drying to nuts because previous reports concluded that it was not viable due to the poor qualities of the dried product. The microwave-assisted drying process required around 5 hours as opposed to 140 hours for conventional drying. Quality of the dried products also improved, the moisture content in the sample vaporized much faster than at atmospheric pressure. This evaporation process reduced the amount of intense levels of heat anywhere in the sample. So even higher quality dried product that is uniform throughout the sample was obtained when there were resting periods during the microwave processing time, was obtained a uniform product quality when microwave heating duration – was 10 seconds of irradiation, in one-minute interval, these operating conditions removed the temperature gradients throughout the sample, thus allowing the sample to heat more uniformly [5,8].

Other drying applications was at the non-foodstuff , mainly as a pre-treatment for material processing or as an intermediate step in production. Was studied the potential for microwave-assisted drying of silica sludge to reduce disposal costs. The removal of water content was reported to be independent of the nature and presence of the sludge solid. As such, an aluminium stirrer, was placed in the ceiling of the microwave oven throughout the cavity. Furthermore, a magnetic stirrer placed in the beakers was shown to lower the temperature gradient in the sample solution. The amount of power used for drying was reported to have an optimal value, and that exceeding it did not have a significant influence on reducing the drying time for silica sludge[21,25].

Another application of microwave energy that has been studied is the potential of destroying pit membranes in wood to improve the overall moisture diffusivity during drying [10,11,14,15]. Drying materials that do not have a uniform moisture distribution can be problematic for conventional methods, as it relies on the diffusion of moisture to the surface – the non-uniform distribution would remain even after the drying process. Microwave drying has also been applied to dry moisture-sensitive products such as acetylsalicylic acid for pharmaceutical purposes[7,24]. They have reported on the application of microwave-assisted drying for the production of acetylsalicylic acid where the product was dried in its production container, thus, reducing the potential for contamination through human interactions.

Pasteurization is an important process in food industries to ensure product quality and safety prior to shipping[26,27]. Conventional methods for pasteurizing fruits and vegetables employ chemical pesticides and fungicides also hot water bath or steam treatments. As heat is a common means for inactivating moulds and bacteria, the use of microwave energy as an energy source became an attractive field of study due to its rapid and efficient heating characteristics [6,17]. Was researched the use of microwave heating to pasteurize packaged beef frankfurters inoculated with bacteria(*Listeria monocytogenes)* as an alternative to water immersion heating. The heating rate can theoretically be higher, but it was reported that the packaging absorbed some of the microwave energy. Heating by microwave energy increased the rate of inactivation of *bacteria* by 30-75% but the use of microwave heating affected the physical properties of the frankfurters. After the microwave treatment, the frankfurters were reported to shrink in the longitudinal direction and expand in the radial direction by approximately 10%; this was attributed to the extended duration of microwave irradiation and uneven heating, was suggested the use of a higher-powered magnetron to reduce the irradiation duration[6].

Adjustments to operating parameters, such as irradiation duration and power level, to optimize the residual moisture content, nutritional content, and sensory content are areas of interest to researchers. In [27] they studied the use of microwave energy to cook two different types of bacon, streaky and back bacon, and evaluated the product quality based on consumer standards. The evaluation on the quality of the cooked product was based on the crispiness, severity of drying and uniformity of cooking. The optimal product based on the criteria then underwent testing for shelf life times under vacuum-packed storage at 0-4˚C. For streaky bacon, it was reported that when a power level of 500 W was used, the edges of the bacon were becoming charred; similar results were found when a power level of 800 W was used. The phenomenon of edge overheating while the majority of the rasher remaineduncooked was attributed to possible overheating at the edges due to long heating process. A metal rack to elevate the bacon sample plate produced a significant difference in the subjective quality and uniformity of the cooked product. This phenomenon was attributed to microwave energy reflecting off the metallic turntable and into the center of the bacon rashers through the plate.

The use of microwave energy to fry potato slices in oil was studied in [13] to optimize the parameters required to attain product meeting desirable values for its moisture and oil content, colour, and texture. Potato slices with initial moisture contents of 80-82% on a wet basis were fried in a domestic microwave oven at 400, 550, and 700 W using sunflower, corn and hazelnut oil. Optimal parameters to minimize colour difference while maintaining the desirable moisture content, oil content, and texture, were using the medium microwave power level of 550 W for 2.50 minutes with sunflower oil. Using these parameters, the microwave-fried potatoes had 13.88% less oil content than by conventional methods [13].

The selective and volumetric heating property of microwaves allows efficient heating of materials for applications such as introducing thermal stress, material joining and material curing. Due to the ability to attain higher temperatures over conventional heating methods, it becomes possible to use microwave energy to alter physical properties of materials that are inefficient or costly to heat with conventional methods. Furthermore, the physical changes are often attained with shorter heating times and show superior properties compared to conventional methods.

Although ceramics are generally transparent to microwave energy, their adsorption increases as the material's temperature increases. On the other hand, this property of ceramics can lead to imperfections in the product such as thermal runaway and air pockets, while joining ceramics as the porous ceramics become molten and push the trapped air to the surface. As such, controlling the temperature of the ceramic sample is highly desirable to avoid thermal runaway and excessive formation of beads and blowholes when joining ceramics. Conversely, rapid increase in temperature can aid in reducing the heating time during sintering processes, as higher temperatures are required[28,29]. Was studied the application of microwave-assisted joining of porous ceramics with the goal of formulating strategies for controlling the temperature of the sample to obttain characteristic properties of conventional methods without physical degradation. It was reported that the critical temperature of the ceramic tested (48% alumina-32% zirconia- 20% silica) had a critical temperature of 350˚C above which, the rate of temperature rise rapidly increases. The power level used was reported to significantly affect the temperature rise as power levels of 900 W or lower exhibited slow heating. The optimal power level was between 1000 W and 1500 W. As such, a relatively lower incident power level produced better joining properties as the distribution of micropores were mostly uniform while minimizing the presence of blowholes. With sintering processes, temperatures around 1100˚C are required for the ceramic particles to conglomerate completely.

It was concluded that the significant reduction in sintering time is a clear indication that the use of microwave energy as a heat source is able to heat sample with a higher efficiency than conventional methods.

Curing of resin and polymers can require extended treatment times at high temperatures to form properly. The application of microwaveassisted curing can improve the overall process due to its ability to deliver energy directly to the sample, thus, removing the heat conduction period. Through the selective heating ability of microwaves, unexpected changes to the chemical and physical properties may occur in the product.

The application of microwave-assisted curing for denture acrylic resins and the morphology and impact resistance properties of the polymethyl methacrylate. The products cured by microwaves and conventional thermal methods were evaluated for their hardness, porosity, flexural properties, solubility, and molecular weight. Microwave cured acrylic did not absorb as much flexural energy prior to fracture as water-bath cured acrylics, and there was no statistical difference between transverse strength and hardness [18,20].

The effects of microwave curing on epoxy-anhydride based resin and evaluated them based on their mechanical properties and dynamic characteristics was studied[18,29]. They considered possible disagreements on the properties due to the resin system demonstrating different dipole structures and dielectric properties, the effect of the cavity used, the size and shape of the sample to affect heat distribution as longer curing times allow a higher degree of homogeneity, and curing conditions such as microwave power and time control.

Other resins and accelerators were reported to have similar strengths as the conventional curing process using thermal heating. The mechanical properties of the sample strongly depended on the chemical structure, formulation, and curing time as the reduction of accelerator concentration to 1% required an additional 20 minutes to properly cure while the mechanical properties of the samples did not exhibit any improvement. The authors concluded that the optimal property values depend on the resin system as changes in the hardener used can cause changes to the optimal curing time. The concentration of the accelerator did not have a significant effect on the degree of conversion when microwave energy was used as a heating source. As a result, a shorter curing time with similar or a better degree of conversion was obtained with the more efficient microwave curing treatment .

Catalysis is a highly desirable technique to reduce the costs and time required for reactions to occur. An attractive application of microwave assisted catalysis is in enhancing the performance of catalytic converters in vehicles, especially to improve cold-start behaviours and lean fuel conditions. This could reduce vehicle emissions, a highly desirable goal due to government standards and societal pressures. The ability of improving emissions was evaluated based on the conversion of hydrocarbons (HC), carbon monoxide (CO), and nitrous oxides (NO_x).

The effects of microwave energy assisting a catalyst on the purification of simulated automotive exhaust was presented[9,19,23,30]. This provides evidence that the utilization of microwave energy can significantly improve the performance of catalytic converters for lean-fuel conditions, which is important to meet future emission requirements. Using microwave energy, attaining the same conversion rate with the same concentration of catalyst only required a reaction temperature of 260˚C.

It was concluded that although the application of microwave-assisted catalysis cannot improve the conversion of NO, it can significantly decrease reaction emperatures and increase the operating window at higher O_2 concentrations. Furthermore, the X-ray diffraction spectra results reported that the catalyst maintains its stability after microwave irradiation.

III. CONCLUSIONS

Microwave energy has gained the attention of many researchers for various applications. It has been shown that this fundamentally different form of heating offers benefits to conventional reactions. Furthermore, the utilization of microwave energy can greatly decrease the costs and use of toxic chemicals to perform conventional methods – making it economically and environmentally competitive to implement into industrial systems.

This review attempted to demonstrate that there is a rather large number of applications reported in literature but a substantial part of work is being carried out and that some results are publicly disclosed. Successful applications are being practiced in the industrial field, especially in the pharmaceutical sector. Despite all of this scientific and technological activity, it is difficult to reach a conclusion or even to make a simple determination as to how to asses the potential of using microwave in industrial applications.

The rigorous methodical approach to microwaves applications in the industry is lacking and also the medical applications will be presented in other paper. This leads to the difficulty of comparing data between applications and even within an application as operating conditions are not always the same from a dielectrics standpoint even though they may appear to be. So all of these will be used to provide dielectric properties data, in order to find some definitive answers in terms of microwave influence on processes and to determine the potential for the use of microwaves as an efficient selective energy source in environments.

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