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Fundamentals of Heating and Microwave Heating

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Abstract: Almost everybody has access to a domestic microwave oven. For Most people the concepts of microwaves are baffling because microwaves are invisible. In industry, microwave heating has been applied to tempering of frozen meats, processing of potato chips and most importantly vulcanization of rubber. The use of microwaves for the processing of organic materials and inorganic materials such as polymers, ceramics and minerals has been widely reported. The heating of materials is controlled by variations in the power, duration of radiation exposure and the dimension of the cavity in which the microwave radiation is exposed.

Keywords: Microwave heating, Dielectric heating, Electromagnetic, Radiation

I. INTRODUCTION

Microwave energy for heating dielectric materials finds many uses in domestic and industrial environment. The most popular application is microwave oven for domestic and industrial applicaions. Industries who deal in rubber vulcanization, Food, and material processing find microwave heating efficient compared to conventional methods of resistance heating and induction heating. In 1945, Dr. Percy Spencer at Raytheon discovered, supposedly by chance the heating effect of th magnetron while passing a radiating antenna. Thus, Raytheon introduced world's first commercial microwave oven.

Microwave are a form of electromagnetic radiation wit wavelengths ranging from about one meter to one millimeter. Frequency of the microwave ranges from 300MHz to 300GHz. Microwaves include the entire SHF(Super High Frequency) band(3 to 30 GHz or 10 to 1centimeter). he IEEE radar band designations for microwave ranges S, C, X, K_u,K_a band, similiar to NATO or EU designations. Generally 2.45GHz is widely used for domestic and industrial application 915MHz frequency is also used mostly in food processing.

The present conventional methods of heating can be inefficient in terms of time and power consumption. In these methods, heat is transferred to the surface of the material by conduction, convection and radiation. The surface is therefore hotter than the center. Nonetheless, microwaves or a combination of microwaves and conventional heating are commonly an improvement to conventional heating.

II. ISM FREQUENCIES

Industrial, Scientific, and Medical frequency band of radio frequencies are reserved for international use other than telecommunication. Powerful emissions of these devices can create electromagnetic interference and disrupt radio communication using the same frequency, so these devices are limited to certain bands of frequencies. The use case was followed initially, however over the years, the use of the ISM Bands become more widespread for short-range, low power wireless communications systems like cordless phones, WiFi, Bluetooth, NFC and a host of other short range wireless applications.

The original ISM specifications envisioned that the bands would be used primarily for noncommunication purposes, such as heating. The bands are still widely used for these purposes. For many people, the most commonly encountered ISM device is the home microwave oven operating at 2.45 GHz which uses microwaves to cook food. Industrial heating is another big application area; such as induction heating, microwave heat treating, plastic softening, and plastic welding processes. In medical settings, shortwave and microwave diathermy machines use radio waves in the ISM bands to apply deep heating to the body for relaxation and healing. More recently hyperthermia therapy uses microwaves to heat tissue to kill cancer cells.

However, as detailed below, the increasing congestion of the radio spectrum, the increasing sophistication of microelectronics, and the attraction of unlicensed use, has in recent decades led to an explosion of uses of these bands for short range communication systems for wireless devices, which are now by far the largest uses of these bands. These are sometimes called "non ISM" uses since they do not fall under the originally envisioned "industrial", "scientific", and "medical" application areas. One of the largest applications has been wireless networking (WiFi). The IEEE 802.11 wireless networking protocols, the standards on which almost all wireless systems are based, use the ISM bands. Virtually all laptops, tablet computers, computer printers and cellphones now have 802.11 wireless modems using the 2.4 and 5.7 GHz ISM bands. Bluetooth is another networking technology using the 2.4 GHz band, which can be problematic given the probability of interference. Near field communication devices such as proximity cards and contactless smart cards use the lower frequency 13 and 27 MHz ISM bands. Other short range devices using the ISM bands are: wireless microphones, baby monitors, garage door openers, wireless doorbells, keyless entry systems for vehicles, radio control channels for UAVs(drones),wireless systems, RFID systems for merchandise, and wild animal tracking systems.

Some electrodeless lamp designs are ISM devices, which use RF emissions to excite fluorescent tubes. Sulfur lamps are commercially available plasma lamps, which use a 2.45 GHz magnetron to heat sulfur into a brightly glowing plasma.
Long-distance wireless power systems have been proposed and experimented with which would use high-power transmitters and rectennas, in lieu of overhead transmission lines and underground cables, to send power to remote locations. NASA has studied using microwave power transmission on 2.45 GHz to send energy collected by solar power satellites back to the ground.

Also in space applications, a Helicon Double Layer ion thruster is a prototype spacecraft propulsion engine which uses a 13.56 MHz transmission to break down and heat gas into plasma.

III. HEATING METHODS

“Heating” is a traditional technique known to humanity. It has been ever changing the way we live. There are an innumerable ways in which we have been generating heat and using the heat to do work. One of the key applications of “heat” has been the Industrial Process Applications.

Design of an industrial heating system starts with assessment of the temperature required, the amount of heat required, and the feasible modes of transferring heat energy. In addition to conduction, convection and radiation, electromagnetic heating methods can use electric and magnetic fields to heat material.
Industrial heating processes can be broadly categorized as;

Low-temperature (RT to about 400 °C), which include baking and drying, curing finishes, soldering, molding and shaping plastics.

Medium temperature (between 400 °C and 1150 °C), which include melting plastics and some non-metals for casting or reshaping, as well as annealing, stress-relieving and heat-treating metals.

High temperature (beyond 1150 °C), which include steelmaking, brazing, welding, casting metals, cutting, smelting and the preparation of some chemicals.

Process Heating is essential and the heart of many industrial products including those made out of metal, plastic, rubber, concrete, glass & ceramics. Fundamentally Process Heating is subdivided into the three Conventional Categories as;

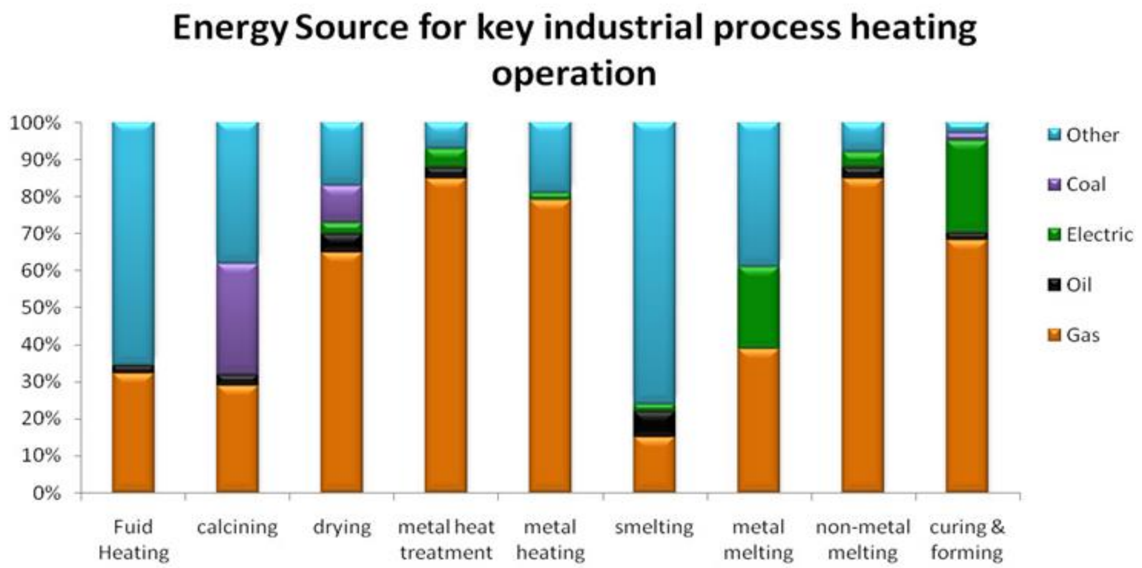
1. Steam-Based Heating: Heating Steam has several favorable properties for process heating applications. Steam holds a significant amount of energy on unit mass basis (between 1,000 and 1,250 British thermal units per pound [Btu/lb]). Since most of the heat content of steam is stored as latent heat, large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute in many process heating applications. Steam-based heating heating has low toxicity, ease of transportability, and high heat capacity.

2. Fuel-Based Heating: Heating with fuel-based systems, heat is generated by the combustion of solid, liquid, or gaseous fuel, and transferred either directly or indirectly to the material. The combustion gases can be either in contact with the material (direct heating), or be confined and thus be separated from the material (indirect heating, e.g., radiant burner tube, retort, muffle). Examples of fuel-based heating equipment include furnaces, ovens, kilns, lehrs, and melters. Within the United States, fuel-based heating (excluding electricity and steam generation) consumes 5.2 quads of energy annually, one which equals roughly 17% of total industrial energy use. Typically, the energy used for process heating accounts for 2% to 15% of the total production cost.

3. Electricity-Based Heating: Heating with Electricity-based heating systems (sometimes called electro-technologies) use electric currents or electromagnetic fields to heat materials. Direct heating methods generate heat within the work piece, by either

(1) passing an electrical current through the material,
(2) inducing an electrical current (eddy current) into the material or
(3) exciting atoms and/or molecules within the material with electromagnetic radiation (e.g., microwave).

Indirect heating methods use one of these three methods to heat an element or Susceptor, which transfers the heat to the work piece by either conduction, convection, radiation, or a combination of these.



A. Hybrid System

use a combination of process heating systems by using different energy sources or different heating methods of the same energy source. Electric infrared, in combination with either an electric convection oven or a gas convection oven is a hybrid system. A paper drying process that combines a natural gas or electric-based infrared technology with a steam-based drum dryer is also a hybrid system.

B. Electric heating is widely used in industry

Advantages of electric heating methods over other forms include precision control of temperature and distribution of heat energy, combustion not used to develop heat and the ability to attain temperatures not readily achievable with chemical combustion. Electric heat can be accurately applied at the precise point needed in a process, at high concentration of power per unit area or volume. The heating apparatus can be built in any required size and can be located anywhere within a plant. The Electric heating processes are generally clean, quiet, and do not emit much byproduct heat to the surroundings. Furthermore these heating equipments have a high speed of response, lending it to rapid-cycling mass-production equipment. Typically Electric Heating Methods include Resistance Heating, Ohmic Heating, Induction Heating, RF/Dielectric Heating, Microwave Heating, Infrared and Ultraviolet Heating. Each of these heating methods offer unique advantages of their own in different domains of applications.

IV. MICROWAVE HEATING

Microwave heating is a phenomenon discovered during the research on radar systems during World War II. The first industrial use of microwave processing was in the food industry. Although considerable research and development took place in the 1950s and 1960s to develop other industrial applications, few emerged. Interest in microwaves increased in the 1980s as a way to raise productivity & reduce costs. There are currently many successful applications of microwave processing in a variety of industries, including food, rubber, pharmaceuticals, polymers, textiles & metallurgy.

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A. What are Microwaves

Microwave refers to the portion of the electromagnetic spectrum between 300 MHz and 300 GHz. Microwave radiation travels at speed of light, i.e., c = 300000 km/s in free space and the relationship between wavelength (l) and frequency (f) is : l = c / f

Designation	Frequency	Wavelength
L band	915 MHz	32.7 mm
S band	2450 MHz	12.2 mm
C band	5800 MHz	5.2 mm

B. Principle of Microwave Heating

To avoid conflict with communications equipment, several frequency bands have been set aside for industrial microwave processing. Traditionally Microwaves are used to heat materials that are electrically non-conducting (dielectrics) and composed of polar molecules. Polar molecules /domains have an asymmetric structure and align themselves to an imposed electric field. When the direction of the field is rapidly alternated, the molecules /domains move in synchronization producing heat in the material.

However in recent years, other aspects of microwave interaction with materials has been exploited to extend the microwave processing arena for applications that were once thought to be impossible like Powder Metallurgy. In this case the magnetic dipole movement and hysterisys losses leading to generation of heat is the dominant method of heating. The effect of eddy current losses also contributes significantly in such cases where the processed materials are electrically conductive. The ongoing research in this area is ever expanding the horizon of microwave processing applications.

When materials are exposed to microwave radiation, microwaves partially get Reflected (R), Absorbed (A) or Transmitted (T) depending on the dielectric properties of the material – Permittivity (ε) and Permeability (μ); which is a function of chemical composition, phase and temperature of the material. The absorbed portion of the incident microwaves, heats the material by polarization of the atomic / molecular structure or through dipole movement. As the microwaves travel through the material, it gets attenuated, resulting in volumetric heating.

Microwaves are generated by magnetron tubes, which are composed of a rod-shaped cathode surrounded by a cylindrical anode. Electrons flow from the cathode to the anode, creating an electric and magnetic field. The field frequency is a function of the dimension of the slots and cavities in the magnetron. Oscillations in the slots and cavities form microwaves, which are then radiated out through an antenna projecting out of the cathode space.

A Microwave Processing System Usually Comprises Four Components:

1. Generator. This consists of a magnetron, power supply and a waveguide assembly to carry the waves. Magnetron is typically water or air-cooled and is a consummable component.

2. Applicator. This is the processing chamber in which the material is processed. Waveguides direct microwaves to the product being heated in this space.

3. Control System System that monitors, measures, controls and manages the complete heating process. This is usually in the form of a computer, a PLC or an Human Machine Interface (HMI) with touchscreen.

4. Materials Handling System System that positions the product inside the applicator or exposure area. This is usually a conveying arrangement, a rotary table or a trolly system with associated controls to manage material handling into and out of the system.

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V. ADVANTAGES OF MCROWAVE PROCESSING

A major advantage of high-temperature microwave systems is their "green" nature. Microwave furnaces generally heat only the objects to be processed, not the furnace walls or atmosphere. Microwaves also have a much higher power density and heat the materials faster. Energy-efficient microwave furnaces produce a substantially smaller carbon footprint, less pollutants, and lower operating and end-product costs. In addition, microwave processing can involve up to 90% shorter processing times and a corresponding decrease of up to 80% in energy consumption when compared with conventional methods for many commercial products.

Microwaving also yields improved product quality with finer grain size, higher sintered density, increased corrosion resistance, and greater strength of finished parts. These advantages can be obtained with ceramics, a range of powdered metals (such as titanium, molybdenum and steels), and "hardmetals" like tungsten, tungsten alloys and tungsten carbide. With the realization of not only the technical but also the substantial economic advantages, high and low temperature microwave processing offers the implementation of this new processing method in ceramics and related industries, including advanced ceramic/carbide wear parts, electro-ceramics and bio-ceramics.

Talking about advantages of Microwave Processing for other applications like Rice and Grain disinfestation, sterilisation and similar applications, it is well proven that Microwave processing provides several avenues to drastically improve the product quality and considerably increase the shelf life of food grains. Microwaves are fast becoming the preferred means of treating food grains as there is no need of chemical treatments for food grains.

VI. CONCLUSION

Microwave heating stands out to be the most effective and convenient mode of heating. As the heat travels from the core to the outer surface, the heat is not lossed in the chamber as it is in the resistance heating. The power consumed by the Microwave system turns out to be more economical than conventional method. Setup cost is initially high compared to conventional heaters but the prime object is to have minimal breakdown time and maintenance of the system, thus provided by the Microwave system.

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