

What's New in Electrotechnologies for Industrial Process Heating?

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ABSTRACT

This technical paper provides a review of the state of electric industrial process heating technologies and discusses new heating applications for industrial processes. The information presented in this paper is based in great part on the 2010 EPRI technical update titled “Industrial Process Heating: Current and Emerging Applications of Electrotechnologies”. Four efficient electric process-heating technologies are discussed, namely, induction heating, microwave heating, radio frequency heating, and infrared heating. An overview of industrial process heating, principles of operation and the industries where the process heating technology is applied are discussed. The technical paper also presents current and emerging applications of electric process heating technologies. The information presented will help readers answer questions regarding industrial process heating and provide information on new and efficient heating applications. The technology presented can serve as a reference guide for selecting process heating technologies in industrial applications.

Introduction

This technical paper reviews the state of electric process heating technology and discusses new heating applications for industrial processes. In U.S. manufacturing, process heating accounts for over one-fifth of total energy use, making it the largest end use for energy. Process heating is also significant in net electricity consumption in manufacturing, accounting for nearly 12% of the total.¹ As such, improvements in process heating present significant opportunities to benefit industrial customers through cost reduction through energy savings, efficiency gains and improved productivity, while reducing their greenhouse gas emissions. Four efficient electro-technologies are discussed in the following sections.

In 2011, EPRI will be exploring opportunities for case studies of electric process heating technologies that can provide real-world information to electric utilities and their industrial customers on productivity and efficiency improvements. Other new and emerging technologies that provide efficient and new applications of electric process heating such as heat pumps, electron beam heating, and plasma heating will also be investigated.

Induction Heating

Induction heating is a non-contact method by which electrically conducting materials are heated in an alternating magnetic field. Induction heating may be used to replace a wide variety of conventional process heating methods, such as fossil/electric furnace heating, salt/lead bath heating and flame heating. Induction heating can be used for heating directly, heat treating or melting conductive materials, typically metals. Induction heating generates heat within the workpiece, in contrast to a wide variety of conventional processes which transfer the heat to the

¹ Industrial Energy Efficient Technology Guide 2007. EPRI, Palo Alto, CA: 2007. 1013998.

workpiece. Moreover, the location of the heating can be confined to a specified area on the metal component to achieve accurate and consistent results.

How Does It Work?

Electromagnetic induction, or simply induction, is a way to heat electrically conductive materials, such as metals. An electromagnetic field is produced by applying current with a frequency of 60 Hz to 800 kHz to an inductor coil in proximity to the workpiece. When the magnetic field intersects a work piece made from any electrically conducting material, it generates a circulating current (called eddy currents), which generates heat through I^2R effect.

The basic components of an induction heating system are an induction coil, an alternating current (AC) power supply, and the workpiece itself. The coil, which may take different shapes depending on the required heating pattern, is connected to the power supply. The flow of AC current through the coil generates an alternating magnetic field, which cuts through the workpiece. This alternating magnetic field induces eddy currents and the heating of the workpiece.

What Industries Use It?

Primary induction heating applications in the metals industry fall into four major categories: heating prior to metal working, heat treating, welding, and metal melting. Induction technologies are not limited to heating conductive materials such as metal alloys or graphite, since the use of a susceptor,² such as a graphite crucible, allows heating of products which do not conduct electricity. Applications using susceptors are numerous. They include melting refractory materials, glasses, quartz, sintering carbides, semi conductor fabrication, heating liquids, and heating gases during chemical synthesis. An example of fluid heating is the production of saturated steam and super-heated steam used for drying processes, sterilization, rinsing and cleaning of semi conductor materials, soil purification, or carbonization of organic compounds.

Emerging Application – Industrial Waste Processing: Ultra High Frequency Induction Furnace for Treatment of Industrial Waste

The Ultra High Frequency Induction Furnace (UHFIF, see Figure 1 below) project began in 2005 in Japan and is a cooperative effort between the University of Tohoku, Mitsubishi Materials, Japan Atomic Energy Agency, Fuji Electric Thermosystems and TYK with the purpose of improving the efficiency of existing processes both economically and in terms of safety. Until now, “external” heat treatments (induction smelting furnace with graphite crucible and plasma smelting furnace) were incapable of transmitting sufficient thermal energy, thus limiting products that can be treated in furnaces, and necessitating difficult and uneconomic sorting work.

UHFIF enables simultaneous melting of ceramics (glass, concrete) and metals, and can be used to collectively incinerate combustible and non-combustible waste by electromagnetic induction at 150 kHz. An immediate application of this furnace is the treatment of slightly radioactive waste, a reason for the participation by the Japan Atomic Energy Agency.

² A susceptor is a material that can absorb electromagnetic energy and convert into heat.

Figure 1. Ultra-High Frequency Induction Heating Machine



Source: EPRI Technology Update 1020133

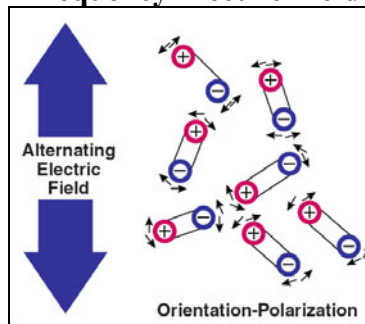
Microwave Heating

Microwave heating uses specific frequencies (100 to 10,000 MHz) of the electromagnetic spectrum to heat the workpiece. The major advantages of using a microwave system for industrial processing are rapid heat transfer, volumetric (no special geometry or shape requirement) and selective heating, compactness of equipment, speed of switching on and off and a pollution-free environment, as there are no products of combustion due to heating (no burning of fossil fuel). The drawback of microwave heating is that the material to be heated should be electrically non-conducting (dielectric) and composed of polar molecules.

How Does It Work?

Microwave heating is accomplished with the application of electromagnetic fields. The material to be heated is placed between two electrodes that are connected to a high-frequency generator. For a substance to be microwaveable it must possess an asymmetric molecular structure. The molecules of such substances (e.g., water molecules) form electric dipoles. The electric dipoles try to align with the orientation of the electric field. This orientation polarization mechanism (please refer to Figure 2) generates movement of molecules, thereby generating heat in the substance (workpiece).

Figure 2. Molecular Oscillations of Polarizable Substances under the Influence of a High-Frequency Electric Field



Source: Industrial Process Heating, EPRI Technology Update 1020133

Industrial microwave heating applications typically use 2,450 MHz systems, one of the four microwave frequencies (915 MHz, 2,450 MHz, 5.8GHz and 24.125GHz) reserved by the Federal Communications Commission (FCC) for industrial, scientific and medical applications of electromagnetic signals.³ However, more expensive 915 MHz systems are becoming increasingly common because their total system efficiencies and penetration depths are higher relative to those of the 2,450 MHz systems.

What Industries Use It?

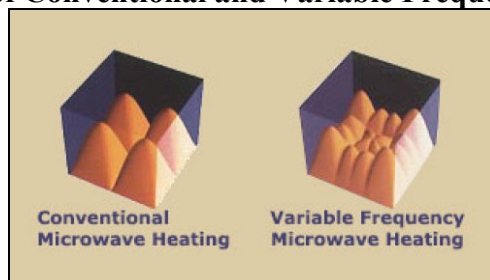
The market penetration of microwave heating in industry is relatively limited. Currently, most industrial microwave applications involve heating and drying of food, paper, and textile products. Two of the most promising applications for microwave technology include the sintering of ceramics and the processing of oil-water emulsions. Though it can be used across a wide array of ceramics, microwave sintering is currently limited to niche applications in the ceramics industry. However an emerging trend can be noticed in the microwave-assisted firing of numerous types of ceramic materials, including alumina, zirconia, silicon nitride, and silicon carbide. The use of microwave heating to promote the dissociation of the oily component from water in wastewater or oily emulsions has wide applicability in numerous industries including the petroleum, metal processing, and steel industries. Other promising microwave applications are emerging, such as in-line processing of pharmaceuticals and enhancing chemical reactions and synthesis. However, many of these applications still remain in the research and development stages.

Emerging Application – Food Sector Microwave Heating Research

The novel methods under consideration include phase control heating, variable frequency ovens and combining microwave with other heating methods:

- Phase control heating involves combining two different microwave signals to build more uniform heating.
- Variable frequency is another method that can achieve heating uniformity (please refer to Figure 3), but variable frequency ovens remain very expensive (about 5 times more expensive than single-frequency MW oven of same power).

Figure 3. Comparison of Conventional and Variable Frequency Microwave Heating



Source: Industrial Process Heating, EPRI Technology Update 1020133

³ FCC Online Table of frequency Allocations, 47 C.F.R. § 2.106, Federal Communications Commission, Revised on July 26, 2010

- Microwave heating has been combined with hot air or infrared to reduce quality problems in foodstuff such as lack of crust color, firmness, excessive moisture migration to the surface and non-uniform heating. An example involves the combination halogen lamp-microwave that has significantly reduced the processing time while achieving high quality product for baking bread.⁴

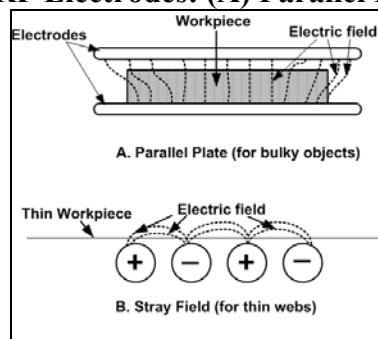
Radio Frequency Heating

RF heating refers to the heating of materials with radio frequency (RF) electromagnetic radiation (which is roughly 10 kHz-300 MHz). The RF radiation penetrates deep into the material and heats the materials at the molecular level. Industrial RF units are typically rated at 10-300 kW output power.

How Does It Work?

An RF generator creates an alternating electric field between two electrodes (please refer to Figure 4). The material to be heated, dried, or cured is held or conveyed between the electrodes where the alternating electromagnetic field causes polar water molecules to continuously re-orient themselves to align with the alternating field much the way magnets would respond to an alternating magnetic field. The friction of this movement causes the water in the material to rapidly heat throughout its entire mass. The heating is from within, so there is no hot, dry outer layer, and water in the middle will move to the surface. Often the material is hot and dry on the inside and cooler and wetter on the outside. In such cases, a combination of two technologies, RF heating and conventional heating, offers potential benefits. The combination will heat the water on the inside, move it to the surface, and remove it from the surface, resulting in more uniform drying.

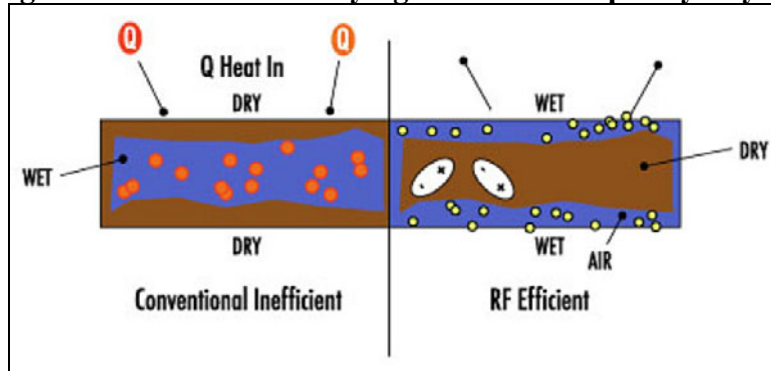
Figure 4. Types of RF Electrodes: (A) Parallel Plate, (B) Stray Field



Conventional (i.e., conduction, convection, and radiant) heating systems have an external heat source which transfers heat to the surface of the material. The heat will then slowly conduct into the middle of the material. A conventionally dried product is hot and dry on the outside and cold and wet on the inside. Part of the difficulty is that the dry outer layer acts as an insulating barrier and reduces the conduction heat transfer into the middle. In addition, over-drying the outer layer can cause quality problems such as surface cracking and a skin on coatings. The following figure (Figure 5) depicts conventional and RF drying.

⁴ Da-Wen Sun, *Emerging Technologies for Food Processing*, 2005

Figure 5. Conventional Drying vs. Radio Frequency Drying



Source: Industrial Process Heating, EPRI Technology Update 1020133

What Industries Use It?

The radio frequencies reserved for industrial use by the Federal Communications Commission (FCC) are 13.56 MHz, 27.12 MHz, and 40.68 MHz; the lower two frequencies are more commonly used for industrial applications. Industrial RF units are typically rated at 10-300 kW output power. In general, the more difficult a material is to heat, dry, or cure with convection or infrared (IR) heating, the more likely it is to be a good candidate for RF. Materials with poor heat transfer characteristics (i.e., low thermal conductivity, high density, and/or high specific heat) are good candidates. As a result, the ceramics and glass fiber industries have used RF dryers over a number of years for a growing variety of advanced ceramic products, refractory materials, and fiberglass materials.

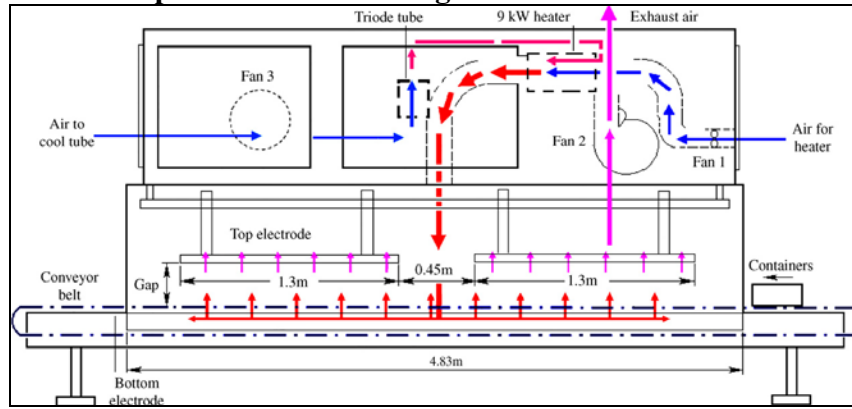
Emerging Application – Food Industry: Pest Control in Walnut Processing

RF heating has a variety of industrial applications for heating, drying, and curing materials. RF is often used for drying crackers, cookies, and other snack foods. Baked goods are dried in a conveyor parallel plate system after baking to remove moisture.

RF heating is showing value for insect control in walnut processing. Researchers at University of California, Davis have found that industrial grade RF heating at 27 MHz, 25kW system is proven to be effective in killing the insects in a walnut without quality degradation.⁵ This process eliminates the need for chemical (Methyl Bromide) fumigation which was banned by US Environmental Protection Agency in 2005. A visual depiction of the RF heating process is shown in Figure 6.

⁵ Industrial-scale radio frequency treatments for insect control in walnuts I: Heating uniformity and energy efficiency, S. Wang a, M. Monzonb, J.A. Johnson c, E.J. Mitchamb, J. Tanga, *Postharvest Biology and Technology* 45 (2007) 240–246

Figure 6. Visual Depiction of RF Heating for Pest Control in Walnut Processing

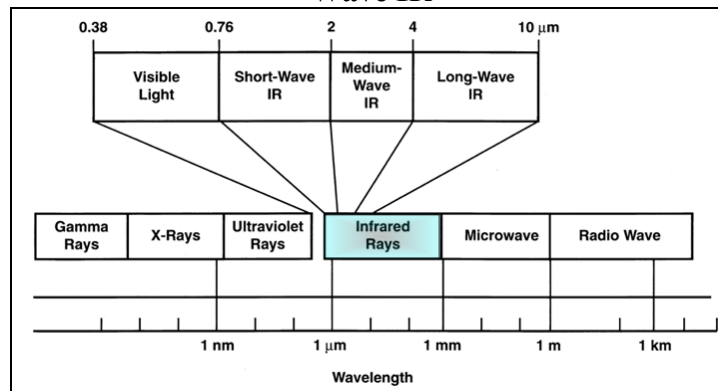


Source: Industrial Process Heating, EPRI Technology Update 1020133

Infrared Heating

Infrared (IR) is the range of electromagnetic energy-spectrum measured between the visible light and radio wave. Infrared heating is a form of radiant heating. Radiant energy is not absorbed by air and does not actually become heat until an object absorbs it. Infrared radiation is typically divided into three different wavelength categories: short, medium, and long. These three different wavelengths are shown in Figure 7.

Figure 7. Electromagnetic Spectrum showing Short-Wave IR, Medium-Wave IR and Long-Wave IR



Source: Industrial Process Heating, EPRI Technology Update 1020133

When radiant energy impinges on an object, it can be absorbed, reflected, or transmitted by that object. The amount of absorption, reflection, or transmission is affected by the wavelength of the radiant energy and the physical and surface properties of the object. Only absorbed energy will contribute to the heating of the product. Infrared radiation can be absorbed and converted into heat energy by most materials rather than being reflected away or transmitted through the object. In addition, the amount of energy a product absorbs can be controlled by selecting the proper wavelength of the IR emitter.

How Does It Work?

IR heating works on the principle that every object with a temperature above absolute zero emits infrared energy. The object that radiates heat is called the emitting source and the object to which it radiates heat (that has lesser amount of heat content) is called the target or workpiece. The amount of power absorbed by the surface of an object is given by the Stefan-Boltzmann law. The law states that the amount of power radiated by an object is proportional to the surface area and the fourth power of the absolute temperature of the surface. Thus the heat transfer equation is:

$$Q = \sigma A (T_p^4 - T_e^4)$$

Where, Q = Total amount of heat transfer (Watts), A = Area of the object (m²), σ = Stefan-Boltzmann Constant = 5.67×10^{-8} Watts m²K⁻⁴, T_p = Temperature of the product in K^o and T_e = Temperature of the product in K^o

For traditional convection ovens the amount of heat transfer is proportional to the first power of temperature where as in case of IR the amount of power transferred is proportional to the fourth power of temperature. This is one of the reasons for higher rate of heat transfer with IR process heating technology.

What Industries Use It?

IR heating finds application in many industries. The following figure (refer to Figure 8) shows the versatility of IR in industrial process heating applications. It can be seen from this figure that IR can be applied to several market segments. For example, in Food industry, IR process heating can be applied to Food Drying, Melting, Preheating, Sterilizing and Tempering Processes. In Plastics industry, IR can be used for Curing, Activating, Drying and other processes as well.

Figure 8. Applications of IR Process Heating in Various Industries

MARKET	PROCESS	Activating	Curing	Drying	Fixation	Foaming	Glueing	Laminating	Melting	Preheating	Shrinking	Soldering	Sterilizing	Tempering
Appliances														
Automotive														
Carpet														
Ceramics														
Converting														
Digital Printing														
Electronics														
Flexo Printing														
Flooring														
Food														
Glass														
Metal														
Packaging														
Paper														
Photovoltaics														
Plastics														
Plastics Heat Staking														
Plastics Welding														
Powder Coating														
Roofing														
Rubber														
Semiconductors														
Textiles														
Web Process														
Wood														

Source: Industrial Process Heating, EPRI Technology Update 1020133

Emerging Application – Automobile Industry: Powder Coating

Powder coating is a process of applying paint or other polymer coating to a surface (often but not always metal) and then applying an electrostatic charge to convert the powder into a liquid, which then coats the surface evenly and uniformly. It is often applied to white goods (appliances, etc.), automotive components and industrial parts. Infrared heating targets powder coating applications very well. While some powder coating applications still solely use convection ovens, the use of convection heating along with infrared preheating generally yields a superior finished product and increased productivity.

As the processing part enters an oven for powder coating, it is critical to get the part to the desired temperature as quickly as possible. This allows the flow of the coating to begin. The quicker the part reaches the target temperature, the shinier and smoother the coating becomes. Hot air is unsuitable for this, as increased air velocity will merely displace the powder. Infrared, with its ability to apply high intensity heat in an instant, helps get the process to target temperature quickly. Another advantage of using IR for powder coating is that the curing requires only a few infrared lamps, making it a cost-effective solution. Even a small infrared lamp added to an existing convection system can yield these benefits:

- Faster line speeds
- Increased productivity (more products treated per minute)
- Reduced use of convection gas burners (energy savings)
- Better quality (increased shine, gloss, durability)
- Increased process control

Summary

This paper has presented a solidly researched overview of the most prevalent industrial process heating technologies and some of their existing and new applications in industry. It points out the advantages of electric process heating from electricity's ability to deliver concentrated, precisely-controlled energy efficiently. The information presented will be helpful to utilities and their industrial customers in making decisions on appropriate technologies, for technical, business, and environmental reasons.

Since this paper captures current information on emerging applications of technologies, a need is anticipated for updates. Tracking and reviewing emerging applications of process heating technologies is a key to maintaining the freshness and relevance of the information.

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