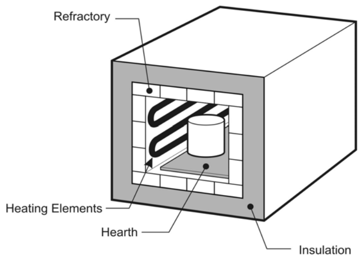
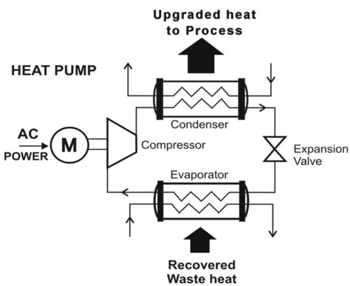
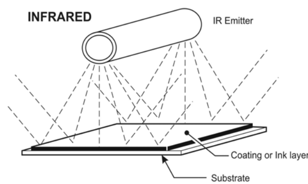
ELECTROTECHNOLOGIES

Energy Efficiency Reference Guide

For Small to Medium Industries







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The use of certified practitioners for the application of the information contained herein is strongly recommended.

This guide was prepared by Stricker Associates Inc for the CEA Technologies Inc. (CEATI) Customer Energy Solutions Interest Group (CESIG) with the sponsorship of the following utility consortium participants:

Appreciation to Ontario Hydro, Ontario Power Generation and others who have contributed material that has been used in preparing this guide.

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1 INTRODUCTION

This Electrotechnologies Energy Efficiency Guide provides brief descriptions, characteristics, and advantages and disadvantages of various industrial processes used in small- to medium-size industrial plants. These specific processes involve the use of energy whether it is electricity, natural gas or other fuels.

Because of the rising cost of all fuels, the need to reduce the production of greenhouse gases, and increasing competition, industries need to continuously look for ways to reduce the energy required for production, increase the speed of production and improve the quality of the products. This guide was developed with these three goals in mind.

While electrotechnologies use a premium-priced fuel, electricity, they have specific advantages over the use of other technologies, and may in fact result in a much reduced amount of energy required to perform the equivalent job. For example, generating heat in a metal can be done much more efficiently, more quickly and with much more control by inducing eddy currents in the piece (via induction heating) than by heating in a convection or radiation oven.

The material in this guide has been prepared from information developed by electric utilities, universities, research laboratories and industrial suppliers of equipment, and will direct the reader to the appropriate type of equipment.

This guide also provides links to additional sources of information. As some of the sources change over time, the reader may be re-directed. It is always wise to search for the most recent information on the topic.

For brevity, and to meet the objectives of this guide, the subjects are covered in sufficient detail to give the reader a basic understanding of the terminologies, the principles used and the particular features that make the electrotechnology energy efficient. For further information, please contact your electric utility customer service representative, the industry association or corresponding equipment suppliers listed under each section.

This guide covers electrotechnologies under the following eight broad categories:

1. Industrial Heat Pumps & Mechanical Vapour Recompression
2. Infrared Heating
3. Induction Heating
4. Radio-frequency Heating
5. Microwave Heating
6. Direct Resistance Heating
7. Indirect Resistance Heating
8. Ultraviolet Radiation

Various equipment configurations and typical applications are described within each category.

2 MEETING THE CHALLENGES OF BUSINESS

Globalization, the migration of manufacturing to countries with much lower wages and increasing energy prices are forcing manufacturing industries in North America to become more efficient, produce superior quality products, and remain competitive in order to survive. A plant manager's responsibilities include minimizing the amount of energy used in the plant, maximizing product quality, maintaining the highest possible rate of production and reducing as much as possible the environmental impact of the operation.

There are usually several options for industrial processes involving heating, melting, annealing, drying, distilling, separating, coating, drying, etc. This guide looks at the application of electrotechnologies from the business point of view, i.e. by reviewing and highlighting the properties that make the process both more energy efficient and faster and offer better control over quality of the product. The following are just some examples of how the application of the most appropriate electrotechnologies can achieve these goals.

a. Reducing the Energy Required to Produce Goods

Heating a manufactured component by producing heat inside the material by induction, dielectric heating or microwave, rather than by heating it from the outside in, by use of an oven, radiant heating, etc. that must be kept fired continuously during production.

b. Reducing Greenhouse Gases

Certain intermittent processes require that combustion equipment be on continuously. These can often be replaced by electrotechnology processes that do not consume energy while on standby, for example, the application of induction and radio frequency heating in controlled atmosphere environments.

c. Improving Product Quality

In drying applications, several electrotechnologies can be applied to improve product quality and value while saving energy: for example, to control edge dryness in rolling paper strips, to prevent warping in drying lumber and in the final drying of food products. In these applications, the use of radio frequency (dielectric) heating, heat pump drying by depressing the dew point and the use of microwave heating on nearly dry products respectively, provide the desired results.

d. Increasing the Speed of Production

Processes that require heating a product normally require a certain length of time for the product to reach the required temperature of the process due to material thickness, conductivity, and surface properties, as well as the temperature limits needed to avoid product damage or undesirable changes. There are several electrotechnologies that speed up the rate of material heating without exceeding surface temperature limits, getting around the thermal conductivity and surface property issues. The efficiency of these processes is normally much higher than that of conventional ovens, heating tunnels and radiant heaters. Improved rate of heat transfer and higher efficiency translates into faster production rate and lower energy cost.

e. Improving the Work Environment for Employees

Since electrotechnologies can replace combustion equipment, the work environment usually improves by lowering temperatures and eliminating combustion products from the shop floor.

3 OVERVIEW OF APPLICATION POTENTIAL IN INDUSTRY

The following table provides the reader with an indication of the electrotechnologies that may be applicable to specific industry groups depending on the actual processes in their plant. This "roadmap" will assist plant managers in understanding the potential applications of electrotechnologies in their facilities. It provides a good starting point for this assessment and maps the main electrotechnologies against the North American Industrial Standard Classification system (NAICS) of industries. The intersections are labeled with a qualitative potential for application, (High, Medium or Low).

For example, the Food classification (NAICS 311) includes industries that process large volumes of liquids and fresh foods. The electrotechnologies of industrial heat pumps, mechanical vapour recompression, microwave and indirect resistance heating are very likely to be applicable. The Fabricated Metal Products (NAICS 322) manufacturing industries have a high application potential for nearly all of the high temperature electrotechnologies, since these industries require both high temperatures and surface treatment or finishing processes.

Table1. Map of Application Potential of Electrotechnologies across the North American Industrial Classification System

Electro-Technology	3-digit North American Industrial Classification System (NAICS)									
	Food 311	Beverage & Tobacco 312	Textile Mills & Products 313; Textile Product Mills 314	Clothing Mfgrs 315	Leather & Allied 316	Wood Products Manuf 321	Paper 322	Printing & Related 323	Petroleum & Coal Products 324	Chemical Mfg'g 325
Ind HP & MVR	**H**	**H**	M	L	L	**H**	M	L	M	M
Infrared	M	M	**H**	M	M	M	**H**	**H**	M	M
Induction	L	L	M	L	L	L	L	L	L	M
Radio-Frequency	M	M	**H**	L	L	M	M	L	L	L
Microwave	**H**	M	L	L	L	L	L	L	L	M
Direct Resistance	M	L	L	L	L	L	L	L	L	L
Indirect Resistance	**H**	M	M	M	M	M	M	M	M	M
Ultaviolet	L	L	M	L	L	M	M	**H**	L	L

LEGEND: - Application Potential

H = High M = Medium L = Low

Electro-Technology	3-digit North American Industrial Classification System (NAICS)									
	Plastic & Rubber 326	Non-Metallic Mineral Products 327	Primary Metal Mfg 331	Fabricated Metal Prooducts 332	Machinery Mfg 333	Computer & Electronic Product Mfg 334	Elect Equip, Appliances & Components 335	Transportation Equipment Mfg 336	Furniture and Related Products Mfg 337	Misc Mfg'g 339
Ind HP & MVR	L	L	L	L	L	L	L	L	L	L
Infrared	**H**	**H**	M	**H**	**H**	**H**	**H**	**H**	M	**H**
Induction	M	M	**H**	**H**	**H**	M	**H**	**H**	M	M
Radio-Frequency	**H**	L	L	**H**	**H**	L	**H**	L	M	L
Microwave	M	M	M	L	L	L	**H**	L	L	L
Direct Resistance	L	M	**H**	**H**	M	M	M	M	M	M
Indirect Resistance	M	M	M	**H**	M	M	M	M	M	M
Ultaviolet	M	L	L	**H**	**H**	**H**	**H**	**H**	M	M

LEGEND: - Application Potential

H = High M = Medium L = Low

For a more in-depth assessment of the opportunities, one needs to look into the specific requirements of a particular process, and then identify which electrotechnology will provide the greatest benefit.

In addition, this guide provides many useful web links to external sources of information, which can be helpful while evaluating electrotechnology applications.

4 Industrial Heat Pumps and Mechanical Vapour Recompression

a. Principle

Industrial heat pumps are used to recover waste heat from one part of a process and boost its temperature so that it can be used to heat another part. The basic means to achieve this is by mechanical compression of a vapour. In this manner, thermal energy is moved from a lower temperature source to a higher temperature sink through the use of evaporation, vapour movement with compression and condensation. When the vapour is compressed in a closed loop involving two or more heat exchangers and recirculated, the system is called a heat pump (HP). When the vapour is extracted and pumped out of the system through a heat exchanger, it is called mechanical vapour recompression (MVR).

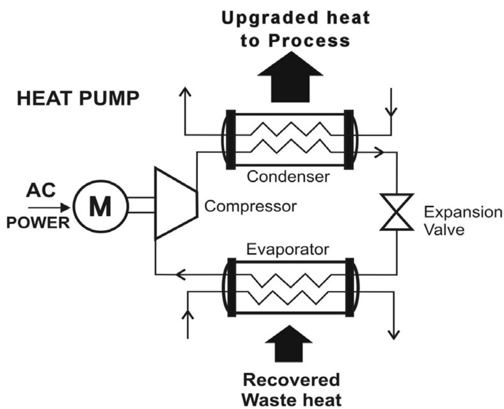
What makes HPs and MVRs particularly efficient is the fact that these systems are capable of moving thermal energy from a low temperature source to a higher temperature sink by using only <u>a small fraction of the total energy</u> being moved. The alternative method involves conventional combustion furnaces and heat transfer by conduction across heat exchangers.

b. Types of Systems

There are two common types of industrial heat pumping systems: closed and open.

Closed Systems

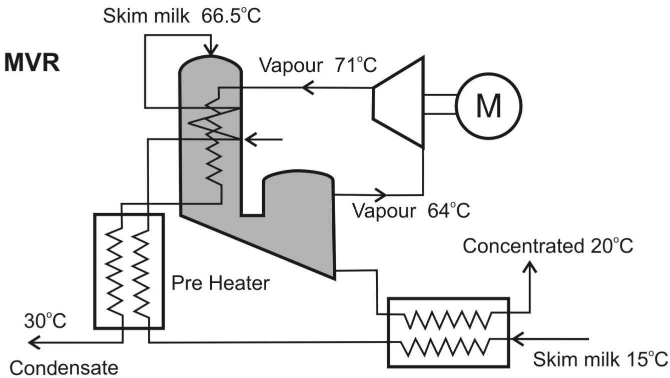
Closed systems use an intermediary working medium, a refrigerant fluid. Vapour is driven by a mechanical compressor from one heat exchanger (the evaporator) to a second heat exchanger (the condenser) and back to the evaporator through an expansion device. The condenser and evaporator transfer the heat to the required sink and source respectively. Currently applied working fluids limit the maximum output temperature to 120°C. Closed systems are commonly called *Heat Pumps*.[1]



[1] A Heat Pump Energy Efficiency Guide is being produced by CEATI for space and water heating/cooling applications.

Open Systems

In open systems, there is no intermediary heat transfer fluid or refrigerant. The compressor works directly on the vapour form of the fluid being processed, usually water vapour or a solvent vapour. The following diagram illustrates an MVR system for concentrating milk.



This type of system normally has a single heat exchanger, a condenser, or no heat exchanger when the compressed vapour is used directly in the process. In this particular example, the compressor draws the water vapour directly from the container holding the solution or mixture to be concentrated (milk), cooling the liquid. The compressed vapour is cooled by preheating the milk and then removed from the system as water. In this manner, the heat of the compressed vapour or the condenser is transferred to the liquid being processed to reheat the liquid. Returning the heat of evaporation to the liquid being processed via the condenser increases the efficiency of the evaporation process by recycling the heat energy in the vapour and in the condensate. Because the temperature lift is generally small, the performance of MVR systems is high, with typical coefficients of performance (COPs) of 10 to 30. Current MVR systems work with heat-source temperatures from 70-80°C, and deliver heat between 110 and 150°C, in some cases up to 200°C.

c. Applications

MVR systems are well suited for use in process streams to move large amounts of thermal energy at relatively low temperatures from one part of the process to another as well as for upgrading the temperature differences, (below about 90°C). Common applications involve the removal of water or water vapour in drying, dehumidification, distillation and concentration processes, or in the recovery of heat and upgrading of temperature of gases and liquids.

Typical Applications of Heat Pumps

- Drying of wood, leather, fabric and grain.
- Distillation in chemical and petrochemical plants.
- Dehumidification.
- Concentration of solutions.

Typical Applications of Mechanical Vapour Recompression

- De-watering solutions or mixtures such as:
    - Diluted galvanic baths to recover substances and active ingredients.
    - Oil emulsions to recover oil.
    - Degreasing baths rich in soap and detergents.

    - Concentrated acid baths or highly corrosive solutions.
    - Photographic developing baths.
    - Concentrated saline solutions.
    - Landfill leachate and drippings from waste stocking and disposal.
    - Bilge waters.
    - Rinsing waters containing exhausted inks.
    - Waste waters of the chemical, cosmetic and pharmaceutical industries.
- Concentration of fruit juices, milk, whey, black liquor (in pulp and paper industry) and other liquids.
- Distillation of alcohol, petrochemicals and organic chemicals.
- Recompression of overhead vapours in a petrochemicals distillation tower to recover the energy.
- Crystallization of sugar through evaporation.
- Re-injection of low pressure steam into high pressure system (mechanical and thermomechanical pulp processes.

d. Advantages

- Very high energy efficiency (e.g. reduces energy requirement by 75% in milk drying).
- Possible utilization of waste heat from low-temperature process or polluted environments.
- Perfectly suited for low-temperature controlled drying processes by dehumidification.
- Means of initiating an energy management approach to industrial energy intensive processes.

- Improves product quality and reduces product losses through improved control of drying characteristics.

e. Limitations

- High initial investment.
- Savings depend on cost difference between electricity and the alternative fuel(s).
- More complex to use than conventional techniques.
- More complicated maintenance.
- Upper temperature limit is relatively low for industrial processes.

f. Typical Performance

- Energy conversion efficiency (heat output divided by electricity input in consistent units):
    - For heat pumps: from 3 to 5 normally.
    - For mechanical recompression: from 10 to 30 normally.

g. Application Considerations

- Cost differential between electricity and fuel being displaced.
- Capital cost of equipment and payback period (much shorter for original installations rather than for retrofits).
- Absolute temperature and temperature difference between source and sink being considered.

- Nature of operation: drying, dehumidifying, distilling, energy recovery, temperature upgrading, evaporation, etc.
- Capacity required (required rate of energy flow), load factor, available power capacity, stability over time.
- Nature of source and sink fluids (air, vapour, steam, water, liquids, impurities, etc.).

h. Components and Terminology

- Compressors:
  - Hermetic, Semi-hermetic, Open
  - Piston
  - Screw
  - Centrifugal
- Heat exchangers: evaporator and condenser.
- Expansion valve.
- Heat transfer fluid or refrigerant (compromise choice based on process operating temperatures and pressure levels, compressor size and temperature tolerance).
- Electric power supply.
- Type and characteristics of controls.
- Auxiliary devices specific to the process (backup heat source, thermal storage, purging, etc.).

i. Installation examples

http://www.p2pays.org/ref/11/10451.htm

This site describes several industrial heat pump applications and opportunities in the USA that significantly improve plant efficiency and recover wasted energy resources including:

- A system of dryers and evaporators to mill, cook, and convert corn starch to high-fructose corn syrup.
- In a synthetic rubber factory, heat pumps are used to produce medium-pressure process feedwater and to heat boiler feedwater.
- In an integrated pulp and paper mill, a heat pump is used to utilize dirty low pressure steam for heating boiler feedwater.
- At a specialty refinery, a heat pump system is to be used to recompress the overhead vapors of a distillation tower to recover the energy contained in these vapors.

CEA Report 9114 U 859D ***Opportunities for Electrotechnologies: Heat Recovery Applications in Industry***, 1993. This report describes six promising heat pump application opportunities in Canadian industries including:

- Heat recovery from an acetaldehyde reactor.
- Heat recovery from refrigeration reject heat.
- Heat recovery from refining and deodorizing process cooling water.
- Thermomechanical pulping vent steam heat recovery.
- Heat recovery from white water
- Heat recovery from kraft recovery boiler flue gas scrubbers.

CEA Report 614 U 566 ***Review of Industrial Heat Pump Installations in Canada***, 1988. This report documents the operational experience of twelve heat pump systems, savings achieved, problems, what corrective actions were taken and finally draws conclusions regarding the state of industrial heat pump technology applied in Canadian industry at that time and provides valuable information to improve on future applications.

j. Useful Sources of Information

http://www.heatpumpcentre.org/

IEA’s Heat Pump Centre provides up-to-date information on the application and sizing of heat pumps for space and water heating as well as for heat recovery from refrigeration in supermarkets and other commercial establishments.

http://www.heatpumpcentre.org/About_heat_pumps/HP_tec
hnology.asp

This site provides a detailed explanation of ***MVR***, ***Heat Pumps*** as well as the lesser known ***Absorption Heat Pump*** (Type I), ***Heat transformers*** (Type II) and the ***Reverse Brayton-cycle heat pumps*** used to recover solvents from gases in many processes.

http://tristate.apogee.net/et/exth.asp

This site describes simply various heat pump configurations for different applications and estimate calculations.

http://www.owr.ehnr.state.nc.us/ref/32/31234.pdf

Industrial Heat Pumps for Steam and Fuel Savings, publication by the US Department of Energy describing principles and typical applications in various industries.

k. Equipment and Service Suppliers

http://www.topdownloads.org/directory/show.php?/Business/Industrial_Goods_and_Services/Machinery_and_Tools/Thermal_Process/Heat_Exchangers/

This site lists numerous heat exchanger manufacturers and suppliers.

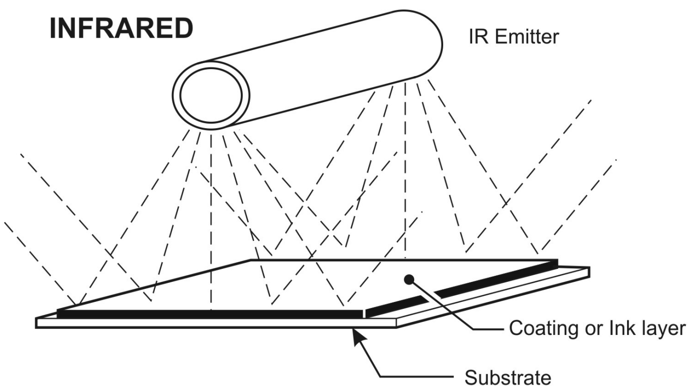
Notice: This list of vendors is not meant to be a complete or comprehensive listing. Mention of any product, process, service or vendor in this publication is solely for educational purposes and should not be regarded as an endorsement by the authors or publishers.

5 INFRARED HEATING

a. Principle

Infrared heating uses radiation emitted by electrical resistors, usually made of nickel-chromium or tungsten, heated to relatively high temperatures. The infrared region is usually divided into three ranges: near-infrared, intermediate-infrared and far-infrared.

The following diagram illustrates how a hot infrared (IR) emitter transfers radiant energy to a surface through the air without any contact with the surface. This particular characteristic makes IR heating especially useful in certain applications.



b. Types of Systems

Infrared Emitters					
Range	**Near infrared**		**Intermediate infrared**		**Far infrared**
Emitter	Tungsten filaments under vacuum		Nickel-chromium wire in quartz or silica	Steel-clad elements	Elements embedded in Pyrex or ceramic
	Glass or quartz lamp	Quartz tube with reflector			
Power	150 W 250 W 375 W	12-14 cm: 500 W 27-28 cm: 1000 W 64-70 cm: 5000 W	30-250 cm: 500-8000 W	600 - 6000 W	150-1000 W
Operating Tempe-rature	2000°C	2200°C	Quartz tubes:1050°C Silica panels: 650°C	750°C	Pyrex panels: 350°C; Ceramic elements: 300° to 700°C
Maximum product tempe-rature	300°C	600°C	Quartz tubes: 500°C Silica panels: 450°C	400°C	Pyrex panels: 250°C; Ceramic elements: 500°C

Reproduced with permission of Hydro-Quebec

c. Applications

Infrared radiation is used in a great variety of applications involving most materials, where surface treatment is required. It is often combined with hot air to remove vapours and to help prevent premature surface hardening. Examples of applications include:

1. Metals

- Drying of washed parts.
- Drying of paint, varnish or vitreous enamels.
- Heating of calandrias, surface heating of molds.
- Preheating of metal before shot blasting or welding.
- Heat treatment (annealing, hardening).

2. Plastics

- Preheating before thermo shaping.
- Drying of granules and washed sheets.
- Preheating of pipes before bending.
- Polymerization of plastifying agents.
- Curing of powder coatings.

3. Food Products

- Bakingdehydration of breads, biscuits and cookies.
- Reheating of food products.
- Roasting of meat.
- Crusting of pâté.
- Pasteurization and sterilization of milk and fruit juice.

4. Glass

- Preheating of bottles and laminated glass.
- Drying of coatings including enamel and mirror.

5. Textiles

- Drying of textiles, adhesives and inks.

- Polymerization of resins.
- Heat setting of latex foam on carpet backing.

6. Rubber

- Vulcanization.
- Heating of rubberized adhesives.

7. Ceramics

- Drying of clay pottery green ware and vitreous enamels.

8. Paper

- Drying of paper adhesives, coatings and ink.
- Polymerization of additives.

9. Miscellaneous

- Drying of wood panels and tobacco.
- Thermo sealing of batteries.
- Softening of wax.
- Heat shrinking of plastic wrapping.

d. Advantages

Infrared radiation is a highly efficient and attractive means of heating. Energy can be transferred to the surface of an object without contact and without any significant direct absorption by the environment.

The low thermal inertia of near and intermediate infrared emitters eliminates the need for long startup periods, and may reduce the amount of waste or scrap material generated.

The radiation can be concentrated, focused, directed or reflected. The incident power density can be as high as 250 kW/m^2. This results in compact equipment and rapid processing.

e. Limitations

Since infrared radiation is absorbed by the surface of a material, the heat takes time to travel through the material, depending on thermal properties. As a consequence, infrared radiant energy is less suitable for bulk heating. Heating of reflective coatings is difficult. Maintenance of IR emitters is higher in dirty environments.

f. Typical Performance

- Smaller equipment size due to faster processing times.
- Low to moderate capital cost depending on application.
- Low maintenance, primarily emitter cleaning and replacement.
- High overall efficiency compared to alternative heating processes.

g. Application Considerations

- Unit operation to be performed (drying, heating, curing, etc.).

- Emission wavelength based on the absorption factor of the product to be treated.
- Product shape.
- Material type or formulation (e.g. solvent-based vs. powder coating), and thickness.
- Processing method (continuous/batch treatment).
- Furnace characteristics (e.g. risks of shock between product and emitters).
- Emitter type (temperature of active element, power density, etc.).
- Distance between emitters and product to be heated, ventilation conditions.

h. Components and Terminology

- Near infrared emitters:
    - Vacuum or inert gas tubes or lamps.
- Intermediate infrared:
    - Metal filaments placed in quartz or transparent silica tubes.
    - Radiant panels.
    - Radiant tubes.
- Far infrared emitters:
    - Glass or ceramic panels heated by resistance (thin layer of metal oxide, embedded nickel-chrome resistance, etc.).
    - Coil element or surface strips of resistances on a fibrous ceramic substrate.
- Ventilating system (the ventilating air can also be used for cooling the emitters to increase overall furnace efficiency).

- Regulation (temperature of source in operation, product movement speed, etc.).
- Electrical power supply.

i. Installation Example

Drying of a Molded Pulp Product		
Parameter	**Infrared Furnace**	**Convection Furnace**
Primary Energy	Electricity	Propane
Drying Process	Infrared/convection	Convection
Installed power	1 MW	1.1 MW equivalent
Air temperature	150°C average	
Overall efficiency	> 80%	~ 45%
Drying Time	~ 9 minutes	~15 minutes
Specific energy consumption	0.85 kW/kg water evaporated	1.35 kW_{equiv} /kg water evaporated

Adapted from Reference 1

j. Useful Sources of Information

Industrial Heating Equipment Association (IHEA)
Phone: (513) 231-5613 / Web: http://www.ihea.org

A group that seeks to provide services to member companies that will enhance member company capabilities to serve end users in the industrial heat processing industry and improve the member company's business performance, as well. IHEA has an Infrared Equipment Division (IRED).

k. Equipment and Service Suppliers

Applied Heat Equipment Co. Limited
1312 Britannia Rd. E., Mississauga, ON L4W 1C8 Canada
Voice: (905) 670-2200 / Fax: (905) 670-1927
Web: http://www.appliedheatequipment.com

Casso-Solar Corp.
230 Rt. 202, P.O. Box 163, Pomona, NY 01970 USA
Toll-Free: 1-800-988-4455 / Voice: (845) 354-2500
Fax: (845) 362-1856 / Web: http://www.cassosolar.com

Canadian Representatives for Casso-Solar Corp.:

a) **Synergetic Technologies** (ON, MB, SK, AB, BC)
1120 Speers Rd., Oakville, ON L6L 2X4 Canada
Voice: (905) 849-7115 / Fax: (905) 849-0001
Web: http://www.synergetic.on.ca
No glass applications

b) **Gaston Belanger** (QB, NB, NS)
7623 Thames; Anjou, QC H1K 4C2 Canada
Voice: (514) 493-3824
Includes glass applications for all provinces

Fostoria Industries Inc., Process Heating Division
1200 N. Main, Fostoria, OH 44830 USA
Toll-Free: 1-800-495-4525 / Voice: (419) 435-9201
Fax: (419) 435-0842
Web: http://www.fostoriaindustries.com

Gasmac Inc.,
509 Clair Road West, Guelph, ON N1H 6H9 Canada
Voice: (519) 836-5362 / Fax: (519) 836-4242
Web: http://www.gasmac.com

Glenro Inc.
39 McBride Ave., Paterson, NJ 07501-1799 USA
Toll-Free: 1-888-453-6761 / Voice: (973) 279-5900
Fax: (973) 279-9103 / Web: http://www.glenro.com

ITW BGK Finishing Systems
4131 Pheasant Ridge Drive North, Blaine, MN 55449 USA
Toll-Free: 1-800-663-5498 / Voice: (763) 784-0466
Fax: (763) 784-1362 / Web: http://www.itwbgk.com

Research, Inc.
7128 Shady Oak Road, Eden Prairie, MN 55344 USA
Voice: (952) 941-3300 / Fax: (952) 941-3628
Web: http://www.researchinc.com

Tempco Electric Heater Corporation
607 N. Central Avenue, Wood Dale, IL 60191 USA
Toll-Free: 1-888-268-6396 / Voice: (630) 350-2252
Fax: (630) 350-0232 / Web: http://www.tempco.com

Canadian Representative for Tempco Electric Heater Corp.:

a) **Process Heaters Inc.**
750 Oakdale Rd., #58, Toronto, ON M3N 2Z4 Canada
Toll-Free: 1-877-747-8250 / Voice: (416) 747-8250
Fax: (416) 747-1860 / Web: http://www.processheaters.ca

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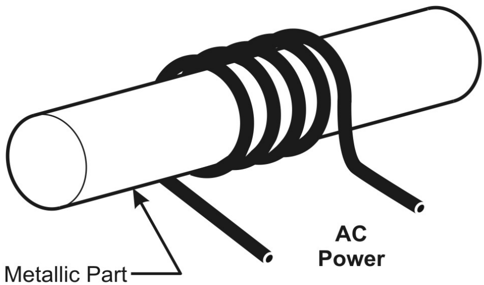
6 INDUCTION HEATING

a. Principle

Induction heating consists of applying an electromagnetic field created by an inductance coil to an electrically conducting object.



The variable (oscillating) magnetic field applied to a metal body produces an electric current (called an induced current) that flows through this body and heats it by the "Joule effect." From an energy efficiency point of view, induction heating of a metal piece is usually much more efficient and much faster than heating in a convection or radiant oven because the heat is generated directly in the material, and although there are some losses associated with the power supply, these losses are much less than the losses of fuel-fired or electric kilns or radiant heaters. From a control point of view, the power input to the piece can be accurately controlled by the shape of the coils, the intensity of the field and the time applied. Since no heated chamber or chimney are required with induction heating equipment, replacing combustion-type equipment with induction heating equipment can significantly improve the working environment around the process.

- Electromagnetic induction heating is generally used either for heating metal materials (i.e. direct heating) or for heating metal containers that, through conduction and convection, transfer their heat to the non-metallic contents to be treated (i.e. indirect heating).
- The process is based on the same principle as that of the transformer. The source of the variable magnetic field constitutes the primary circuit (the inductor) and the heated metal body, through which the short-circuit current flows, represents the secondary circuit.
- Because of the direct and immediate heat generation in the metal piece or metal container, induction heating results in highly efficient energy use, since very little energy is imparted to the surrounding materials or to the air and most of the energy is delivered within the magnetic field to the solid metal or container and its contents (as in induction cooking). In this manner, less heat is released to the local area or to the exhaust of the process.

b. Types of Systems

- Line frequency; high frequency & dual frequency systems.
- Melting & smelting & holding systems:
    - Channel induction furnaces.
    - Coreless induction furnaces.

- Heating systems:
    - Solenoid coils.
    - Flat induction coils.
    - Conveyor types.

c. Applications

Direct Heating of Metals (metallurgical applications)

- Virtually all forms of metal heating.
- Smelting and melting of steel, cast iron, aluminum, copper, zinc, lead, magnesium, precious metals and alloys.
- Heating prior to forming or forging (slabs, billets, sheets, tubes, bars, slugs, etc.).
- Heat treatments (hardening of gears and annealing of tubes, welds, wire, sheets, etc.).
- Heating prior to surface treatments of metal parts (cleaning, stripping, drying, galvanizing, tinning, enameling, organic coatings, etc.).
- Welding and brazing.
- Epoxy hardening.
- Selective heating of parts and bonding of metals and non-metallic bodies.

Indirect Heating of Materials in Metal Containers

- Heating of dies and press platens in the plastics industry.
- Heating of chemical reactors in the manufacture of resins, paints and inks.
- Heating of vats in the food industry.

- Heating of fluidized beds.
- Melting and crystallization of glass, refractory oxides and nuclear waste.

d. Advantages

The outstanding feature of induction heating is the absence of any physical contact between the energy source and the object to be heated. Other advantages include:

- Very fast heating (immediate) for less residence time and faster production rate.
- Repeatable.
- Immediate.
- Optimized by resonance.
- High efficiency levels.
- No energy loss during idling time.
- Directed heating with the possibility of localized heating and controlled depth of penetration; no risk in heating undesired components.
- Reduction of oxidation losses and absence of decarburization.
- Small size.
- Substantial improvement in working conditions (through decreased heat and noise) and environmental conditions (heat on the part, not into the air around it; heat loss of the equipment is very low).
- Elimination of combustion products, undesirable reactions and contamination.
- Bath stirring in melting processes (favours the homogeneity of alloys and rapid melting).
- Can be applied in controlled atmosphere conditions.

- Safe to use.

e. Limitations

- Not well suited to irregularly-shaped parts during forging.
- Need to change inductor and sometimes compensation for parts that are non-repetitive in shape.

f. Typical Performance

- Very high power density: 50 to 50,000 kW/m^2
- Good overall efficiency: 70 to 75% on average, and as much as 90%.
- The efficiency depends on the operating parameters: geometry of the inductors, distance between inductor and material, nature of materials to be treated and properties of the inductor's conductors, etc.
- Specific power output: up to several MW.

g. Application Considerations

- The materials to be treated may conduct electricity well (metallic bodies) or poorly. In the former case, the treatment is direct; in the latter, the material is indirectly heated by a metal container, itself heated by induction.
- Size and shape of the part (smaller, slender parts are often heated more efficiently by direct resistance heating).

- The choice of frequency of the variable magnetic field is important because the penetration depth of the field, and therefore of the heating effect, is inversely proportional to the square root of the frequency.
- Also to be considered are the magnetic permeability, electric resistivity and thermal conductivity of the material to be heated, as well as the way these parameters change according to the temperature.
- The configuration of the inductors is related to that of the materials; they must be as close together as possible for good efficiency.

h. Components and Terminology

- The source frequency must be chosen according to the size and nature of the object, as well as the desired degree of penetration. This, in turn, is dictated by the requirements of a specific application. Oscillating-current source:
    - 60-Hz transformer.
    - Frequency converters and oscillators from tens of Hz to MHz.
- Inductor coil (or applicator) to transform the oscillating current into an alternating magnetic field of suitable geometry (wide variety of inductors available). The types of coil used in industry include:
    - Solenoid inductance coils for broad shaped products.
    - Tunnel inductance coils per series of small objects.
    - Flat inductance coils for flat objects.
    - Trimmer capacitors.

- Furnaces of various types (crucible, channel, ladle, conveyor, etc.).

i. Installation Example

Hot Forging of Billets 30,000 Tons / year; 4,000 hrs per year		
Parameter	**Induction**	**Gas furnace**
Relative installation cost	3	1
Heating Efficiency	60%	15%
Material losses	0.75%	3%
Relative labour	1	2
Relative annual operating cost	1	1.3

Adapted from Reference 1

j. Useful Sources of Information

http://www.ihea.org/

Industrial Heating Equipment Association - Member directory (industrial heating service and equipment providers: all types and processes and fuel types)

http://www.ameritherm.com/appnotes.html

Excellent application notes for specialty applications of induction heating especially involving combinations such as metals and plastics

k. Equipment and Service Suppliers

http://www.industrialheating.com/CDA/Articles/Tabloid_Showcases

The International Journal of Thermal Technology – This website showcases a number of induction heating equipment and service providers.

http://www.cihinduction.com/

Cheltenham Induction Heating Limited provides equipment for induction heating applications ranging between 1 kW and 120 kW.

http://www.ameritherm.com/

Ameritherm produces RF power supplies with outputs from 10 W to 250 kW at frequencies of 5 kHz to 400 kHz.

http://www.rdoinduction.com/inductionheating.htm

Induction heating equipment supplier, for heating, brazing, soldering, etc. from fraction of a Watt to 100 kW capacities, induction casting equipment for precious metals and alloys (up to 7.5 kW).

http://www.fluxtrol.com/

Flux control and induction coil design services and products to concentrate and redistribute magnetic flux over the work piece.

http://www.heattreatquotemaster.com/

Contract Heat Treatment Services - The Metal Treating Institute (MTI) has represented the largest Network of Commercial Heat Treaters meeting the specialization and capacity needs of In-House Captive Heat Treaters. MTI is made up of commercial heat treating companies who specialize in dozens of steel and metal processes and treatments including annealing, brazing, forging, sintering, tempering and other thermal processing. Heat Treat QuoteMaster is a user-friendly system that facilitates the entire sourcing process by automatically distributing request for quotes (RFQs) to active members of MTI throughout North America.

http://www.inductionatmospheres.com/

Induction Atmospheres is an independently owned system integrator with extensive laboratory facilities, engineering expertise, in-house machining and manufacturing capabilities. It offers turnkey induction systems for "lean manufacturing" including induction brazing under controlled atmospheres.

http://www.advancedenergy.org/industrial_process_heating

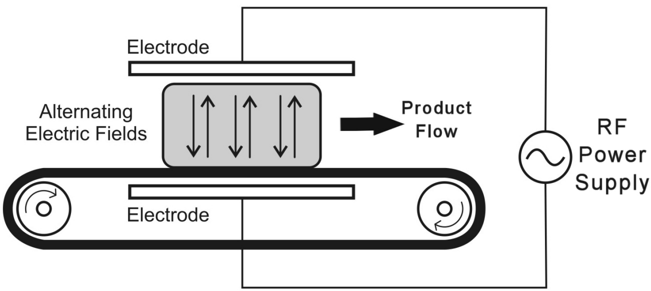
Advanced Energy is a nonprofit, independent organization that can evaluate, test and recommend unbiased solutions in industrial heating applications.

Notice: This list of vendors is not meant to be a complete or comprehensive listing. Mention of any product, process, service or vendor in this publication is solely for educational purposes and should not be regarded as an endorsement by the authors or publishers.

7 RADIO-FREQUENCY HEATING

a. Principle

When a non-electrically-conducting material is placed in a high-frequency (alternating) electric field, electron and proton charges within the molecules of the material try to align themselves with the applied electric field. This produces a rapid agitation of the molecules which is converted into heat within the material as a result of molecular interaction (e.g. friction). The heat produced does not depend on the thermal conductivity of the material itself, but rather on the dielectric properties of the material to be treated. The frequency range used for dielectric heating is between 10 MHz and 300 MHz. The material to be heated is placed between a pair of electrodes; the electric field between the plates oscillates causing heating in the materials introduced into the field (see illustration below).



This characteristic is useful for speeding up the heating and drying of adhesives in the production of laminated products, since the heat is produced within the material and does not have to travel into the material by conduction from the surface.

b. Types of Systems

- Fixed or variable frequency operation.
- Batch or continuous heating (i.e. conveyor) systems.
- Conveyor Systems (characterized by electrode configuration):
  - Flat plate types for thick objects.
  - Stray field types for thin webs.
  - Staggered electrode types for thick sheets.
- Tubular heating systems (for liquids).

c. Applications

- Heating and evaporation of water in any material to be dried. As long as it is dielectric and fairly regular in shape (paper, cardboard, board, textiles, wood, etc.).
- Heating of any dielectric material, as long as it has a high loss factor (glues, plastics, resins, etc.).
- Applications that have been implemented by industrial users include:
  - Drying and moisture leveling of webs, sheets, boards and bulk materials.
  - Drying of water-based coatings, inks and adhesives in paper manufacturing and converting.
  - Atmosphere and vacuum dying of wood products, dimensional lumber and timber.
  - Drying and setting of dyes on textile yarns, fabrics and garments.

- Drying of fiberglass yarn and chopped strands.
- Drying of ceramic greenware prior to firing.
- Drying of resin-based sand casting cores.
- Drying of filter cake.
- Gluing of laminates, paper bags and cardboard boxes.
- Welding and sealing of plastics.
- Preheating of plastic sheets prior to forming and molding.
- Heating and hardening of composite board.
- Post-baking drying and moisture control of biscuits, crackers, cereals and other food products.
- Heating, cooking and pasteurizing of flowable materials.
- Heat treating, de-infestation and pasteurizing of bagged materials.
- Sterilization of medical waste.

d. Advantages

- This process allows the inside of dielectric materials to be heated directly and instantly (not possible with traditional heating methods).
- Possibility of applying high power densities throughout the process; hence significantly reduced treatment time and floor space, and increased productivity.
- In drying:
    - Favorable water-elimination gradient.
    - High efficiency even in final drying.

  - Selective water heating: "moisture-leveling" within the material treated and no overheating of product (resulting in less energy used and better quality).
  - RF power consumption with humid materials alone; advantageous for separate or spaced (intermittent) parts.
- Heat transfer more or less independent of temperature and volume of ventilating air:
  - Ventilation decreased (volume and energy) to just what is necessary to eliminate moisture.
  - Operation at low temperature (reduced losses through walls and exhaust stack).
- Instant start and stop.

e. Limitations

- High capital cost:
  - Applications are more cost-effective for products with high added value.
  - Applications are more cost-effective when combined use with less expensive processes (e.g. infrared, hot air).
- Protection against electromagnetic radiation required.

Comparisons with Microwave Heating

Collectively radio-frequency and microwave are called ***dielectric heating***. Radio-frequency (RF) and microwave (MW) heating differ notably in the behavior of the various materials treated and the nature of the components used:

- The capital cost for RF equipment is about half as much as for MW equipment.
- There is no RF power dissipation when there is no load (unlike MW).
- Power outputs available from RF sources (tubes or solid-state amplifiers) are higher than for microwave sources, thus allowing a scale reduction in costs (RF: up to 900 kW_{RF}; MW: up to 75 to 100 kW_{MW}).
- RF is better suited to large, flat materials (uniform power and applicator type), while irregularly shaped products are more easily treated in MW multimode cavities.
- Wider choice of RF frequencies to adapt to different situations.
- MW heating is more suited to materials with low dielectric-loss factor.
- MW heating lends itself better to application of high power densities without creating a breakdown (e.g. arcing).

f. Typical Performance

- Electricity-to-RF conversion efficiency: typically 55 to 70%; up to 80% with solid-state, high-frequency amplifier technology.
- Overall process efficiency: 50 to 70%.
- Higher overall efficiency with floating-frequency systems, but a higher level of RF-shielding is required.
- In drying, efficiency remains high even in the final drying stages.
- Possible power density: up to 200 kW_{RF}/m^2
- Unit power: up to 900 kW_{RF}/source.

- Tube service life: 5,000 to 10,000 hours.

g. Application Considerations

- The materials to be treated must be dielectric, that is, non-conductors of electricity; otherwise the electric field is totally reflected and does not penetrate.
- The treatment (heating, drying, gluing, etc.) may be performed in batches or continuously.
- The frequency chosen may vary according to the material's reaction; the frequency may be floating or fixed.
- The parts to be treated should preferably be regular or flat in shape.
- The electrode and conveyer types, power density and total power to be installed must be determined.
- The possibility of combining the high-frequency technique with another one, such as infrared or hot air should seriously be considered.

h. Components and Terminology

High-frequency Generator

- RF oscillator with triode supplied by direct high voltage.
- Can operate in two modes:
    - At fixed frequency.
    - At floating frequency (self-adapting to the material load in the applicator).
- Three frequency bands assigned by government regulations: 13.56, 27.12 and 40.68 MHz.

Only authorized frequencies may be used for open systems.

- For furnaces that are closed and suitably shielded, the frequencies used may range from 1 to 300 MHz.

Electric-field Applicators (three main types)

- With parallel plates located on either side of the treated product, used when the product is thick or complex in shape.
- With a "Strayfield" system of electrodes (rods) of alternating polarity on one side of the treated product, which is very thin, flat and has a large surface area.
- With electrodes in a staggered (or garland) arrangement on either side of the treated product, which is relatively thin, flat and has a large surface area).

Furnace

- Batch or continuous (tunnel) treatment.
- Insulating conveyor (fiberglass and Teflon) or steel frame sliding over grounded steel plate.
- Entrance zone for attenuation of the electromagnetic field.

i. Installation Examples

Final drying of paper

600 kW_{RF} (1000 kW). 1925 m^2/min of paper (60 to 120 g/m^2); 30% increase in production rate; overall RF heating efficiency of 70%; 10% decrease in energy for entire machine: humidity profile uniform at ±0.5% [Ref. 1, 3].

Gluing of wood

4 kW_{RF} for 0.1 m^2 of joints in 1 to 2 minutes; 100 kW_{RF} for 4 m^3/h of plywood; 900 kW_{RF} (1,450 kW_{elect}) to make fibreboard panels 2.2 cm thick at a rate of 15.7 kg/m^2 in 4 minutes [Ref. 1, 3].

j. Useful Sources of Information

Association for Microwave Power in Europe for Research and Education (AMPERE)
AMPERE EUROPE LIMITED, IPTME, Loughborough University, Loughborough LE11 3TU UK
Web: http://www.ampereeurope.org

International Microwave Power Institute (IMPI)
7076 Drinkard Way, Mechanicsville, VA 23111 USA
Voice: (804) 559-6667 / Fax: (804) 559-4087
Web: http://www.impi.org

k. Equipment and Service Suppliers

Heatwave USA, Inc.
2700 Orchard Ave., McMinnville, OR 97128 USA
Voice: (971) 241-5060 / Web: http://www.heatwave.com

Nemeth Engineering Associates, Inc.
5901 W. Highway 22, Crestwood, KY 40014 USA
Voice: (502) 241-1502 / Fax: (502) 241-5907
Web: http://www.nemeth-engineering.com

Petrie Technologies Ltd.
Ackhurst Road, Chorley, Lancashire PR7 1NH UK
Voice: +44 (1257) 241 206 / Fax: +44 (1257) 267 562
Web: http://www.petrieltd.com

PSC Division of C. A. Litzler Co., Inc.
21761 Tungsten Road, Cleveland, OH 44117 USA
Toll-Free: 1-800-538-1337 / Voice: (216) 531-3375
Fax: (216) 531-6751 / Web: http://www.pscrfheat.com

Radio Frequency Company, Inc.
150 Dover Road, P.O. Box 158, Millis, MA 02054-0158 USA
Voice: (508) 376-9555 / Fax: (508) 376-9944
Web: http://www.radiofrequency.com

Strayfield Limited
Ely Road, Theale, Berkshire, RG7 4BQ UK
Voice: +44 (0)870 428 1086 / Fax: +44 (0)870 428 1087
Web: http://www.strayfield.co.uk

Solid-State High Frequency Power Amplifiers

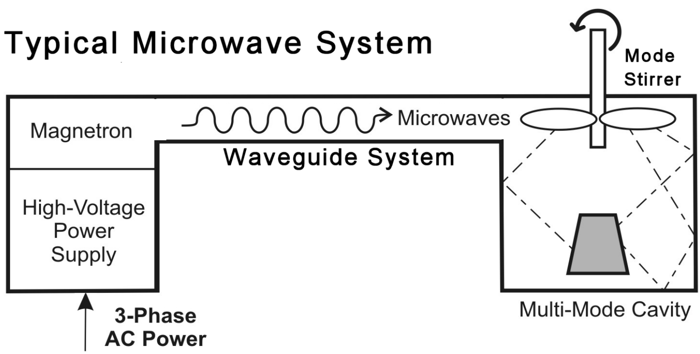
Nautel Limited
10089 Peggy's Cove Rd, Hackett's Cove, NS B3Z 3J4 Canada
Voice: (902) 947-8200 / Fax: (902) 947-3693
Web: http://www.nautel.com

Notice: This list of vendors is not meant to be a complete or comprehensive listing. Mention of any product, process, service or vendor in this publication is solely for educational purposes and should not be regarded as an endorsement by the authors or publishers.

8 MICROWAVE HEATING

a. Principle

The material to be heated is subjected to an ultra high frequency (UHF) electromagnetic field. This field causes molecules in the material to become distorted or to oscillate. The energy of the alternating molecular movements is converted into heat within the material as a result of molecular interaction (e.g. friction). The heat produced does not depend on the thermal conductivity of the material itself, but rather on the dielectric properties of the material being treated. In microwave heating, an ultra high frequency wave generator (magnetron) is used to produce the ultra high frequency field (of either 915 or 2450 MHz) and a waveguide (metallic pipe), a nozzle or horn is used to direct the energy into a material or into a chamber where the material to be heated is located. See a typical system below.



b. Types of Systems

Batch Systems

- Multi-mode (i.e. large heating cavity or oven).
- Single-mode (i.e. small heating zone, high power density).
- Tubular types (for liquids):
    - Standing wave.
    - Serpentine or coiled tube.
- Radiating slotted waveguide .
- Radiating horn.

Continuous Systems

- Multi-mode (i.e. large heating cavity or oven).
- Single-mode (i.e. small heating zone, high power density).
- Tubular types (for liquids):
    - Standing wave.
    - Serpentine or coiled tube.
- Rotary tube systems (for granular and powder materials).
- Slotted waveguide (for webs).
- Radiating slotted waveguide.

c. Applications

- Heating and evaporating water in any dielectric material requiring drying, even complicated shapes, as long as they are not too large.
- Preheating and vulcanizing of rubber products.

- Heating and tempering of frozen meat and other food products.
- Cooking of bacon and various foods.
- Drying of pasta.
- Vacuum dehydration of food products.
- Cold drying.
- Blanching of vegetables.
- Drying and hardening of coatings on carpets, textiles, paper, plastics, electronics .
- Setting of textile dyes.
- Sterilization of already packaged goods.
- Sterilization of medical waste.
- Drying of casting cores (sand and resin) and porous ceramic moulds.
- Drying of ceramic products before firing.
- Drying of investment casting shell between dips.
- Drying of wood, textile, paper products.
- Sintering of ceramics.
- Polymerization.
- Treatment of nuclear or toxic waste.
- Production of plasma in chemical processes.

d. Advantages

- Unique ability to heat inside dielectric materials (i.e. volumetric heating) directly and instantly, not possible with conventional heating.
- Possibility of applying very high power densities; results in smaller equipment and increased productivity (i.e. shorter heating times).

- Selective heating in some applications put energy and heat only where it is needed for high efficiency and productivity.
- Creates a temperature gradient favourable for water elimination/drying.
- Frequently results in reduced material losses / higher yields.
- Near instant start and stop; reduces standby energy losses.
- Heat transfer more or less independent of air movement; decreases requirements for high air flow and temperature, hence reduces heat losses.

e. Limitations

- High capital cost.
- Low unit power; may require multiple power sources; may restrict size of installation.
- Undesirable heating effects with some materials (run-away temperature rise, burning).
- Requires shielding against electromagnetic radiation.
- May be difficult to treat large areas uniformly.

f. Typical Performance

- Overall process efficiency (50% to 70%) is much higher than with conventional heating techniques, and may require much less energy due to faster processing times and the possibility of selective heating.
- Power density: up to 500 kW per m^2
- Generator Unit power: up to 30 kW per tube at 2450 MHz, and 100 kW per tube at 915 MHz.

- Power tube life: typically 5,000 to 8,000 hrs of operation.

g. Application Considerations

- Materials to be treated must be dielectric, i.e. non-conductors of electricity; otherwise the wave is reflected and does not penetrate.
- The type of applicator and configuration (batch or continuous).
- Operation frequency.
- Power density and total power requirements.
- Dielectric loss factor of the material to be treated, and changes with temperature.
- Possible combination with other heating technology.

h. Components and Terminology

Generator

- Magnetron or klystron tubes supplied from high-voltage, direct-current power supplies.

Waveguide System

- Isolators / 3-port circulators.
- Waveguides, antennas, dummy loads, & tuners.

Applicator (main types)

- Multi-mode, batch cavity (e.g. domestic microwave oven).

- Multi-mode, tunnel.
- Slotted waveguide .
- Radiating slot waveguide.
- Traveling wave applicator.
- Single-mode, resonant cavity.

Frequency

- Between 300 MHz and 300 GHz frequency. Industrial-grade heating equipment usually operates at either 915 MHz or 2,450 MHz.

i. Installation Example

Vulcanizing Rubber Extrusions		
Parameter	**Microwave System**	**Salt Bath System**
System configuration	Continuous microwave heating (2450 MHz) with hot-air section	Continuous molten salt bath
Heating section length	Microwave section: 2.8 to 8.8 m Hot-air section: 6.6 m	Tank Length: 7 to 15 m
Operating Temperature	Hot-air temperature: up to 260°C	Salt bath temperature: 200 to 250°C
Process Start up	Near instant startup and heating	Approx. 2 hrs of preheat required
Heat transfer	Volumetric heating, suitable for thick cross-sections	Contact surface heating, with conduction heating of core.
Extrusion size limitations	Cross sections of up to about 200 mm^2	Thickness up to 25 mm (limited by heat transfer rate)
Line Speed	45 m per minute	25 m per minute (for 50 g per m product)
Post-process product cleaning	None required	Cleaning is essential
Salt consumption	None	4 to 5 kg per hour

Adapted from References 1 & 3

j. Useful Sources of Information

Association for Microwave Power in Europe for Research and Education (AMPERE)
AMPERE EUROPE LIMITED, IPTME, Loughborough University, Loughborough LE11 3TU UK
Web: http://www.ampereeurope.org

International Microwave Power Institute (IMPI)
7076 Drinkard Way, Mechanicsville, VA 23111 USA
Voice: (804) 559-6667 / Fax: (804) 559-4087
Web: http://www.impi.org

k. Equipment and Service Suppliers

Cober Electronics, Inc.
151 Woodward Avenue, Norwalk, CT 06854 USA
Voice: (203) 855-8755 / Fax: (203) 855-7511
Web: http://www.cober.com

CoberMuegge LLC
151 Woodward Avenue, Norwalk, CT 06854 USA
Voice: (203) 852-0343 / Fax: (203) 852-0214
Web: http://www.cobermuegge.com

Environmental Waste International
283 Station Street, Ajax ON L1S 1S3 Canada
Voice: (905) 686-8689 / Fax: (905) 428-8730
Web: http://www.ewmc.com

The Ferrite Company Inc.
165 Ledge Street, Nashua, NH 03060 USA
Toll-Free: 1-800-854-1466 / Voice: 603-881-5234
Web: http://www.ferriteinc.com

Industrial Microwave Systems LLC
3000 Perimeter Park Drive - Building I, Morrisville, NC 27560 USA
Toll-Free: 1-888-321-4467 / Voice: 919-990-9900
Fax: 919-990-9596
Web: http://www.industrialmicrowave.com

Microdry Incorporated
5901 W. Highway 22, Crestwood, KY 40014 USA
Voice: (502) 241-8933 / Fax: (502) 241-8648
Web: http://www.microdry.com

Microwave Research and Applications, Inc.
8673 Cherry Lane, Laurel MD 20707 USA
Voice: (866) 953-1771 / Fax: (301) 369-0523
Web: http://www.microwaveresearch.com

Thermex-Thermatron Inc.
11524 Commonwealth Dr., Louisville, KY 40299 USA
Voice: (502) 266-5454 / Fax: (502) 266-5453
Web: http://www.thermex-thermatron.com

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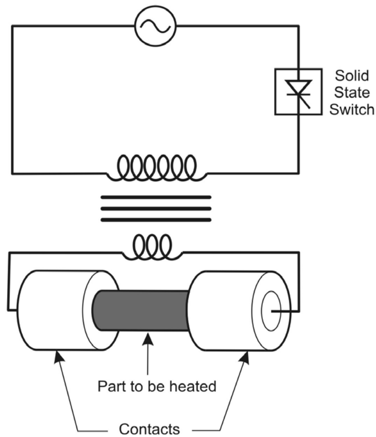
9 DIRECT RESISTANCE HEATING

a. Principle



Direct Resistance heating involves passing a direct-current or alternating-current directly through the product to be heated. Since the part must be electrically conductive, direct resistance heating is often referred to as "conduction heating."

With this type of heating, clamp or roll types of electrodes must be used to physically make contact with the product being heated. See diagram above. For food products, the sauce or gravy is the component that conducts the electric current, and the process is sometimes called "ohmic heating." The resistance (R) of the product to the flow of current (I) passing through it generates the I^2R heating power. Low frequency current (60 Hz) heats the part throughout.High frequency current (400 kHz) tends to heat only the surface of the part.

b. Types of Systems

- Metal heater (billet heaters, heat treating).
- Resistance welders (spot welders, seam welders, etc.).
- Non-metal heat and melting (e.g. glass, silicon carbide, salt baths).

- Food cookers and sterilizers (commonly referred to as "Ohmic heating").
- Steam generators (e.g. high voltage electrode boilers, humidity generators in building HVAC systems).

c. Applications

- Heat treatment of metals.
- Heating of ferrous metals before shaping or forming.
- Metal reheating.
- Metal melting.
- Metal joining: spot, seam and flash welding.
- Glass melting.
- Water heating and steam generation.
- Food cooking and sterilization.
- Graphite electrode production.
- Accelerated curing of concrete.

d. Advantages

- Rapid rate of heating.
- Heating takes place where intended.
- High efficiency - only the piece being heated is involved.
- No combustion products are produced.
- Lower equipment space requirement.
- Moderate capital investment.

e. Limitations

- Contact surfaces must be clean and scale free for good electrical connection.

Heating

- Uniform part cross-section required for uniform heating.
- Part must be long and slender (i.e. length-to-diameter at least 6:1).
- Better suited to smaller cross sections (i.e. < 3 cm diameter).
- Large systems (e.g. glass melting) may be limited to moderate production rates by power supply ratings.

Welding

- Part configuration must provide high resistance to flow of current.

f. Typical Performance

- Power density: up to 100 kW at up to 10^5 kW/m^2
- Electrical energy conversion: >95%
- Overall process efficiency typically 75% to 95%

g. Application Considerations

- Shape, size and homogeneity of material (for uniform heating); generally < 3 cm diameter and length-to-diameter at least 6:1.

- Electrical resistivity of material (voltage/current balance).
- Connection resistances (local over-heating).
- Thermal losses through the surfaces (radiation, convection) and connections (conduction).
- Voltage and power supply (DC, AC, capacity required).
- Skin effect (dissipated power varies according to operating frequency and depth of penetration of the current).

h. Components and Terminology

- Electrical power supply.
- Control and process regulation system.
- Connection systems and current input circuit.
- Treatment chamber (optional).
- Material-handling system.

i. Installation Example

Heating Forging Blanks		
Parameter	**Direct Resistance Heater**	**Fossil-Fired Furnace**
System configuration	Individual heating of blanks	Batch heating of long bars
Forging-blank target temperature	1230°C	1230°C
Temperature control of blank	Automated	Operator judgment
Heating time	< 15 sec	15 to 20 minutes
Energy efficiency	~ 85%	17% to 20% (no recuperation) 35% to 40% (with recuperation)
Energy Usage	~ 280 kWh/ton	~ 140 m^3 NG /ton ~ 70 m^3 NG /ton (with recup.)
Scale formation	Little or none < 0.5%	Significant ~ 2%
Relative Operator labour req'd	0.5 x	1 x
Relative plant floor space req'd	0.8x	1 x
Plant floor environment	Cooler & cleaner	Hot, with fumes & dirt from furnace

Adapted from References 19 & 20

j. Useful Sources of Information

Ohmic Heating of Food

Ohio State University
http://www.osc.edu/research/video_library/ohmic.shtml
http://ohioline.osu.edu/fse-fact/0004.html

Agri-Food Canada
http://sci.agr.ca/crda/pubs/art10_e.htm

Spot Welding and Joining

Resistance Welding Manufacturers Alliance
550 NW LeJeune Road, Miami, FL 33126 USA
Voice: (305) 443-9353 / Fax: 305-442-7451
Web: http://www.aws.org/rwma/index.html

k. Equipment and Service Suppliers

Heating Equipment

IHS (an Inductotherm Group Company)
5009 Rondo Drive, Fort Worth, TX 76106 USA
Toll-Free: 1-800-486-5577 / Voice: (817) 625-5577
Fax: (817) 625-1872 / Web: http://www.ihs-usa.com

Welding Components and Equipment:

Huys Industries Ltd.
175 Toryork Dr., #35, Weston, ON M9L 1X9 Canada
Toll-Free: 1-800-461-9936 / Voice: (416) 747-1611

Fax: (416) 747-7171
Web: http://www.huysindustries.com

Resistance Welding Products Ltd.
9270 Marlborough St., P.O. Box 670, Blenheim, ON, N0P 1A0 Canada
Toll Free: 1-800-265-5262 / Voice: (519) 676-8173
Fax: (519) 676-3329 / Web: http://www.rwpweld.com

WTC Canada
240 Cordova Road, Oshawa, ON L1H 7N1 Canada
Voice: (905) 433-1230 / Fax: (905) 433-1257
Web: http://www.wtc.ca

Boilers

A E P Thermal Inc.
8190 Montview, Montreal, PQ H4P 2L7 Canada
Voice: (514) 342-5656 / Web: http://www.acmeprod.com

Electric Steam Generator Corp.
600 S. Oak St. P.O. Box 21, Buchanan, MI 49107 USA
Toll-Free: 1-800-714-7741 / Fax: (269) 695-7777
Web: http://www.esgcorp.com

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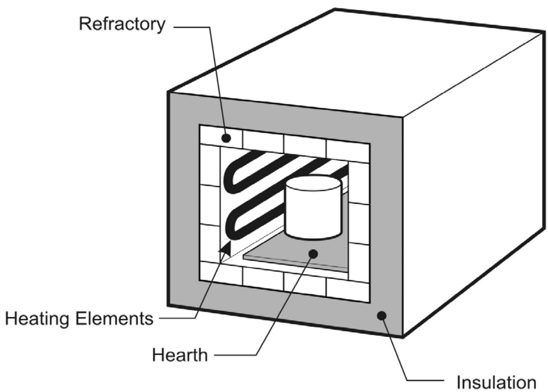
10 INDIRECT RESISTANCE HEATING

a. Principle

Indirect resistance heating involves passing line frequency current through high resistance heating elements. The resistance to the current flow generates heat. The heat is transferred to the process material via conduction, convection, and/or radiation. The process material temperatures can range from ambient to 1700˚C (3100˚F) or more (with an inert atmosphere), depending on the application and type of heating elements. This type of heating is typically performed in a well-insulated enclosure, like an electric oven. This minimizes thermal losses and provides a high heating efficiency, typically in the 80% range.



b. Types of Systems

Indirect resistance heating can be used in several ways:

- Custom heating solutions, using a wide variety of encased resistance heating elements.
- Direct contact with the material to be heated (e.g. immersion-element water heater).
- By heating an intermediate substance (e.g. hot air for drying).
- As the heat source in a thermally insulated enclosure (e.g. furnace).

For furnace applications, various types of heating elements and enclosures may be used, depending on the temperatures needed, the product to be heated and the process used. There are four general categories of resistance furnace:

- Normal or controlled atmosphere furnaces.
- Batch process or continuous process furnaces.
- Batch feeding furnaces (manual, by motor, etc.).
- Continuous feeding (e.g. conveyor belt, etc.) furnaces.

c. Applications

Indirect resistance heating is used in a wide variety of applications, including:

- Heating and melting metals or other substances (glue, wax, etc.).
- Heat treatments.
- Vitrifying ceramics, glass, enamel.

- Roasting and calcining (powders, grains, etc.).
- Sintering of ceramics.
- Cooking, baking and roasting of food products.
- Drying and curing processes (paint, varnish, etc.).
- Water and liquid heating.
- Steam generation.
- Air and gas heating.

d. Advantages

- Simple, well proven techniques.
- Flexibility of application.
- Easy to control and automate.
- Low maintenance costs.
- Easily replacement of fuel oil or gas burners.
- Does not generate smoke, dust or combustion gases.
- Compact, efficient point-of-use equipment can improve the quality of the product and the work-floor environment.
- Compatible with special atmospheres or vacuum.

e. Limitations

- Load temperature limited by the melting point of the refractory material (silica: 1700°C; graphite: 3000°C; etc.) and the maximum operating temperature for the electrical heating elements used (iron, nickel and chrome: 1000°C; graphite: 1800°C, etc.).
- Heat transfer rate between the heating elements and load.
- Heating element service life.

- Operating cost may be high (depends on the cost of electricity).

f. Typical Performance

- Conversion of electrical energy: >95%.
- Power density: up to 70 kW/m^2 of surface of furnace wall .

g. Application Considerations

- Nature and dimensions of the load.
- Heat transfer method based on the desired temperature (over 500°C, radiation is predominant).
- Type and shape of heating elements.
- Thermal losses through walls and openings.
- Furnace utilization method (continuous/discontinuous).
- Application (heating, preheating, baking, etc.).

h. Components and Terminology

- Power supply (generally 60 Hz).
- Control and/or regulation system (on/off, proportional, integral, derivative (PID), etc.).
- Furnace (chamber, movable hearth, crucible, drum. bell, tunnel, etc.).
- Auxiliary cooling equipment, blowers.
- Material handling system (conveyor, vibrator, screw, etc.).

- Insulating and refractory materials (type, thickness, etc.).
- Heating elements.

Insulating Refractory Materials			
Insulating Material Type	**K-factor (W/m•°C)**	**Density (kg/m^3)**	**Relative Cost**
Fibrous ceramic	0.19	0.1	0.5
Insulating Concrete	0.27	1.25	0.7
Insulating Brick	0.28	0.8	0.4
Compressed Brick	1.4	2.3	1.0

Heating Element Types			
Heating Element Family	**Material**	**Maximum Temperature of Element (°C)**	**Application - Remarks**
Iron-Nickel-Chrome Alloys	Fe-20Ni-25Cr	900	Widely used because of their availability and low cost Wide range of temperatures Used in oxidizing atmospheres
	Fe-45Ni-23Cr	1050	
	Fe-65Ni-15Cr	1100	
	80Ni-2-Cr	1150 to 1200	
Iron-Chrome-Aluminum Alloys	Fe-22Cr-14.5Al	1280	Higher temp. than Ni-Cr at about same cost Embrittlement on first heating Used in oxidizing atmospheres
	Kantal AF	1400	
Non-metallic Alloys	SiC (silicon carbide)	1600	Bars are brittle – susceptible to thermal & mechanical shocks Used in oxidizing or reducing atmospheres
	$Cr_2O_3La_2O_3$ (lanthanum chromite)	1800 to 1900	
	Graphite	2500	Low cost of bars Used in neutral or reducing atmospheres, or under vacuum
Noble metals	Molybdenum	2300	Wire or plates Very high cost Only in neutral or reducing atmospheres, or under vacuum
	Tungsten	2500	
	Tantalum	2500	

i. Installation Example

Aluminum Melting in a Foundry		
Parameter	Electric Resistance Melter	Natural Gas Fired Melter
Heating efficiency	~ 70%	15 to 20%
Metal Loss (Dross formation)	Little or none < 1%	Very Significant; ~ 12%
Relative maintenance cost	0.72 x	1 x
Relative production	1.1 x	1 x

Adapted from Reference 21

j. Useful Sources of Information

http://www.ihea.org/

Industrial Heating Equipment Association - Member directory (industrial heating service and equipment providers: all types and processes and fuel types)

k. Equipment and Service Suppliers

ASB Heating Elements Ltd.
20 Bethridge Rd, Toronto, ON M9W 1N1 Canada
Toll-Free: 1-800-265-9699 / Voice: (416) 743-9977
Fax: (416) 743-9424 / Web: http://www.asbheat.com

Bucan Electric Heating Devices, Inc.
3300 Boul. Pitfield, St-Laurent, QC H4S 1K6 Canada
Voice: (514) 335-9665 / Fax: (514) 335-9804
Web: http://www.bucan.com

Tempco Electric Heater Corporation
607 N. Central Ave., Wood Dale, IL 60191 USA
Toll-Free: 1-888-268-6396 / Voice: (630) 350-2252
Fax: (630) 350-0232 / Web: http://www.tempco.com

CCI Thermal Technologies Inc.
5918 Roper Rd., Edmonton, AB T6B 3E1 Canada
Voice: (708) 466-3178 / Fax: (780) 468-5904
Web: http://www.ccithermal.com

Wattco Electric Canada Ltd.
55 Milton Ave, Lachine, QC H8R 1K6 Canada
Toll-Free: 1-800-492-8826 / Voice: (514) 488-9124
Web: http://www.wattco.com

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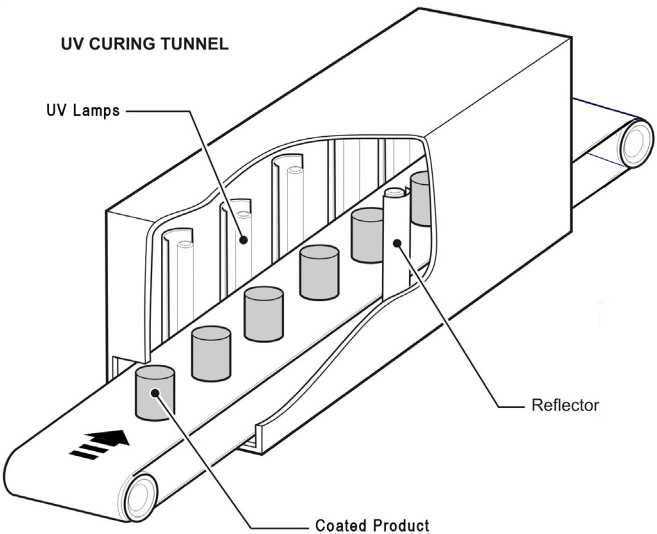
11 ULTRAVIOLET PROCESSING

a. Principle

Ultraviolet radiant curing is an alternative to conventional thermal curing of coatings, inks, and adhesives. Conventional solvent- or water-based formulations must be first dried (to evaporate the solvent or water), then cured with heat or long exposure to air to convert the soft organic base to a tough polymer. UV-curable formulations contain little or no solvent. The organic base contains a photo-sensitive component ("photoinitiator") that triggers a nearly instantaneous curing reaction upon exposure to ultraviolet light.



Thus UV curing produces a completely dry and finished surface in a second or two, compared with minutes or hours for conventional curing. This yields coatings and inks of the highest quality with very high production rates in minimal equipment space.

UV can also disinfect clear or translucent fluids (water, air, etc.) for reuse or recycle.

b. Types of Systems

- Coating curing systems.
- Liquid and air disinfecting systems.

c. Applications

- Curing coatings, inks, and adhesives; on metal, wood, plastic, fabrics, magnetic tape, and electronics.
- Curing textile fiber sizing.
- Compact disc production.
- Disinfecting water, wastewater, air, and other fluids.

d. Advantages

- Cures fast.
- Reduces or eliminates solvents.
- No thermal curing ovens needed.
- Can coat heat sensitive substrates (plastic and wood).
- Fewer coating materials required.
- Small equipment and staging area required.
- Improves coating quality.

- Aids volatile organic compound (VOC) regulatory compliance.

e. Limitations

- Higher cost of UV coating materials.
- Some UV materials require special care (toxic).
- More worker protection required (high energy UV).
- Line-of-sight limitation.

f. Typical Performance

- Low-pressure mercury sources have low unit power (≤ 100 W/tube) and long service life (10,000 h).
- High-pressure mercury sources have very high unit power (up to approximately 10 kW, but limited service life [2000 h]).
- Intensity of applied radiation decreases with age of lamps and fouling of system.
- The electricity/radiation efficiency is 15% to 25%, but total energy used is from 10 to 100 times less than that used in competing thermal curing methods.

g. Application Considerations

Polymerization

- New type of coating to be adopted.
- Thickness of coat.
- Power and length of exposure.
- Lamp type.

- Tunnel furnace.
- Protection of personnel.

Disinfection

- Density of organisms to be eliminated.
- UV dose (intensity and duration).
- Lamp type.
- Strict timetable for cleaning and replacement to maintain anti-microbial effectiveness.
- Density of liquid to be sterilized.
- Flow type.

h. Components and Terminology

Several Source types

- Electrical discharge in mercury vapor (between 2 electrodes or microwave-induced).
- Low-pressure (≤1 torr) up to 100 W/lamp.
- High-pressure (≈760 torr) 10 to 30 kW/lamp .

Special Sources

- Pulsed xenon
- UV laser

Liquid (Purification) Treatment

The reactor is a chamber filled with UV tubes around which the liquid flows (parallel or perpendicular to the tubes). The tubes are protected from the liquid by tubular sheaths made of quartz or non-reactive polymer. The reactor has ultrasonic or mechanical cleaning equipment that is assisted by chemical cleansing products.

Polymerization

UV sources equipped with reflectors are mounted on the upper, inside surface of the processing tunnel; the parts, with the UV-sensitive coating already applied, travel beneath the sources on a conveyor.

i. Installation Example

Printing Line		
Parameter	**Printing & UV Curing**	**Printing & Thermal Curing**
Cycle Time	Near instantaneous curing; allows for faster processing & lower "Work in Progress"	Curing times limit processing speeds
Energy Usage for Curing - Electricity - Natural Gas	 82 kW none	 56 kW 1.1 million BTU/hr
Press Setup & Cleaning Time (typical)	1 hr / day	2.5 hrs / day
Typical Process Up-Time for 3-shift operation	80% (1-shift operations benefit more)	70%
Relative Ink/Coating Cost: - by ink volume - by volume of product printed	 2x to 3x **0.7x to 1.3x**	 1 x 1 x
Relative Capital Cost: - small system - large system	 1 x 0.5x	 1 x 1 x
Plant Space Requirements	0.1 x	1 x
Plant Environment	Cool and solvent free; possibility of UV exposure	Hot, with possibility of solvent exposure
Maintenance cost	Lower cleanup costs, & no cool-down time required	Long cleanup cycles, with long cool-down & re-heat times
Product Loss (Scrap)	Low	Significant
Waste & Environmental Emissions	Low	Significant

Adapted from Reference 23

A printing company is using UV curing on a print line to produce labels, coupons, and tags. UV-curable inks and overprint varnish maintain high quality and consistency in the colors and give the product an attractive and durable finish. Print quality variations due to evaporation of solvent in ink trays have been eliminated. Line speed is about 67% higher for the UV-cured lines. Startup and shutdown/cleanup times have been reduced dramatically with the UV inks. Rejects and product loss at startup have also been sharply reduced. [Reference 24]

j. Useful Sources of Information

The International Ultraviolet Association Inc. (IUVA)
P.O. Box 1110, Ayr, ON N0B 1E0 Canada
Voice: 519-632-8190 / Fax: 519-632-9827
Web: http://www.iuva.org

- *The IUVA is relatively new, incorporated as a non-profit association in April 1999, and dedicated to serving all professional fields with interests in ultraviolet technology.*
- *The IUVA site contains information on manufacturers and distributors of equipment, industry announcements and events, and other general information on a wide range of UV applications.*

k. Equipment and Service Suppliers

The International Ultraviolet Association (IUVA) website includes a *"buyers' guide"* with links to both manufacturers and distributors of UV equipment and components. Link to the *"buyers' guide"* from the IUVA homepage at http://www.iuva.org under the menu-item *"UV information."*

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12 OTHER ELECTROTECHNOLOGIES

Other electrotechnologies include Electric Arc, Laser, Plasma and Membrane technologies. These technologies are application-specific, tend to be expensive, and are used primarily by large or highly specialized industries.

a. Electric Arc

Electric arc heating is a specific kind of plasma heating. An electric arc is created when a current passes through ionized gas between two electrodes. Such arcs are quite powerful and allow temperatures of up to 4,000°C to be reached. Electric arcs are used in furnaces as radiant heat sources or as submerged arcs. Electric arcs are used in open furnaces for heating and melting in the production of steel and cast iron. Electric arcs are also used in closed reduction furnaces, submerged under the materials being reduced in applications such as the production of certain chemicals such as calcium carbide and phosphorous and for the production of ferroalloys such as ferrosilicon, ferromanganese and cast iron.

b. Laser

A laser is a device that emits an extremely intense and highly directional beam of light. The light is produced either by an electrical discharge in a gas and configuration of specific requirements or by strong flashes of ultraviolet light illuminating a crystal of particular composition and shape. The laser beam may be continuous or pulsed. It can be concentrated within a very small area and thus can attain very high power densities at the point of impingement. Beams can be continuous or pulsed, their intensity and power can be controlled, and the beam can be used for such diverse applications as micromachining, drilling, milling, cutting of metals, ceramics, plastics, etc. and for ablating tissue in surgery, for etching and engraving, and numerous other applications.

c. Plasma

Traditionally, matter exists in three states: solid, liquid and gaseous. However, there is a fourth state: plasma, a gaseous matter that has been ionized (composed of positively charged ions and free electrons, but remains electrically neutral) and has become electrically conducting. Plasma can be produced by various types of electrical discharges: by an electrical arc at atmospheric or higher pressures, by low temperature luminescent discharge, induced discharge at high frequency, or by microwave of sufficiently high intensity. Plasma generators can achieve up to about 50% ionization, and as such, can be used for numerous applications where extreme temperatures (as high as 10,000°C) are required (for example, as plasma torches for cladding, coating, welding and cutting).

d. Membranes

Membrane technologies can be subdivided into two basic groups of processes; pressure-driven and electrically-driven. The main benefit of these techniques is much lower energy consumption when compared with traditional techniques for separation or purification.

Pressure-driven membrane processes use hydraulic pressure to force water molecules through the membranes. Impurities are retained and concentrated in the feedwater, which becomes the reject water or concentrate stream. Processes include ultrafiltration, microfiltration, nanofiltration and reverse osmosis. Membrane classification standards vary considerably from one filter supplier to another. What one supplier sells as an ultrafiltration product, another manufacturer calls a nanofiltration system. When comparing two membrane systems, it is better to look directly at pore size and molecular weight cutoff (MWCO) values.

- Microfiltration (MF) is defined as a membrane separation process using membranes with a pore size of approximately 0.03 to 10 microns, a MWCO of greater than 100,000 daltons[2], and a relatively low feedwater operating pressure of approximately 100 to 400 kPa (15 to 60 psi). Representative materials removed by MF include sand, silt, clays, *Giardia lamblia* and *Cryptosporidium* cysts, algae, and some bacterial species. MF is not an absolute barrier to viruses; however, when used in combination with disinfection, MF appears to control these microorganisms in water. MF can significantly reduce chemical addition, such as chlorination. When used with feedwater pretreatments (e.g. coagulants and powdered activated carbon) it is effective in removing natural or synthetic organic matter to reduce fouling potential. MF is also used as a pretreatment to RO or NF processes to reduce fouling potential.

[2] Dalton is a measure of molecular weight or mass. One hydrogen atom has mass of 1 Da. Proteins and other macromolecule molecular weights are usually measured in kDa or kD (kilodaltons) - 1000 Da.

Applications of MF include bacterial and particle removal from process water, cold sterilization of beer and wine, clarification of beverages (e.g. wine and dark juices), pre-filtration of cheese whey prior to concentration by ultrafiltration, etc.

- Ultrafiltration (UF) involves the pressure-driven separation of materials from water using a membrane pore size of approximately 0.002 to 0.1 microns, a MWCO of approximately 10,000 to 100,000 daltons, and an operating pressure of approximately 200 to 700 kPa (30 to 100 psi). UF will remove all microbiological species removed by MF (partial removal of bacteria), as well as some viruses (but not an absolute barrier to viruses) and humic materials. The primary advantages of low-pressure UF membrane processes compared with conventional clarification and disinfection (post-chlorination) processes are: No need for chemicals (coagulants, flocculants, disinfectants, pH adjustment); size-exclusion filtration as opposed to media depth filtration; Good and constant quality of the treated water in terms of particle and microbial removal; process and plant compactness; and simple automation. Applications of UF include potable water treatment, concentration of liquors used in pulp and paper industry, recovery of oil, paint, chemical products from waste streams, concentration of juices, milk products, egg products, sugars, enzymes, hormones, blood, separation of water and oil, etc.

- Nanofiltration (NF) membranes have a nominal pore size of approximately 0.001 microns and a MWCO of

1,000 to 100,000 daltons. Pushing water through these smaller membrane pores requires a higher operating pressure and more pumping energy than either MF or UF. Operating pressures are usually near 600 kPa (90 psi) and can be as high as 1,000 kPa (150 psi). These systems can remove virtually all cysts, bacteria, viruses, and humic materials. Applications of NF include water softening, desalination of dyestuffs, acid and caustic recovery and colour removal.

- Reverse osmosis (RO) also requires pumping energy to apply a high pressure; 1,400 to 10,000 kPa (200 to 1,500 psi) on a water solution to cause water to pass through a semi-permeable membrane in the reverse direction from the solution side to the pure water side. In this process, there is a simultaneous production of pure water and concentrated solution. RO systems are compact, simple to operate, and require minimal labor, making them suitable for small systems. They are also suitable for systems where there is a high degree of seasonal fluctuation in water demand. RO can effectively remove nearly all inorganic contaminants from water, and can also effectively remove radium, natural organic substances, pesticides, cysts, bacteria, and viruses. Applications of RO include elimination of up to 90% of BOD from industrial waste or municipal sewage, concentration of juice, milk, coffee, purification of water, desalination of water, etc.

Electrically-driven membrane processes use electric current to move ions across the membrane leaving purified water behind. The ions are collected in the concentrate stream for disposal. The product water is the purified feedwater. Technologies include electrodialysis and electrodialysis reversal.

- In electrodialysis (ED), an electric field is used as a motive force that pushes electrically charged ions from a solution through a membrane that is capable of selecting ions. An alternate series of anionic membranes (that let through only negatively charged ions) and cationic membranes (that let through only positively charged ions) define the various compartments in an electrolytic bath that permit concentration of a liquid or partial elimination of the dissolved matter. Applications of ED include the demineralization of water, removal of salts in sugar production, de-acidification of fruit juices, demineralization of whey, recovery of metals from plating solutions, metal removal from ethylene glycol, etc.

- Electrodialysis reversal (EDR) is an improvement over the original electrodialysis processes. In EDR, the direct-current driving force is periodically reversed to prevent scaling and fouling of the membrane surface. This innovation improves both efficiency and the operating life of the membranes. During the short time that the field is reversed, the output of the EDR cells is flushed to waste.

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14 GLOSSARY OF TERMS

Conduction or Direct Resistance Heating
In conduction heating, the material is heated directly by an electric current passing through it. Conduction heating is used with both metallic and non-metallic materials that conduct electricity. Applications include heat treatment of metals, heating of metals before forming, and glass melting. Also known as "direct-resistance heating" or "ohmic heating."

Dielectric Heating
Refers to a family of heating processes that are used to heat "dielectric" (i.e. non-metallic) products. The material is through-heated by the movement of the electric charges within the material due to the electric field applied by either a radio-frequency (RF) or microwave (MW) source.

Electric Arc
Electric arc heating is a specific kind of plasma heating. An electric arc is created when a current passes through ionized gas between two electrodes. Such arcs are quite powerful and allow temperatures of up to 4,000˚C to be reached. Electric arcs are used in furnaces as radiant heat sources or as submerged arcs.

Electro-membranes – see "Membranes"

Electrotechnologies
Electrotechnologies are electric technologies that are used in industrial processes such as heating, drying, heat treatment and smelting to obtain significant improvements in energy use.

Fuel Cells and Advanced Batteries
Fuel cells and advanced batteries are energy storage devices. The fuel cell works on the process of chemical reaction (as opposed to combustion reaction) between oxygen and a supply of hydrogen to provide a source of electricity; advanced batteries refer to various new chemical combinations that act to provide a self-contained storage capability of electricity that can be accessed for providing current.

Heat pumps (HP)
Gases heat up when compressed and cool down when expanded. Heat can therefore be obtained by placing a gas in a closed circuit comprising two heat exchangers, a compressor and an expansion valve. This is the principle behind the heat pump. Energy can thus be transferred from a low-temperature source such as the ambient air, a gas or a liquid, to an application at a higher temperature.

High Frequency (HF)
Also known as Radio-Frequency (RF) heating. Uses the same heating mechanism as microwave (MW), except that the material to be heated is placed between the electrodes in which the field oscillates causing heating. The frequency is between 10 MHz and 300 MHz. MW and HF heating are sometimes jointly described as dielectric heating.

Indirect Resistance
Indirect resistance heating consists of passing an electric current through conductors, the heating being proportional to the electrical resistance of the conductor (Joule effect). The heat generated is confined in an insulated enclosure such as a container or an oven. This heat can be used by direct contact with the material to be heated or by the influence of an intermediate substance.

Induction
Induction heating consists of applying the electromagnetic field of an inductance coil to an electrically conducting object. The application of alternating current to the coil induces current in the object and causes it to heat up due to internal resistance heating (Joule effect).

Infrared (IR)
Infrared heating uses radiation emitted by electrical resistors, usually made of nickel-chromium or tungsten, heated to relatively high temperatures. The infrared region is usually divided into three ranges: near-infrared, intermediate-infrared and far-infrared.

Laser
A laser is a device that emits an extremely intense beam of light. The beam can be concentrated within a very small area and attain very high power densities. This technology is used in micromachining, drilling, milling and cutting in the micromechanics and electronics industries.

Mechanical Vapour Recompression (MVR)
Vapours produced by evaporation are mechanically compressed and directed into a condenser where they reach higher temperature and pressure levels. The condenser is used as a heat source to assist in the evaporation of the vapours. The process uses the vapours themselves as the working fluid, it has only one heat exchanger and its efficiency factor is very high.

Membranes
These separation technologies are subdivided into pressure-driven and electrically-driven subcategories. Pressure-driven membrane technologies include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis

(RO). Electrically-driven processes include electrodialysis (ED), and electrodialysis reversal (EDR). Membrane processes are used to separate and concentrate various fractions of liquid containing suspended or diluted products. The basic characteristic of these techniques is low energy consumption when compared with traditional separation techniques.

Microwave (MW)
In microwave heating, a non-conducting material is subjected to an ultra high frequency (UHF) electric field. The material is through-heated by the movement of the electric charges within the material due to the electric field applied (even though it is a poor conductor of heat). A frequency of either 915 or 2450 MHz is used. A microwave heating system comprises an ultra-high-frequency wave generator, a waveguide, a nozzle or horn and devices for control and handling.

Motors and Variable Speed Drives
These devices turn electricity into mechanical action such as rotation. A recent innovation is variable-speed capability, which is not limited by specific voltage or technical design so as to be able to operate at different speeds at the command of the operator.

Ohmic Heating
When a food product, usually contained in a non-metallic pipe, is heated directly by the flow of an electric current passing through it, the process is commonly referred to as "ohmic heating." This form of heating is also known as "conduction heating" or "direct-resistance heating."

Plasma
Traditionally, matter is considered to exist in three states: solid, liquid and gaseous. However, there is a fourth state:

plasma, a gas that has been ionized and has become electrically conducting. Plasma generators can heat gases at temperatures as high as 10,000°C.

Radio-frequency (RF)
Also known as High-Frequency (HF) heating. Uses the same heating mechanism as microwave (MW), except that the material to be heated is placed between the electrodes in which the field oscillates causing heating. The frequency is between 10 MHz and 300 MHz. MW and RF heating are sometimes jointly described as dielectric heating.

Ultraviolet (UV)
Unlike the other electrical processes, ultraviolet radiation does not have a primarily thermal effect on matter but rather a photochemical effect. Its industrial applications to date include accelerated hardening and curing of inks, varnishes and rubber, chemical synthesis and sterilization of food products, pharmaceuticals, water and air.

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Your feedback and comments are appreciated.
Please provide suggestions to:

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