EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

15. Conversion of electrical energy to heat energy

15.1 Introduction, sources of heat, advantages of electrical heating

15.2 Basic principle and characteristics of resistance and arc furnace, applications

15.3 Induction and dielectric heating

15.4 Examples of electric heating in household

Doc. Ing. Stanislav Kocman, Ph.D.
August 2018

15.1. Introduction, sources of heat, advantages of electrical heating

15.1.1. Introduction

Electric heating is a process in which electrical energy is converted to heat energy. Some metals (e.g., copper, platinum, gold, etc.) are usually good conductors of thermal energy which is converted from energy of the flowing electrical current. But they have too low resistivity for a production of heat energy besides an economy aspect. Thus electrical resistor as a heating element is used which works on the principle of Joule heating (https://en.wikipedia.org/wiki/Electric_heating). They are widely used in domestic sector and in industry.

$$Q = R \cdot I^2 \cdot t$$

15.1.2. Sources of electric heat

The sources of electric heat can be classified as follows:

- Electrical resistance:
  - Metal heating elements
  - Metal heating cables or conductors
- Electrical arc:
  - Electric arc furnaces
  - Welding
- Electromagnetic induction:
  - AC magnetic field
  - Dielectric losses
- Electromagnetic radiation:
  - Infrared, microwave and radio waves

15.1.3. Advantages of electric heating

Electric heating offers considerable advantages, but it also has certain disadvantages. Among principal advantages belong rather high efficiency (e.g. the efficiency of electric space heating is almost 100%), low investment costs (compared to gas, oil), low maintenance costs (e.g. no annual check), small dimension (small requirements for a space), ecology (no dust, waste...), good adjustability (regulation of power, accuracy of electronic controls), operation safety (absence of gas, fire), quiet operation.

Disadvantages of electric heating: it must be well insulated against heat loss, higher operating costs.

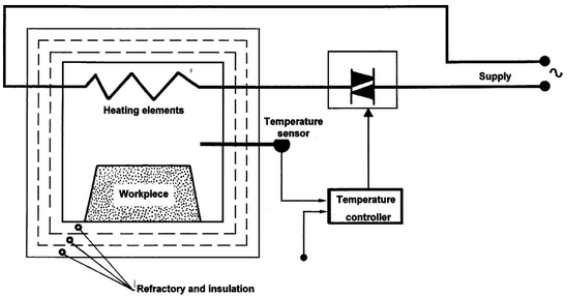
15.2. Basic principle and characteristics of resistance and arc furnace, applications

15.2.1. Resistance furnace

They use the heat generated by Joule effect in a conductive element in which an electrical current flows. Resistance furnaces are split into two main groups:

- Indirect: the heat is developed in elements (resistors) located on the walls of the furnace chamber and transmitted into a heated material by radiation and convection. Used in many applications.
- Direct: the current flows directly in a heated material. Less used, esp. for special applications, they have higher efficiency than the indirect system (S. Lupi: Fundamentals of Electroheat).

15.2.2. Indirect resistance furnace



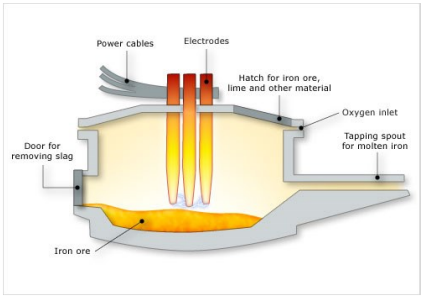
It is used for non-metallic and metallic workpiece (material). It comprises these main elements: a heating chamber to accommodate the given material, designed with refractory and insulation materials able to withstand the maximum working temperature and to keep heat losses down to an acceptable value; heating elements carrying the electrical current; a temperature control system; the supply from the mains; systems for loading and unloading the heated material; auxiliary devices, like fans in forced convection furnaces (S. Lupi: Fundamentals of Electroheat). There are some requirements for the heating elements (=resistors) such as high resistivity, low temperature resistance coefficient, size constant, high melting point, oxidation immunity, high

mechanical strength, good workability. Usage of indirect resistance furnaces is for melting or for heating liquids and solid charges, metal workpiece heat treatment, drying electric machines windings, drying whole electric machines, enameling, sterilization (in health service)…

15.2.3. Direct resistance furnace

Because the electric current is flowing directly across the heated material some requirements are necessary, such as metallic heating heated material, large resistivity of the heated material, supply conductors of small resistance (losses aspect), the voltage source of large capacity (to achieve sufficient current).

15.2.4. Electric arc furnace



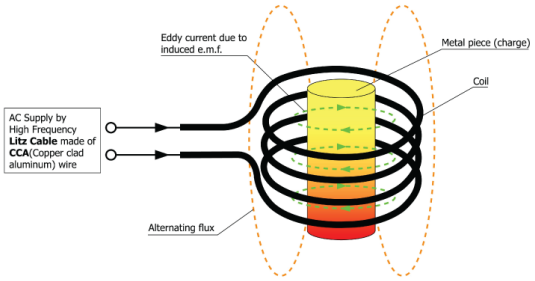
It is a furnace that heats heated material by means of an electric arc. The temperature in an industrial electric arc furnace can be up to 1800 ^{0}C. It is used to reduce iron from iron ore. Oxygen is blown into the furnace, and lime and other materials are added to combine with the impurities and form slag. Molten iron is extracted and poured out via a tapping spout. According the kind of electrical supply current they are:

- direct current (DC) arc furnaces (with a single electrode, in the bottom of the furnace shell is the second electrode)
- alternating current (AC) arc furnaces with three electrodes (direct arc furnace), or with two electrodes (indirect arc furnace, the current of the electric arc is not flowing across the charged material, but between two electrodes above the material to which the heat is transmitted by radiation, so the temperature is lower than at the direct arc furnace)

Usage of the electric arc furnaces is production and refining of various grade of steel, melting of non-ferrous metals (brass, copper, zinc, etc. having lower melting points, in this case the indirect system is used). Electrodes of the furnace are carbon or graphite, requirements on them are good electric conductivity, high mechanical strength, high oxidation temperature, low content of ash and sulfur. Next usage of electric arc is: arc welding and arc-lamp (https://en.wikipedia.org/wiki/Electric_arc_furnace).

15.3. Induction and dielectric heating

15.3.1. Induction heating



It is used for heating an electrically conducting object (usually a metal) by electromagnetic induction, through heat generated in the object by eddy currents. The supply current flowing across electromagnet (or induction heating transformer) or coil is alternating. The heating depth depends on frequency of the current (smaller one means higher frequency), so semiconductor inverter can be used. The advantage of the induction furnace is a clean, energy-efficient and well-controllable melting process compared to most other means of metal melting. The one major drawback to induction furnace usage in a foundry is the lack of refining capacity; charge materials must be clean. The usage of induction heating is heat treatment in metallurgy, melting iron and other metals, heating of silicon and other semiconductors, induction cooking, etc. (https://en.wikipedia.org/wiki/Induction_furnace).

15.3.2. Dielectric heating

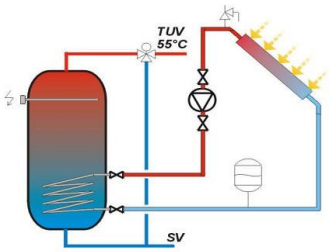


It is the process in which radio wave or microwave electromagnetic radiation heats a dielectric material. The molecules of the heated dielectric material rotate by aligning with the oscillating electric field excited by alternating voltage source. The agitating molecules in this way increases the temperature of the material (https://en.wikipedia.org/wiki/Dielectric_heating). Heating depends on electric field intensity, frequency (c. 10–100 MHz), and parameters of heated material. It is killing parasites and pests.

The usage of the dielectric heating is heating non-metallic materials, pieces…, drying, sterilization, pasteurization, food preservation, preparing certain kinds of food (microwave oven, operates at 2,45GHz).

15.4. Examples of electric heating in household

15.4.1. Water heating



- Storage water heaters. They use electricity, natural gas, propane, heating oil, solar energy to heat water in a tank (https://en.wikipedia.org/wiki/Water_heating). In the case of electric heater cold water in a tank enters the chamber and it is heated by heating elements in which the electrical current is flowing. The heated water rises to the top. The temperature is regulated. Solar system uses heat from sun to warm water by solar panels, called collectors.
- Tankless water heaters (instantaneous). Heaters instantly heat water as it flows through the device. They are located just above the hot water consumption.

15.4.2. Space heating

- Radiant heaters. They use heating elements that reach a high temperature. The element emits infrared radiation.
- Fan heaters. Electric fan to speed up the airflow. They operate with noise caused by the fan.
- Storage heating. They take advantage of cheaper electricity prices, sold during low demand periods such as overnight. The storage heater stores heat in clay bricks, then releases it during the day when required.
- Electric underfloor heating. Heating cables embedded in the floor warm it by direct conduction and will switch off once it reaches the temperature set by the floor thermostat. It is also realized as the hydronic system by using water (https://en.wikipedia.org/wiki/Electric_heating).

15.4.3. Next examples of heating

- resistance heating
  - iron, electric kitchen stove, hair dryer, washing machine, dishwasher, jug kettle
- dielectric heating
  - microwave oven
- infrared heating (radiation)
  - infra heater