Fundamentals of Heat Transfer

Muhammad Rashid Usman

Institute of Chemical Engineering and Technology

University of the Punjab, Lahore.

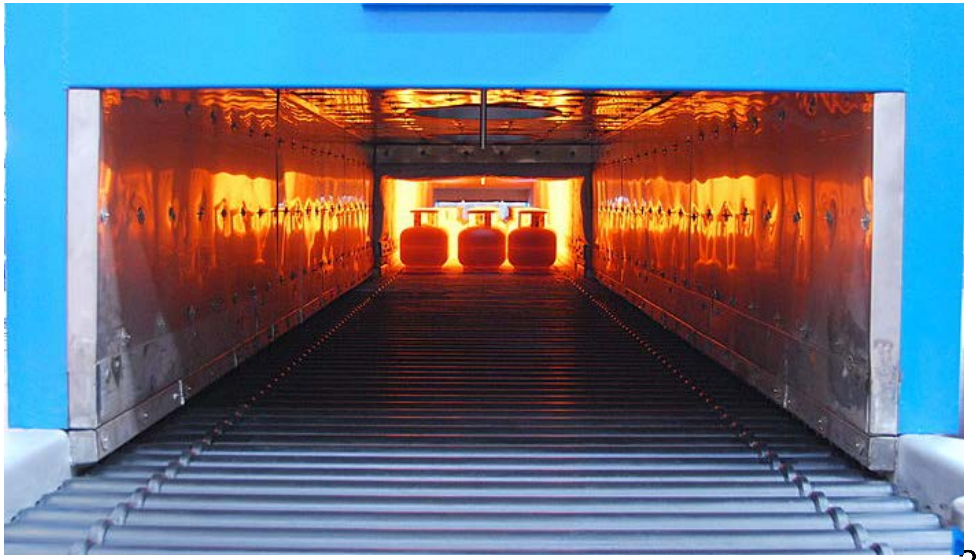
Figure taken from: http://heatexchanger-design.com/2011/10/06/heat-exchangers-6/ Dated: 17-Jan-2012

Course contents mid term

Introduction to transfer processes. Definition, applications, and various units of heat transfer. Modes of heat transfer: Conduction, convection, and radiation heat transfer. Fourier's law of heat conduction. Thermal conductivity of gasses, liquids, and solids. Units of thermal conductivity. Effect of temperature, pressure, and composition on thermal conductivity of materials. Estimation of thermal conductivity of gases, liquids, and solids. Introduction to steady-state heat transfer. Heat conduction through plane wall, hollow cylinder, and hollow sphere. Numerical problems related to heat conduction through plane wall, hollow cylinder, and hollow sphere. Thermal resistances in series: Composite plane wall, composite hollow cylinder, and composite hollow sphere. Numerical problems related to heat conduction through composite plane wall, composite hollow cylinder, and composite hollow sphere. Free and forced convection. Rate equation for convective heat transfer coefficient. Brief description of hydrodynamic boundary layer and heat transfer coefficient. Units of heat transfer coefficient. Individual and overall heat transfer coefficients: plane wall and hollow cylinder. Numerical problems regarding overall heat transfer coefficient. Determination of heat transfer coefficient. Description of various heat transfer correlations. Heat transfer in coiled and jacketed agitated vessels.

Heat conduction through a plane wall: Problem-1

The wall of an industrial furnace is constructed from 0.15 m thick fireclay brick having a thermal conductivity of 1.7 W/m·K. Measurements made during steady-state operation reveal temperatures of 1400 and 1150 K at the inner and outer surfaces, respectively. What is the rate of heat loss through a wall that is 0.5 m by 1.2 m on a side? [4]



http://forevermaterial.en.made-in-china.com/product/BqRmDZYynbpH/China-Low-Porosity-Fireclay-Brick.html
http://www.directindustry.com/prod/sistem-teknik-industrial-furnaces/roller-hearth-furnaces-26280-577854.html

Heat conduction through a plane wall:
Problem-2

Calculate the heat loss per m^2 of surface area for an insulating wall composed of 25.4 mm thick fiber insulating board, where the inside temperature is 352.7 K and the outside temperature is 297.1 K. Thermal conductivity of the material is 0.048 W/m·K. [1]

Answer: 105.1 W/m^2

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Heat conduction through a plane wall with variable thermal conductivity

In the previous problem, thermal conductivity is assumed to constant with temperature.

Taking thermal conductivity as a linear function of temperature, it may be shown

$$k = a + b \cdot T$$

If it is a polynomial of second degree, it may be shown as below:

$$k = a + b \cdot T + c \cdot T^2$$

Where, *a*, *b*, and *c* are constants.

For derivation procedure, see class notes.

Heat conduction through a plane wall with variable thermal conductivity

- It can be any function of temperature, and in each case one has to integrate it while keeping within the integral on the right side of the Fourier's equation.
- If you are given *T* vs *k* data, you can develop your own suitable function by fitting the given data which may be used with Fourier's law. Always keep temperatures of interest in your mind.
- When thermal conductivity is a linear function of temperature, use two point linear interpolation to find the thermal conductivity at arithmetic mean of the temperatures of interest and incorporate the interpolated value of the thermal conductivity in Fourier's law.

Homework Problems

A plane wall has a 25 cm thickness and the extreme sides of the wall are maintained at 200°C and 50°C. Calculate the heat flux (heat rate per square meter) through the wall. The thermal conductivity of the wall is fixed at 0.5 W/m·K. Also calculate the temperature distribution at various points of the wall.

Hint: The temperature distribution can be obtained from the following equation.

$$T = \frac{T_2 - T_1}{\Delta x} \cdot x + T_1$$

Homework Problems

The data for thermal conductivity of mercury (Hg) is given below. Plot a graph between T and k and develop a mathematical relationship between T and k.

Table *Thermal conductivity of mercury at various temperatures*

T (°F)	k Btu/h·ft·°F
40	4.55
60	4.64
80	4.72
100	4.80
150	5.03
200	5.25
250	5.45
300	5.65
400	6.05
500	6.43
600	6.80
800	7.45

Using interpolation, calculate the thermal conductivity of mercury at 75 °F.

Homework Problems

The wall of a container (30 cm thick) is made of stainless steel. The inside and outside temperatures of the container wall are 400 K and 300 K. Calculate the heat loss from this container through this wall. The thermal conductivities of stainless steel are 16, 17.3, and 23 W/m·K at 293 K, 373 K, and 573 K, respectively.

Develop a generalized heat rate equation for a steady-state, one-dimensional heat conduction problem when thermal conductivity is a taken as a function of temperature as given below:

$$k = a + bT + \frac{c}{T}.$$

Hint: Start from the Fourier's law and insert the above relationship in place of k and then integrate to find the final expression.

Heat conduction through a plane wall with variable thermal conductivity

What are isotropic and anisotropic materials?

Think about wood!

Think about an aluminum block!

Heat conduction through a plane wall with variable thermal conductivity

What if thermal conductivity even varies in a single direction?

How can we introduce the variation of thermal conductivity along the direction of flow in Fourier's law?

References

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