Fundamentals of Heat Transfer

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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.

Effect of temperature, pressure, and composition on thermal conductivity

Unlike specific volume, specific heat capacity, specific volume, thermal conductivity is a non-additive property.

Gases:

•Thermal conductivity increases with increasing pressure. The effect is small at low pressures and near 1.0 bar the effect is ignorable.

•Generally, thermal conductivity increases with increase in temperature.

•Thermal conductivity increases nearly as square root of the absolute temperature upto few atmospheres.

•At very high pressures (i.e., for dense gases) increasing temperature, decreases the value.

Effect of temperature, pressure, and composition on thermal conductivity

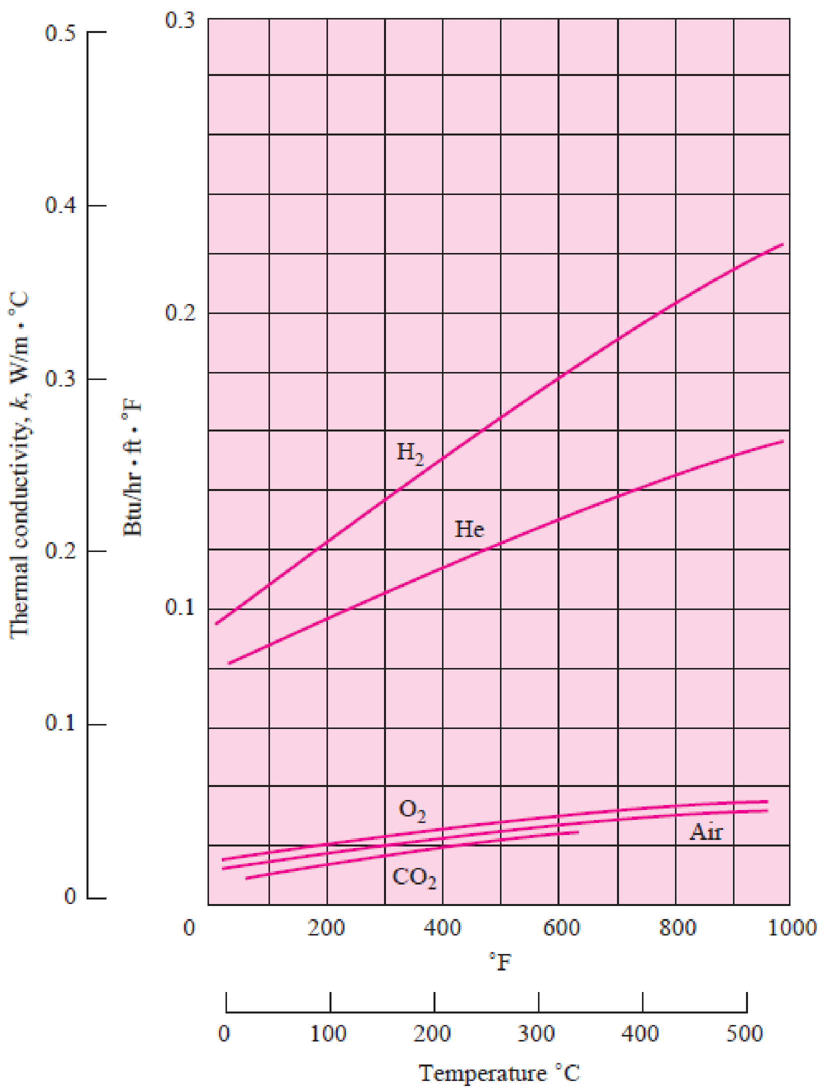
Liquids:

- Generally speaking, thermal conductivity of liquids are relatively not affected by pressure.
- Raising the temperature , usually decreases the thermal conductivity, and the variation may be expressed as linear.

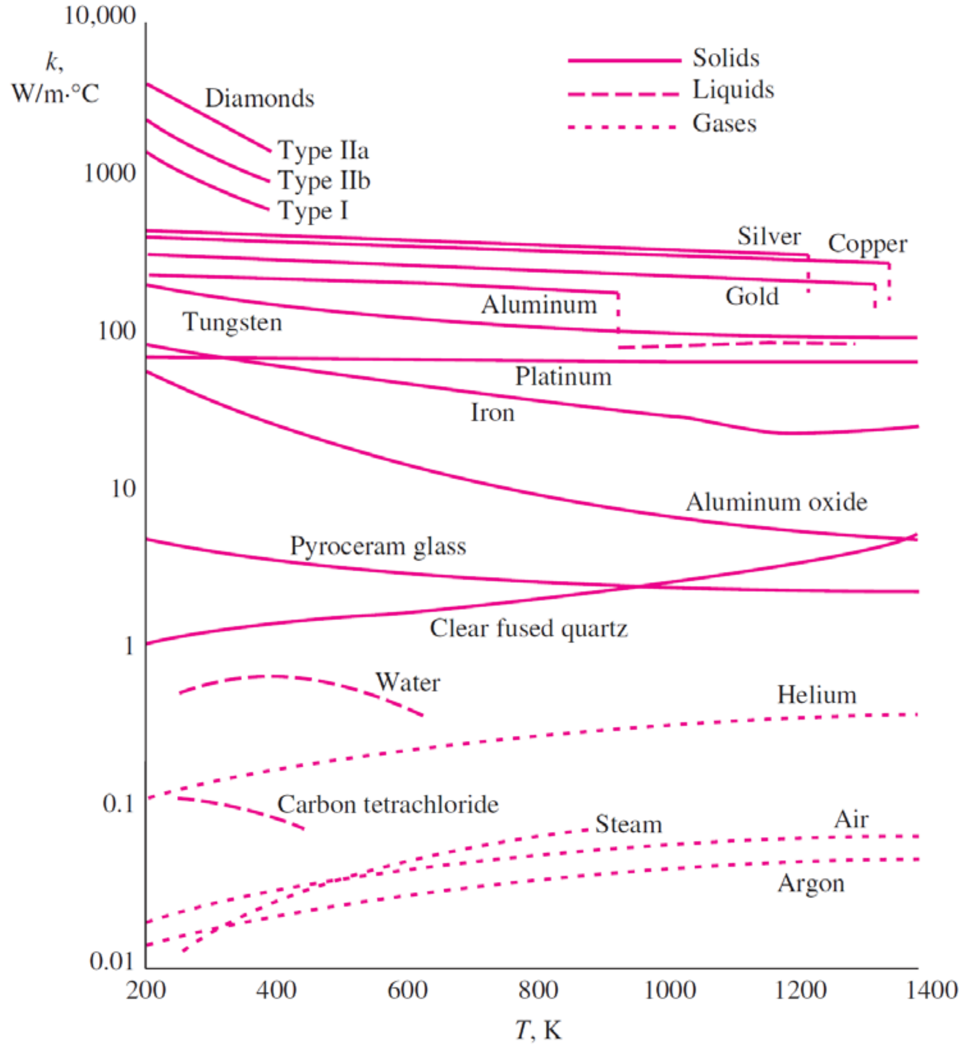
Solids:

- Thermal conductivity of pure metals decreases with an increase in temperature. Explain Why?

Effect of temperature on thermal conductivity [2]



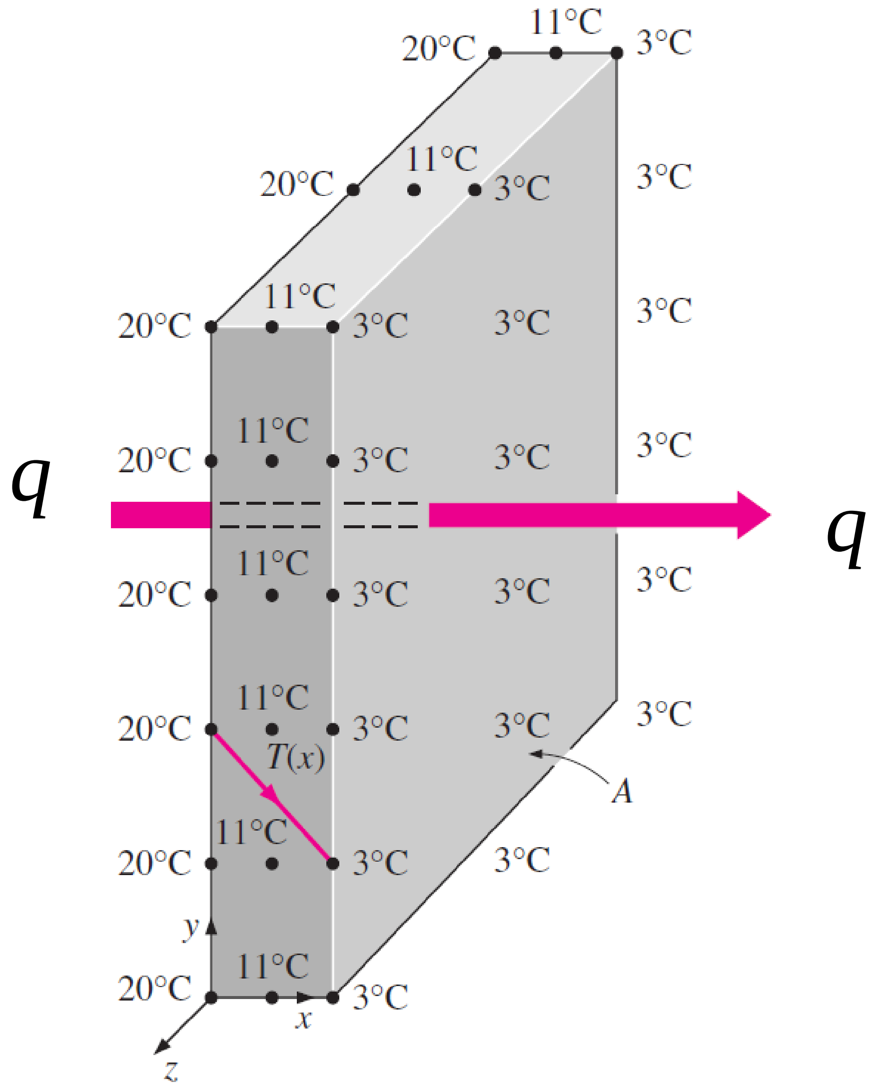
Effect of temperature on thermal conductivity [3]



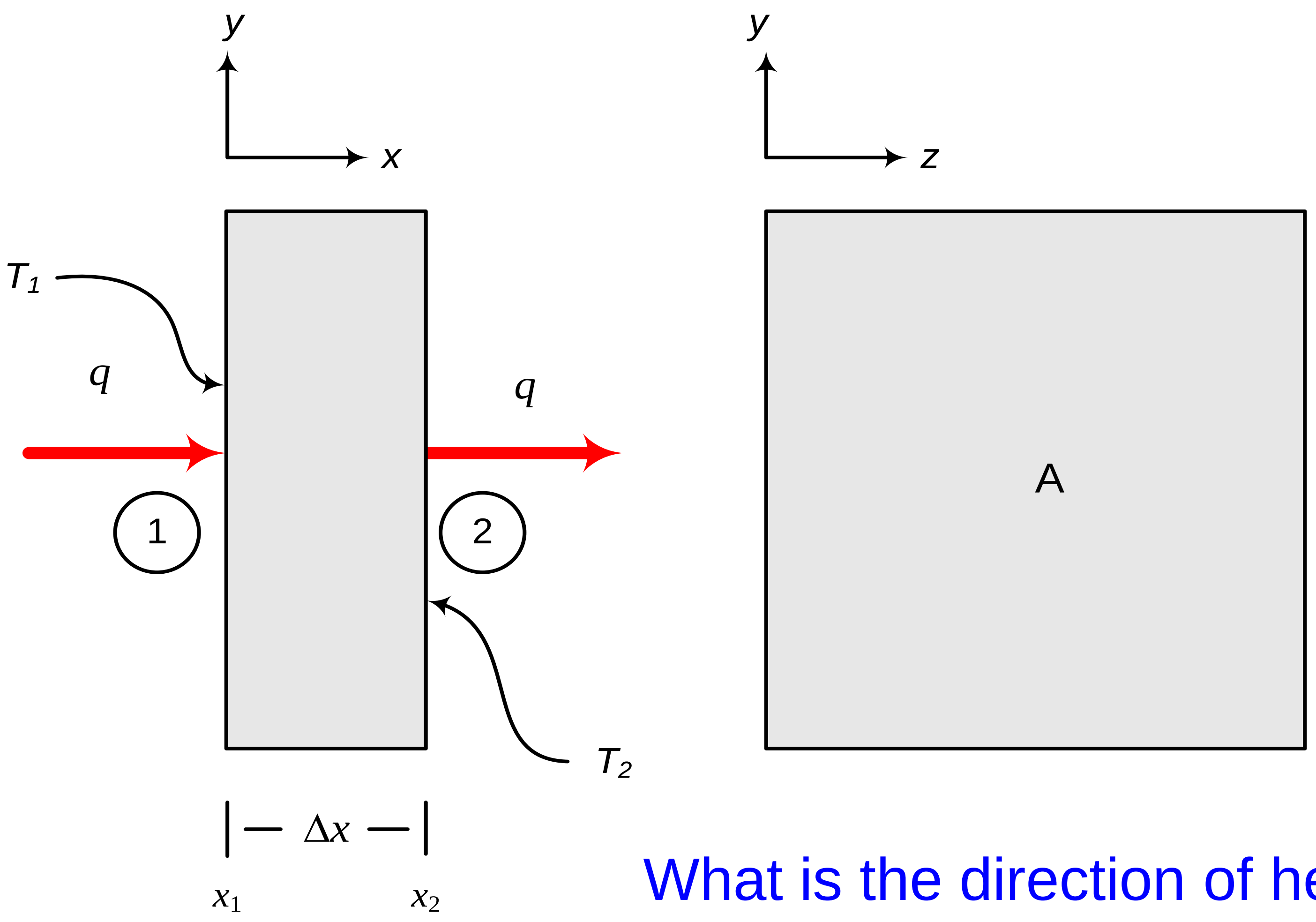
Estimation of thermal conductivity

- When experimental thermal conductivity data is not available in the literature, we need to do experiments to find the value and when not possible we use a reliable estimation method. Students are referred to Poling, B.E., Prausnitz, J.M., O'Connell, J.P. (2001) The properties of gases and liquids. 5th ed. McGraw-Hill. Singapore.
- Further discussion on thermal conductivity is beyond the scope of this course. Students are expected to go through 9th chapter of Bird, R.B., Stewart, W.E., Lightfoot, E.N. (2000) Transport Phenomena. 2nd ed. John Wiley & Sons, Inc., Singapore in higher semesters to have more insight knowledge.

One-dimensional steady-state heat conduction [3]



Heat conduction through a plane wall

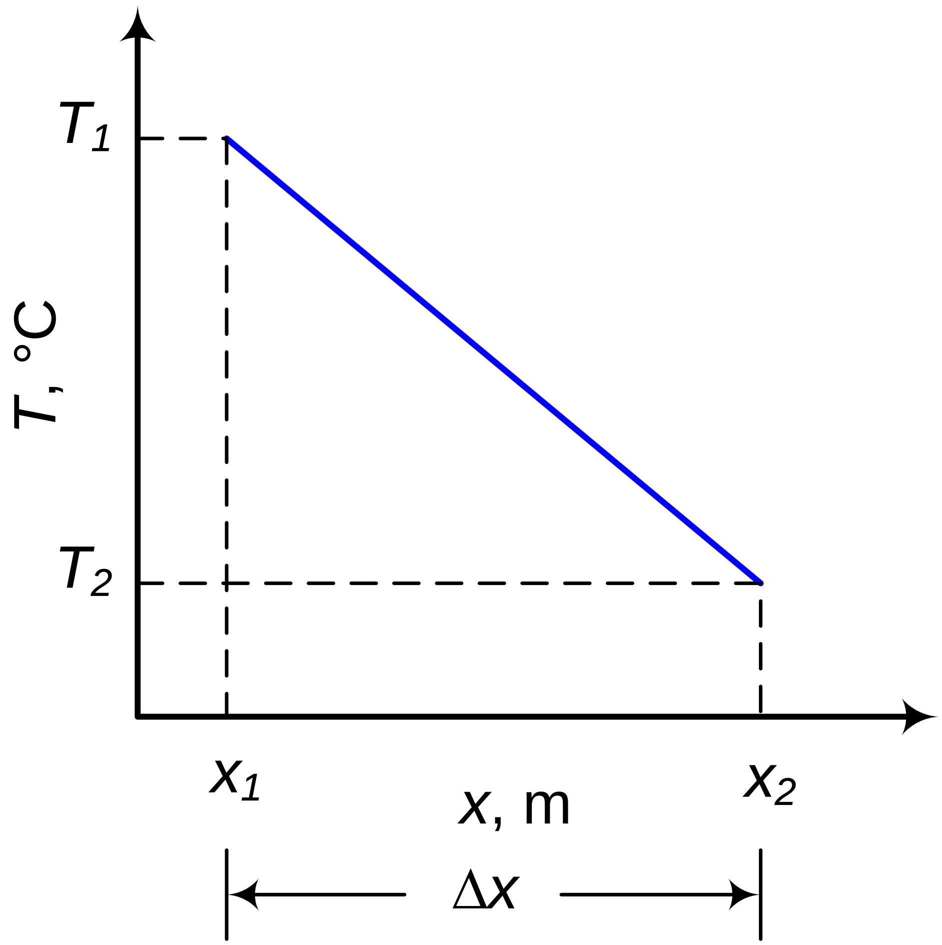


What is the direction of heat?

Heat conduction through a plane wall: Temperature profile

What about variation of temperature with distance?

Heat conduction through a plane wall: Temperature profile



Heat conduction through a plane wall

$$\text{Rate of heat transfer} = q = k \cdot A \cdot \frac{T_1 - T_2}{\Delta x}, \text{ J/s}$$

$$\text{Heat flux} = \frac{q}{A} = k \cdot \frac{T_1 - T_2}{\Delta x}, \text{ W/m}^2$$

$$Resitance = \frac{\Delta x}{k \cdot A}, \ ^\circ\text{C/W}$$

$$q = \frac{T_1 - T_2}{\left(\dfrac{\Delta x}{k \cdot A}\right)} = \frac{Temperature\ differnece}{thermal\ resistance}, \text{ J/s or W}$$

References

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3. Cengel, Y.A. (2003). Heat transfer: A practical approach. 2nd ed. McGraw-Hill.
4. Incropera, F.P.; DeWitt, D.P.; Bergman, T.L.; Lavine. A.S. (2007) Fundamentals of heat and mass transfer. 6th ed. John Wiley & Sons, Inc.
5. Kern, D.Q. (1965). Process heat transfer. McGraw-Hill International Book Co., Singapore.
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7. Coulson, J.M.; Richardson, J.F.; Backhurst, J.R.; Harker, J.H. 1999. Coulson and Richardson's Chemical engineering: Fluid flow, heat trasnfer and mass transfer. vol. 1. 6th ed. Butterwoth-Heinemann, Oxford.
8. Staff of Research and Education Association. (1984). The heat transfer problem solver. Research and Education Association, New Jersey.