Thermal Unit Operation  
(ChEg3113)  

Lecture 3- Examples on problems having different heat transfer modes  

Instructor: Mr. Tedla Yeshitila (M.Sc.)
Today…

- Review
- Examples
- Multimode heat transfer
- Heat exchanger
- Types of flow
Review

Conduction through a solid or a stationary fluid:

\[ Q_x = -kA \frac{dT}{dx} \]

Convection from a surface to a moving fluid:

\[ Q = h_c A (T_w - T_\infty) \]

Net radiation heat exchange between two surfaces:

\[ Q_r = \varepsilon \sigma A (T_s^4 - T_{sur}^4) \]

Fig. Conduction, convection, and radiation heat transfer modes \(^1\)
Notations

✓ Note the following differences in the terms:

\( q \): heat rate \((W \text{ or } J/s)\)

\( q' \): heat rate per unit length \((w/m)\)

\( q'' \): heat flux or rate of heat transfer per unit area \((w/m^2)\)

✓ The heat flux represents the rate of heat transfer through a section of unit area, and it is uniform (invariant) across the surface of the wall.
Chapter 1
Introduction to Thermal Unit Operation

Example 1:
The wall of an industrial furnace is constructed from 0.15m-thick fireclay brick having at thermal conductivity of 1.7 W/m.K. Measurements made during steady-state operation reveal temperatures of 1,400 and 1,150K at the inner and outer surfaces, respectively. What is the rate of heat loss through a wall that is 0.5 m*1.2 m on a side?
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• Solution for example 1:

*Given:*  
*Required:*  
*Solution:*  

*Assumptions:*  
1. Steady-state conditions.  
2. One-dimensional conduction through the wall.  
3. Constant thermal conductivity.

\[ q_x = 1,700\, \text{W} \]
Example 2:

An uninsulated steam pipe passes through a room in which the air and walls are at 25°C. The outside diameter of the pipe is 70 mm, and its surface temperature and emissivity are 200°C and 0.8, respectively. If the coefficient associated with free convection heat transfer from the surface to the air is 15 W/m²K, what is the rate of heat loss from the surface per unit length of pipe?
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• Solution for example 2:

Given:

Required:

Solution:

Assumptions:
1. Steady-state conditions.
2. Radiation exchange between the pipe and the room is between a small surface and a much larger enclosure.
3. The surface emissivity and absorptivity are equal.

=> q’=998W/m
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Multimode heat transfer

✓ In most of the practical heat transfer problems, heat transfer occurs due to more than one mechanism.

✓ Using the concept of thermal resistance developed earlier, it is possible to analyze steady state multimode heat transfer problems in a simple manner, similar to electrical wires.

✓ You can`t directly apply the concept of thermal resistance and electrical network for unsteady state heat transfer.
Example 3: Building wall

✓ Assume there are two rooms ($T_1 > T_2$, so there is heat transfer) and assume the surrounding of the rooms is similar to room temperature (surface temperature). The two rooms are separated by multi wall (three layers of wall).

✓ Heat transfer from surrounding surface to the wall is by radiation (because surface temperature of the wall and surface temperature of room surrounding different), then convection from the wall to the air in the room and conduction take place from one layer to another layer of the wall. Therefore it is multimode heat transfer.
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\[ R_{\text{total}} = \left( \frac{R_{\text{conv}2}R_{\text{rad}2}}{R_{\text{conv}2} + R_{\text{rad}2}} \right) + (R_{w-33} + R_{w-2} + R_{w-1}) + \left( \frac{R_{\text{conv}1}R_{\text{rad}1}}{R_{\text{conv}1} + R_{\text{rad}1}} \right) \]

\[ Q_{1-2} = \frac{(T_1 - T_2)}{R_{\text{total}}} \]

\[ R_{\text{parallel}} = \frac{R_1R_2}{R_1 + R_2} \]

\[ R_{\text{series}} = R_1 + R_2 + \ldots \]

Overall heat transfer coefficient \((U) = \frac{1}{R_{total}A}\)

✓ Parallel shows simultaneously occur, while series connection show heat transfer occurs step by step occur.
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Example 4: Composite cylinder (hollow heat transfer)

✓ A metallic tube through which fluid is flowing and outside there is insulation. The surround have different temperature ($T_o$) than the fluid ($T_i$). Where $A_0$ is outer surface area of tube.

✓ There are different resistance first convective inside the tube because fluid is flowing, then conduction by tube wall, then by insulation, and finally convective transfer outside heat transfer. So four resistance in series.
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\[ Q = U_o A_o (T_i - T_e) \]

\[ \frac{1}{U_o} = \frac{1}{h_i A_i} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi L k} + \frac{\ln\left(\frac{r_1}{r_2}\right)}{2\pi L k} + \frac{1}{h_o A_o} \]

- If the fluid is not clean, there will be formation of scale inside the tube, so there will be additional resistance \( R/A \) will be added where \( R \) is resistance of scale.
Chapter 2
Classification of Heat Exchanger Equipment's

What is heat exchanger?

✓ Heat exchangers are devices whose primary responsibility is the transfer (exchange) of heat, typically from one fluid to another across a solid surface.

✓ Basically common heat exchangers include two stream, one hot and one cold, then they will be contact through solid surface.

✓ Heat exchangers are not only used in heating applications, such as heaters, but are also used in cooling applications, such as refrigerators and air conditioners.
Chapter 2
Classification of Heat Exchanger Equipment's

• A typical heat exchanger involves both conduction and convection heat transfers.

• A wide variety of heat exchangers are extensively used in refrigeration and air conditioning.

• In most of the cases the heat exchangers operate in a steady state, hence the concept of thermal resistance and overall heat transfer coefficient can be used very conveniently.

• Heat exchangers (HX) facilitate the exchange of heat transfer (Q).

• There are three requirements for HX:
  1. There should be two streams: stream 1 \((S_1)\) and stream 2 \((S_2)\)
  2. There should be temperature difference between the two streams: \(T_1\) and \(T_2\)
  3. There should be no mixing
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Classification of Heat Exchanger Equipment's

• In parallel-flow heat exchangers, both fluid involved move in the same direction, entering and exiting the exchanger side by side.

• In cross-flow heat exchangers, the fluid paths run perpendicular to one another.

• In countercurrent heat exchangers, the fluid paths flow in opposite directions, with each exiting where the other enters.

• Countercurrent heat exchangers tend to be more effective than other types of exchangers.
Chapter 2
Classification of Heat Exchanger Equipment's

- In general the temperature of the fluid stream may vary along the length of the heat exchanger.

- In the previous multimode heat transfer the temperature remains constant ($T_o$ and $T_i$ was constant). So to take care of the heat variation along the tube, the concept of Log Mean Temperature Difference (LMTD) is introduced in the design of heat exchangers.

- This equation is applicable for pure parallel type of flow heat exchangers and pure counter type of flow heat exchangers. For cross flow we have to add another factor to consider other flow direction.
Chapter 2
Classification of Heat Exchanger Equipment's

✓ LMTD is defined as: \( LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \)

✓ For constant overall heat transfer coefficient:

\[
Q = U_0 A_o (LMTD) \text{ and also } \\
Q = U_i A_i (LMTD)
\]
At the end of this class:

• You will be able to understand multimode heat transfer
• You will be able to solve heat transfer problems having conduction, convection, radiation, or multimode heat transfer
• You will be able to define heat exchanger and also different types of flow
End of lecture -3