Heat and mass Transfer

MECH_KIOT_SALEM.
Heat Transfer

• Heat always moves from a warmer place to a cooler place.
• Hot objects in a cooler room will cool to room temperature.
• Cold objects in a warmer room will heat up to room temperature.
Question

• If a cup of coffee and a red popsicle were left on the table in this room what would happen to them? Why?

• The cup of coffee will cool until it reaches room temperature. The popsicle will melt and then the liquid will warm to room temperature.
Heat Transfer Methods

- Heat transfers in three ways:
  - Conduction
  - Convection
  - Radiation
When you heat a metal strip at one end, the heat travels to the other end.

As you heat the metal, the particles vibrate, these vibrations make the adjacent particles vibrate, and so on and so on, the vibrations are passed along the metal and so is the heat. We call this Conduction.
Metals are different

The outer electrons of metal atoms drift, and are free to move.

When the metal is heated, this ‘sea of electrons’ gain kinetic energy and transfer it throughout the metal.

Insulators, such as wood and plastic, do not have this ‘sea of electrons’ which is why they do not conduct heat as well as metals.
Why does metal feel colder than wood, if they are both at the same temperature?

Metal is a conductor, wood is an insulator. Metal conducts the heat away from your hands. Wood does not conduct the heat away from your hands as well as the metal, so the wood feels warmer than the metal.
What happens to the particles in a liquid or a gas when you heat them?

The particles spread out and become less dense.

This effect is called convection.

Heat Transfer
Fluid movement

Cooler, more dense fluids sink through warmer, less dense fluids.

In effect, warmer liquids and gases rise up.

Cooler liquids and gases sink.
Water movement

- Hot water rises
- Cools at the surface
- Convection current
- Cooler water sinks
- Hot water rises

Heat Transfer
Why is it windy at the seaside?

The land is warmer than the sea.

This land warms the air above it, and it rises.

The cold air from above the sea moves in to take the place of warm air that has risen.

Heat Transfer
Cold air sinks

Where is the freezer compartment put in a fridge?

It is put at the top, because cool air sinks, so it cools the food on the way down.

Freezer compartment

It is warmer at the bottom, so this warmer air rises and a convection current is set up.

Heat Transfer
The third method of heat transfer

How does heat energy get from the Sun to the Earth?

There are no particles between the Sun and the Earth so it CANNOT travel by conduction or by convection.

RADIATION
Radiation travels in straight lines
- True/False

Radiation can travel through a vacuum
- True/False

Radiation requires particles to travel
- True/False

Radiation travels at the speed of light
- True/False
Four containers were filled with warm water. Which container would have the warmest water after ten minutes?

The **shiny metal** container would be the warmest after ten minutes because its shiny surface reflects heat **radiation** back into the container so less is lost. The **dull black** container would be the coolest because it is the best at **emitting** heat radiation.
Absorption experiment

Four containers were placed equidistant from a heater. Which container would have the warmest water after ten minutes?

The **dull black** container would be the warmest after ten minutes because its surface absorbs heat **radiation** the best. The **shiny metal** container would be the coolest because it is the poorest at **absorbing** heat radiation.
Convection questions

Why does hot air rise and cold air sink?

*Cool air is more dense than warm air, so the cool air ‘falls through’ the warm air.*

Why are boilers placed beneath hot water tanks in people’s homes?

*Hot water rises.*

*So when the boiler heats the water, and the hot water rises, the water tank is filled with hot water.*
Why are houses painted white in hot countries?

*White reflects heat radiation and keeps the house cooler.*

Why are shiny foil blankets wrapped around marathon runners at the end of a race?

*The shiny metal reflects the heat radiation from the runner back in, this stops the runner getting cold.*
1. Which of the following is not a method of heat transfer?

A. Radiation
B. Insulation
C. Conduction
D. Convection
2. In which of the following are the particles closest together?

A. Solid
B. Liquid
C. Gas
D. Fluid
3. How does heat energy reach the Earth from the Sun?

A. Radiation
B. Conduction
C. Convection
D. Insulation
4. Which is the best surface for reflecting heat radiation?

A. Shiny white
B. Dull white
C. Shiny black
D. Dull black
5. Which is the best surface for absorbing heat radiation?

A. Shiny white
B. Dull white
C. Shiny black
D. Dull black
CONVECTION HEAT TRANSFER

Modes

- **forced**
  flow induced by external agency e.g. pump
e.g. forced-draught air cooler, evaporators

- **natural**
  fluid motion caused by temperature-induced
density gradients within fluid

Examples

- air flow over hot steam pipe, fireplace
circulation, cooling electronic devices
CONVECTION HEAT TRANSFER

Warm (lighter) air rises

Cool (more dense) air falls to replace warm rising air

Figure: Natural convection flow over a heated steam pipe
Modelling Convection

Forced convection generally most-effective transport of energy from solid to fluid.

Engineer's prime concern

\[ rate \] of convection

\[ \downarrow \]

enables sizing of equipment

Heat Transfer
Modelling Convection

Experimentally found that:

\[ \dot{Q} \propto A(T_s - T_b) \quad h - \text{convective heat transfer coefficient.} \]

\[ \dot{Q} = hA(T_s - T_b) \]

Main problem
predict \( h \) value for:

- variety fluids & flow rates
- range of shapes
Rate equation
Written in same form as Ohm’s Law:

\[
\text{Current flow (I)} = \frac{\text{Potential Difference (}\Delta V\text{)}}{\text{Resistance (R)}}
\]

\[
\dot{Q} = hA(T_s - T_b) = \frac{(T_s - T_b)}{1/hA} = \frac{T_s - T_b}{R}
\]

\(T_s - T_b\) = driving force

\(1/hA\) – thermal resistance (R) for convection heat transfer.
TYPICAL UNITS FOR $h$

S.l.: $W \, m^{-2}K^{-1}$ or $J \, s^{-1} \, m^{-2}K^{-1}$
British: $Btu \, hr^{-1} \, ft^{-2} (F \, deg)^{-1}$
Conversion: $1 \, W \, m^{-2}K^{-1} = 0.176 \, Btu \, hr^{-1} \, ft^{-2} (F \, deg)^{-1}$

Typical Values

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>free convection (air)</td>
<td>5 - 60</td>
</tr>
<tr>
<td>forced convection (air)</td>
<td>25 - 300</td>
</tr>
<tr>
<td>forced convection (water)</td>
<td>200 - 10,000</td>
</tr>
<tr>
<td>boiling water</td>
<td>2,000 - 25,000</td>
</tr>
<tr>
<td>condensing steam</td>
<td>4,000 - 110,000</td>
</tr>
</tbody>
</table>
Air at 20°C is blown over an electrical resistor to keep it cool. The resistor is rated at 40,000 ohm and has a potential difference of 200 volts applied across it. The expected mean heat transfer coefficient between the resistor surface and the air is 50 W m^{-2}K^{-1}.

What will be the surface temperature of the resistor, which has a surface area of 2 cm²?

\[
\text{Air at } 20^\circ\text{C} \quad h = 50 \text{ W m}^{-2}\text{K}^{-1} \\
R = 40,000 \Omega \\
\text{Potential} = 200 \text{ V}
\]
Energy Balance

Generation = heat loss by convection

Rate of heat generation

\[ P = \dot{Q} \]

\[ P = VI = V \left( \frac{V}{R} \right) = \frac{V^2}{R} \]

\[ \dot{Q} = \frac{V^2}{R} = \frac{200^2}{4 \times 10^4} = 1 \text{ watt} \]

Convective loss

\[ \dot{Q} = hA(T_s - T_b) \]

\[ 1 = (50)(2 \times 10^{-4})(T_s - 20) \]

\[ T_s = 120^\circ C \]
Determining the size (H/T area) of the exchanger

\[ \dot{Q} = h_1A(T_1 - T_2) = kA \frac{(T_2 - T_3)}{\Delta x} = h_2A(T_3 - T_4) \]

(10.25)

\[ \dot{Q} = \frac{(T_1 - T_4)}{1 + \frac{\Delta x}{h_1A} + \frac{1}{kA}} + \frac{1}{h_2A} = \text{overall driving force} \sum \text{resistances} \]

(10.26)

Figure 1. Heat transfer between two flowing fluids separated by a rectangular wall.

Heat Transfer
Determining the size (H/T area) of the exchanger

\[ \dot{Q} = \frac{(T_i - T_o)}{R_1 + R_2 + R_3} \]

Figure 2: Heat transfer between two flowing fluids separated by a cylindrical wall

\[ \dot{Q} = \frac{(T_i - T_o)}{h_i A_i + \ln \left( \frac{r_o}{r_i} \right) + \frac{1}{2\pi k L} + \frac{1}{h_o A_o}} \]
Overall heat-transfer coefficient

As a short-hand method of describing heat-exchanger performance, we use the overall heat-transfer coefficient,

\[ \dot{Q} = hA(T_s - T_b) \]

\[ \dot{Q}_{\text{duty}} = U_o A \Delta T \]

\[ \dot{Q}_{\text{duty}} = \frac{\Delta T}{1} = \frac{\Delta T}{R} \]

where

\[ U_o = \text{overall heat-transfer coefficient} \left( \frac{W}{m^2K} \right) \]
Determining the size (H/T area) of the exchanger

Table 10.5 Approximate Values of $U_o$ (from Reference 1)

<table>
<thead>
<tr>
<th>Hot Stream: Cold Stream</th>
<th>$U_o$, Btu/hr ft$^2$°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated vapor: Boiling liquid</td>
<td>250</td>
</tr>
<tr>
<td>Saturated vapor: Flowing liquid</td>
<td>150</td>
</tr>
<tr>
<td>Saturated vapor: Vapor</td>
<td>20</td>
</tr>
<tr>
<td>Liquid: Liquid</td>
<td>50</td>
</tr>
<tr>
<td>Liquid: Gas OR Gas: Liquid</td>
<td>20</td>
</tr>
<tr>
<td>Gas: Gas</td>
<td>10</td>
</tr>
<tr>
<td>Vapor (Partial condenser): Liquid</td>
<td>30</td>
</tr>
</tbody>
</table>
Consider the kettle below. For the conditions given, find the flame temperature for the following values of the heat transfer coefficients:

\[ h_i \text{ (boiling)} = 4000 \text{ W m}^{-2}\text{K}^{-1} \quad h_o \text{ (gas flame)} = 40 \text{ W m}^{-2}\text{K}^{-1} \]
Solution

Plane slab- area constant, eliminate A:

\[ \frac{1}{U_oA} = \frac{1}{h_oA} + \frac{\Delta x}{kA} + \frac{1}{h_1A} \]

\[ \frac{1}{U_o} = \frac{1}{40} + \frac{1.2 \times 10^{-3}}{204} + \frac{1}{4000} \]

\[ U_o = 39.6 \text{ W m}^{-2}\text{K}^{-1} \]
Solution

\[ \dot{Q} = 1883 \text{ W (as before)} \]
\[ A = 3.14 \times 10^{-2} \text{ m}^2 \text{ (as before)} \]

\[ \dot{Q}_{\text{duty}} = U_o A \left( T_o - T_3 \right) \]
\[ \left( T_o - T_3 \right) = \frac{\dot{Q}_{\text{duty}}}{AU_o} \]

\[ \left( T_o - T_3 \right) = \frac{1883}{\left( 3.14 \times 10^{-2} \right) \left( 39.6 \right)} = 1514 \text{K} = 1514^\circ \text{C} \]

\[ T_o = 1514 + 100 = 1614^\circ \text{C} \]
Determining the size (H/T area) of the exchanger

\[ \dot{Q}_{duty} = U_o A \Delta T_{avg} \]  

(10.28)

- The term \( \Delta T_{avg} \) in equation 10.28 represents the temperature difference between the hot and cold streams averaged.

- For single-pass exchangers, the appropriate form of \( \Delta T_{avg} \) is the log-mean temperature difference, \( \Delta T_{\text{log mean}} \) (often abbreviated LMTD), defined as

\[
\Delta T_{\text{log mean}} = \Delta T_{\text{log mean}} 
= \Delta T_1 - \Delta T_2 
\frac{\Delta T_1}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}
\]  

(10.29)
Determining the size (H/T area) of the exchanger

\[ \dot{Q}_{\text{duty}} = U_o A \Delta T_{\text{avg}} \]

\[ A = \frac{\dot{Q}_{\text{duty}}}{U_o \Delta T_{\text{log mean}}} \] (10. 30)

For shell-and-tube exchangers, the inside area \( (A_i) \) of the tubes is smaller than the outside area \( (A_o) \). However, the differences between \( A_i \) and \( A_o \) will be neglected.
Example

Saturated Steam, 280°F, \( m_{\text{stream}} \)

Oil, 110°F, 960 lb\( _m \)/min

\( \text{Hot} \)

\( \text{Cold} \)

Saturated water, 280°F, \( m_{\text{stream}} \)

Oil, 35°F, 960 lb\( _m \)/min

**Balance on cold stream:**

\[
[ \dot{m} \bar{C}_p (T_{\text{out}} - T_{\text{in}}) ]_{\text{cold}} = \dot{Q}_{\text{duty}} \quad (10.24b)
\]

\[
\begin{align*}
\left[ \left( 960 \text{ lb}_m \text{ min} \right) \left( 0.74 \frac{\text{Btu}}{\text{lb}_m ^0\text{F}} \right) (110 - 35)^0\text{F} \right]_{\text{cold}} &= \dot{Q}_{\text{duty}} \\
\dot{Q}_{\text{duty}} &= 53,280 \frac{\text{Btu}}{\text{min}}
\end{align*}
\]
Example

How much area is required for the counter-current heat exchanger in Example 10.5?

Saturated Steam, 280°F, \( m_{\text{stream}} \)

Saturated water, 280°F, \( m_{\text{stream}} \)

Oil, 110°F, 960 lb m/min

Oil, 35°F, 960 lb m/min

\[
\Delta T_1 = (280 - 35) = 245°F \\
\Delta T_2 = (280 - 110) = 170°F \\
\Delta T_{\text{log mean}} = \frac{245 - 170}{\ln\left(\frac{245}{170}\right)} = 205°F
\]
Example

From table 10.5

\[ U_o = 150 \text{ Btu/(hr ft}^2 \text{ °F)} \]

\[ A = \frac{53,280 \text{ Btu/min}}{(150 \text{ Btu/hr ft}^2 \text{ °F})(205 \text{ °F})} \times \frac{60 \text{ min}}{1 \text{ hr}} = 104 \text{ ft}^2 \]
Example

How much area is required for the co-current heat exchanger in Example 10.5?

\[ \Delta T_1 = (280 - 110) = 170^\circ F \]
\[ \Delta T_2 = (280 - 35) = 245^\circ F \]

\[ \Delta T_{\text{log mean}} = \frac{170 - 245}{\ln\left(\frac{170}{245}\right)} = 205^\circ F \]
Example

From table 10.5

\[ U_o = 150 \text{ Btu/} (\text{hr ft}^2 \text{ °F}) \]

\[ A = \frac{53,280 \text{ Btu/min}}{\left(150 \frac{\text{Btu}}{\text{hr ft}^2 \text{ °F}}\right) \left(205 \text{°F}\right)} \bigg| \frac{60 \text{ min}}{1 \text{ hr}} = 104 \text{ ft}^2 \]
Flow Patterns

• Parallel Flow
• Counter Current Flow
• Shell and Tube with baffles
• Cross Flow
Temperature Profiles

\[ \Delta T = \text{Approach Temperature} \]
Heat Exchanger
Temperature Profiles

Figure 11-12 Axial temperature distribution in typical single-pass heat transfer matrices.

Figure 11-13 Axial temperature distribution in a one shell pass, two tube pass heat exchanger.

Figure 11-14 Temperature distribution in a cross-flow heat exchanger. Both fluids are unmixed.
Flow Structure

\[ Q = U A F \Delta T_{\text{lm-counter}} \]

\[ F = \frac{\sqrt{R^2 + 1} \ln \left( \frac{1 - S}{1 - RS} \right)}{(R-1)\ln \left( \frac{2 - S(R+1-\sqrt{R^2+1})}{2 - S(R+1+\sqrt{R^2+1})} \right)} \]

\[ R = \frac{T_{\text{hot in}} - T_{\text{hot out}}}{T_{\text{cold out}} - T_{\text{cold in}}} \]
\[ S = \frac{T_{\text{cold out}} - T_{\text{cold in}}}{T_{\text{hot in}} - T_{\text{cold in}}} \]

Figure 11-16 Correction factor \( F \) for computing \( \Delta T_{\text{corrected}} \) for multipass and cross-flow exchangers. (a) One shell pass and two tube pass or multiple of two tube pass; (b) two shell pass and four tube pass or multiple of four tube pass; (c) single-pass, cross-flow, both fluids unmixed. (From Bowman, Mueller, and Nagle [45].)
Overall Heat Transfer Coefficient

• Series of Resistances
• Basis
  – Inside
  – Outside

\[ U_o = \left[ R_{f,i} \frac{A^o}{A_i} + \left( \frac{D_o}{D_i} \right) \frac{1}{h_i} + \left[ \frac{1}{\left( 2k_w \right)} \right] D_o \ln \left( \frac{D_o}{D_i} \right) + \left( \frac{1}{h_o} \right) + R_{f,o} \right]^{-1} \]

\( R_f = \) fouling factors, inside and outside

See table 18.5 for range of U values for different cases.
Heat Transfer inside a tube

\[ Nu = \frac{hD}{k_f} = 0.027 \, \text{Re}^{0.8} \, \text{Pr}^{1/3} \left( \frac{\mu_b}{\mu_w} \right)^{0.14} \]

\( L/D > 60, \) smooth tube

\[ 0.7 < \text{Pr} = \frac{C_p \mu}{k_f} < 16,700 \]

\( \text{Re} > 10,000 \quad \text{Turbulent} \)

Also other correlations valid over wider ranges
Heat Transfer outside of Tube

\[ Nu = \frac{hD}{k_f} = (0.4 \, \text{Re}^{0.5} + 0.06 \, \text{Re}^{2/3}) \, \text{Pr}^{0.4} \left( \frac{\mu_b}{\mu_w} \right)^{0.25} \]

\[ 0.25 < \frac{\mu_b}{\mu_w} < 5.2 \]

\[ 0.67 < \text{Pr} = \frac{C_p \, \mu}{k_f} < 300 \]

\[ 40 < \text{Re} < 100,000 \]

Also other correlations valid over wider ranges
## Thermal Conductivity

### Table B-9 Illustration of physical properties of metals and nonmetals in both Btu and SI units

| Material          | Temperature, °F °C | $c_p$, Btu/lb °F | $c_p \times 10^{-3}$, W/kg °C | $k$, Btu/h·ft °F/m °C | $k$, W/m °C | $\rho$, lb/ft³ | $\rho$, kg/m³ | $\alpha$, ft²/h | $\alpha \times 10^6$, m²/s |
|-------------------|-------------------|------------------|-------------------------------|----------------------|-------------|--------------|--------------|---------------|----------------|-----------------|
| Metals            |                   |                  |                               |                      |             |              |              |               |                |                 |
| Aluminum          | 32  0             | 0.208            | 0.871                         | 117                  | 202.4       | 169          | 2,719        | 3.33          | 85.9           |
| Copper            | 32  0             | 0.091            | 0.381                         | 224                  | 387.6       | 558          | 8,978        | 4.42          | 114.1          |
| Gold              | 68  20            | 0.030            | 0.126                         | 169                  | 292.4       | 1204         | 19,372       | 4.68          | 120.8          |
| Iron, pure        | 32  0             | 0.104            | 0.435                         | 36                   | 62.3        | 491          | 7,900        | 0.70          | 18.1           |
| Cast iron (c = 4%)| 68  20            | 0.10             | 0.417                         | 30                   | 51.9        | 454          | 7,304        | 0.66          | 17.0           |
| Lead              | 70  21.1          | 0.030            | 0.126                         | 20                   | 34.6        | 705          | 11,343       | 0.95          | 25.5           |
| Mercury           | 32  0             | 0.033            | 0.138                         | 4.83                 | 8.36        | 849          | 13,660       | 0.172         | 4.44           |
| Nickel            | 32  0             | 0.103            | 0.431                         | 34.4                 | 59.52       | 555          | 8,930        | 0.60          | 15.5           |
| Silver            | 32  0             | 0.056            | 0.234                         | 242                  | 418.7       | 655          | 10,539       | 6.60          | 170.4          |
| Steel, mild       | 32  0             | 0.11             | 0.460                         | 26                   | 45.0        | 490          | 7,884        | 0.48          | 12.4           |
| Tungsten          | 32  0             | 0.032            | 0.134                         | 92                   | 159.2       | 1204         | 19,372       | 2.39          | 61.7           |
| Zinc              | 32  0             | 0.091            | 0.381                         | 65                   | 112.5       | 446          | 7,176        | 1.60          | 41.3           |
| Nonmetals         |                   |                  |                               |                      |             |              |              |               |                |                 |
| Asbestos          | 32  0             | 0.25             | 1.047                         | 0.087                | 0.151       | 36           | 579          | 0.010         | 0.258          |
| Brick, fireclay   | 400  204.4        | 0.20             | 0.837                         | 0.58                 | 1.004       | 144          | 2,317        | 0.020         | 0.516          |
| Cork, ground      | 100  37.8         | 0.48             | 2.010                         | 0.024                | 0.042       | 8            | 128.7        | 0.006         | 0.155          |
| Glass, Pyrex      | 32  0             | 0.20             | 0.837                         | 0.68                 | 1.177       | 150          | 2,413        | 0.023         | 0.594          |
| Granite           | 32  0             | 0.19             | 0.796                         | 1.6                  | 2.768       | 168          | 2,703        | 0.050         | 1.291          |
| Ice               | 32  0             | 0.49             | 2.051                         | 1.28                 | 2.215       | 57           | 917          | 0.046         | 1.187          |
| Oak, across grain | 85  29.4          | 0.41             | 1.716                         | 0.111                | 0.192       | 44           | 708          | 0.0062        | 0.160          |
| Pine, across grain| 85  29.4          | 0.42             | 1.758                         | 0.092                | 0.159       | 37           | 595          | 0.0059        | 0.152          |
| Quartz sand, dry  | 0.19             | 0.796            | 0.15                          | 0.10                 | 0.260       | 103          | 1,657        | 0.008         | 0.206          |
| Rubber, soft      | 0.45             | 1.884            | 0.40                          | 0.173                | 0.173       | 69           | 1,110        | 0.003         | 0.077          |
What Temperature Approach

  - Near-optimal minimum temperature approaches in heat exchangers depend on the temperature level as follows:
    - 10°F or less for temperatures below ambient,
    - 20°F for temperatures at or above ambient up to 300°F,
    - 50°F for high temperatures,
    - 250 to 350°F in a furnace for flue gas temperature above inlet process fluid temperature.
Where are the Heat Exchangers? What is happening in each

Octane Reaction
\[ 2\text{C}_2\text{H}_4 + \text{C}_4\text{H}_{10} \rightarrow \text{C}_8\text{H}_{18} \]
P = 20 psia, T = 93°C, X = 98% Conversion

\[ \text{C}_2\text{H}_4 \quad -103.7 \degree \text{C} \]
\[ \text{C}_4\text{H}_{10} \quad +0.5 \degree \text{C} \]
\[ \text{C}_8\text{H}_{18} \quad +125.52 \degree \text{C} \]
Where are the Heat Exchangers?
Heat Transfer With Phase Change

• Tricky Problems
  – Examples
    • Reboiler on Distillation Unit
    • Condenser on Distillation Unit
    • Flash Units
    • Boilers
A Word About Steam

• Simulator Assumptions
  – Inlet – Saturated Vapor
    – Pressure
    – 100% Vapor
  – Outlet – Saturated Liquid
    • Liquid Only Leaves via steam trap
      – Pressure = $P_{in} - \Delta P$ (1.5 psi, Heuristic-31)
      – 100% Liquid
Where are the Tricky Heat Exchangers?

Figure 5. The complete flowsheet with a heat-integrated distillation column.

Figure 6. The complete flowsheet with a stand-alone distillation column.
Condensation Heat Transfer

• Drop Wise Condensation
  – Special Case
    • Very High Heat Transfer
    • 5 to 10 x Film Condensation

• Film Condensation
  – Laminar

\[
Nu_x = \frac{h_x x}{k_l} = \left[ \frac{g \rho_l (\rho_l - \rho_v) \Delta H_{vap} k_l^3}{4 \mu_l (T_v - T_w) x} \right]^{1/4}
\]
Laminar to Turbulent Condensate Flow

Figure 10-4 Average heat transfer coefficient for filmwise condensation on a vertical surface for laminar and turbulent flow regions.
Boiling Heat Transfer Coefficient

Figure 10-6 Principal boiling regimes in pool boiling of water at atmospheric pressure and saturation temperature $T_s$ from an electrically heated platinum wire. (From Farber and Scorah [62].)

Various correlations depending upon boiling mechanism

Highest Heat Transfer Coef. But hard to control HX operating here
Heuristic 28

• Boil a pure liquid or close-boiling liquid mixture in a separate heat exchanger, using a maximum overall temperature driving force of 45 F to ensure nucleate boiling and avoid undesirable (low h) film boiling.
Effective Flow Conditions with Boiling in Thermo siphon

Figure 10-10 Various flow and heat transfer regimes in forced convection inside a vertical tube subjected to uniform heat flux.
Kettle (Re)Boiler Design

**Figure 13.10** Kettle reboiler: (1) shell; (2) shell outlet nozzles (vapor); (3) entrainment baffles; (4) vapor-disengaging space; (5) channel inlet nozzle; (6) channel partition; (7) channel outlet nozzle; (8) tube sheet; (9) shell inlet nozzle; (10) tube support plates; (11) U-tube returns; (12) weir; (13) shell outlet nozzle (liquid); (14) liquid holdup (surge) section; (15) top of level—instrument housing (external displacer); (16) liquid level gauge.
Aspen - Zone Analysis
ProMax – Heat Release Increments

• Heuristic 29.
  – When cooling and condensing a stream in a heat exchanger, a zone analysis, described in Section 18.1, should be made to make sure that the temperature difference between the hot stream and the cold stream is equal to or greater than the minimum approach temperature at all locations in the heat exchanger. The zone analysis is performed by dividing the heat exchanger into a number of segments and applying an energy balance to each segment to determine corresponding stream inlet and outlet temperatures for the segment, taking into account any phase change. A process simulation program conveniently accomplishes the zone analysis.
Pressure Drop & Flow Rate

• Laminar vs. Turbulent
  – Heuristic 31.

  • Estimate heat-exchanger pressure drops as follows:
    – 1.5 psi for boiling and condensing,
    – 3 psi for a gas,
    – 5 psi for a low-viscosity liquid,
    – 7-9 psi for a high-viscosity liquid,
    – 20 psi for a process fluid passing through a furnace.
Controlling $\Delta P$ in Simulator

- **Shell side**
  - Nozzle diameter
    - Inlet and Outlet
  - Number of Baffles
  - Tubes
    - Number, diameter, pitch, No. passes

- **Tube side**
  - Nozzle diameter
    - Inlet and Outlet
  - Tubes
    - Number, diameter, pitch, No. passes

*Note interactions!*
Shell Heads, Shell Type

- See ProMax Help/index “Shell, types”
HX Cost

• Size Factor HX Area
  \[ C_{\text{Base}}(6-2000) = \exp[11.0545 - 0.9228 \ln(A) + 0.09861 \ln(A^2)] \]

• Purchase Price
  \[
  C_{\text{P-fob}} = F_P(P) * F_{\text{Material}}(A) * F_L(L) * C_{\text{Base}} * (\text{CPI/394})
  \]
  \[
  C_{BM} = F_{BM} * C_{\text{P-fob}}
  \]
  \[
  C_{BM} = 3.17 * C_{\text{P-fob}}
  \]

• Cost depends on HX Area

• Pumping Cost
  \[ \text{Work} = Q \Delta P \]
Controlling A in Simulator

- \( A = N_{\text{tubes}} \pi D_{\text{tubes}} L_{\text{tubes}} \)

- Shell
  - Shell Diameter and pitch determines \( N_{\text{tubes}} \)

- Tubes
  - \( D_{\text{tubes}} \)
  - \( L_{\text{tubes}} \)
  - Tube pitch-The transverse pitch is the shortest distance from the center lines of two adjacent tubes.
  - Tube pitch ratio 1.25 to 1.5 typically
Other Issues

• Materials of Construction
  – Strength at temperature, life time, heat conduction, fouling

• Design layout
  – Tube pitch, baffles, tube and shell diameters
Heat Exchangers

• Heaters (sensible heat changes)
• Coolers (sensible heat changes)

• Condensers (also change of state, V to L)
• Evaporators (also change of state, L to V)
Types of Heat Exchanger

- Shell and tube
- Double pipe
- Plate
- Finned tubes/gas heaters
- Spiral
- Vessel jackets
- Reboilers and vapourisers/evaporators
- Etc
- Direct/indirect
Uses in chemical processes

- Chemical reactors (jackets, internal heat exchangers/calandria)
- Preheating feeds
- Distillation column reboilers
- Distillation column condensers
- Air heaters for driers
- Double cone driers
- Evaporators
- Crystallisers
- Dissolving solids/solution
- Production support services – HVAC, etc
- Heat transfer fluids
- Etc
continued

Important consideration in:

• Scale-up i.e. laboratory scale (‘kilo lab’) to pilot plant scale (250 litres) to full plant scale operation (10000 litres)

• Energy usage and energy costs

• Process design and development
Heat transfer fluids

- Steam (available at various temperatures and pressures)
- Cooling water (15°C)
- Chilled water (5°C)
- Brines (calcium chloride/water fp. -18 deg cent. at 20% by mass; sodium chloride/water fp. -16.5 deg cent. at 20% by mass)
- Methanol/water mixtures
- Ethylene glycol/water mixtures
- Propylene glycol/water mixtures (fp. -22 deg cent at a concentration of 40% by mass)
- Silicone oils (‘syltherm’)
Low temperature heat transfer fluids

Considerations:
• Temperature(s) required
• Freezing point
• Viscosity
• Specific heat
• Density
• Hazardous properties
Mechanisms for heat transfer

• Conduction
• Convection
• Radiation

Driving force for heat transfer is temperature difference. Heat will only flow from a hotter to a colder part of a system.
Heat transfer by conduction

Fourier's law

\[
\frac{dQ}{dt} = -kA\frac{dT}{dx}
\]

- \(dQ/dt\) – rate of heat transfer
- \(k\) – thermal conductivity
- \(A\) – area perpendicular to direction of heat transfer, \(x\)
- \(dT/dx\) – temperature gradient in direction \(x\)
Heat transfer by conduction (steady state)

Q = $k_m A \left( \frac{\Delta T}{x} \right)$

or $q = k_m \left( \frac{\Delta T}{x} \right)$

$q$ – heat flux, J/s m$^{-2}$
$Q$ - rate of heat transfer, J/s
$k_m$ – mean thermal conductivity,
$A$ – area perpendicular to the direction of heat transfer, m$^2$
$\Delta T$ – temperature change ($T_1 - T_2$), K
$x$ – length, m
Thermal conductivity, $k$

<table>
<thead>
<tr>
<th></th>
<th>$k$ (300K), Wm$^{-1}$ K$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>400</td>
</tr>
<tr>
<td>Water</td>
<td>0.6</td>
</tr>
<tr>
<td>air</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Conduction of heat through cylindrical vessels

\[ Q = k 2 \pi L \Delta T / \ln(r_2 / r_1) \]

- \( L \) – length of tube/cylinder
- \( r_2 \) – external radius
- \( r_1 \) – internal radius
$A_L$, log mean wall area

\[ Q = k_m A_L (T_1 - T_2) \]
\[ r_2 - r_1 \]

where \( A_L = \frac{2\pi L (r_2 - r_1)}{\ln(r_2/r_1)} \)
‘thin walled tube’approximation

Assumptions:

• Thin wall and therefore $x_w$ is small and since $k$ is large, term $x_w/kA_L$ is negligible compared to other terms

• Also A terms cancel as they are approximately equal

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2}$$
Fouling factors

Heat transfer surfaces do not remain clean. They become contaminated with dirt, scale, biofilms etc. This has the effect of reducing the overall heat transfer coefficient and reducing the rate of heat transfer. We take account of this by adding a term $1/Ah_d$ for each deposit to the equation for the overall heat transfer coefficient, $U$, where $h_d$ is the fouling factor for the deposit and $A$ is the corresponding area term. They represent an additional resistance to heat transfer. This will have the effect of reducing $U$ and therefore $Q$. 
Heat flow (duty)

\[ Q = hA\Delta T \]

or

\[ Q = UA\Delta T \]
Sensible heat changes

\[ Q = mc_p \Delta T \]

\( m \) mass flow, kg/s

\( C_p \) specific heat J kg\(^{-1}\) K\(^{-1}\)

\( \Delta T \) change in temperature of fluid
Enthalpy balance

Enthalpy lost by hot fluid = enthalpy gained by cold fluid

(Assume negligible heat losses to surroundings)
Simple double tube single pass heat exchanger

- Co-current operation
- Counter-current operation
- Temperature profiles
- LMTD
Heat exchanger duty

\[ Q = UA\theta_{\text{Imtd}} \]
Multi pass shell and tube heat exchangers

- LMTD correction factor, $F$
- LMTD value used is that for counter current flow with same fluid inlet/outlet temperatures

$$Q = UA\theta_{\text{lmtd}} F$$
Example – double pass

$T_1 = 455\text{K}; \quad T_2 = 388\text{K}; \quad t_1 = 283\text{K}; \quad t_2 = 372\text{K}$
continued

\[ P = \frac{372 - 283}{455 - 283} = 0.52 \]
\[ R = \frac{455 - 388}{372 - 283} = 0.75 \]

Therefore \( F = 0.87 \) (from graph)

To obtain maximum heat recovery from the hot fluid, \( t_2 \) must be as high as possible.

\( T_2 - t_2 \) is known as the approach temperature.
Dittus-Boelter equation

Used for calculating h values in circular tubes under turbulent flow conditions.

\[ \text{Nu} = 0.023 \, \text{Re}^{0.8} \, \text{Pr}^{0.4} \]
Heat transfer by radiation

\[ q = e\sigma(T_1^4 - T_2^4) \]

- \(q\) – heat flux
- \(e\) – emissivity (0 to 1) – typically 0.9
- \(\sigma\) – Stefan-Boltzmann const. \((5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4})\)
- \(T_1\) – temp. of body (K)
- \(T_2\) – temp. of surroundings
Types of heat exchanger – shell & tube

- Passes
- shell
- Multiple tubes
- Baffles
- Co- and counter current operation
Plate

- Individual separated thin corrugated parallel s.s. plates
- Gaskets separate plates
- Gap approx. 1.4mm
- Plate and frame arrangement
- High $h$ values at relatively low Re values and low flow rates
- Can operate with small $\Delta T$
- Reduced fouling
- Easy cleaning
Finned tubes

- Radial fins
- Longitudinal fins
- For air/gas heaters where film heat transfer coefficients on gas side will be very low compared with condensing steam on the other side of tube. Rate of heat transfer is increased by increasing surface area on side of tube with the limiting (low) heat transfer coefficient (gas side).
References

• *An Introduction to Industrial Chemistry*, Ed. C. A. Heaton
• Concepts of Chemical Engineering 4 Chemists, Ed. S. Simons, RSC, 2007
• *Unit Operations of Chemical Engineering*, W. L. McCabe et al
• *Chemical Engineering* Vol. 1, Coulson & Richardson
• *Heat Transfer*, R. Winterton
• *Introduction to Heat Transfer*, F. P. Incropera & D. P. DeWitt
• *Ullmans Encyclopedia of Industrial Chemistry*
• *Engineering Thermodynamics*
Definition of Radiation

• “Radiation is an energy in the form of electromagnetic waves or particulate matter, traveling in the air.”
• Forces: There are many interactions among nuclei. It turns out that there are forces other than the electromagnetic force and the gravitational force which govern the interactions among nuclei.

• Einstein in 1905 showed 2 more laws: energy/mass, and binding energy
Radioactivity: Elements & Atoms

Atoms are composed of smaller particles referred to as:

- Protons
- Neutrons
- Electrons

**NEUTRON = PROTON + ELECTRON**
Basic Model of a Neutral Atom.

• Electrons (-) orbiting nucleus of protons (+) and neutrons. Same number of electrons as protons; net charge = 0.

• Atomic number (number of protons) determines element.

• Mass number (protons + neutrons)
NEUTRAL ATOM

Heat Transfer
Radioactivity

• If a nucleus is unstable for any reason, it will emit and absorb particles. There are many types of radiation and they are all pertinent to everyday life and health as well as nuclear physical applications.
Ionization

- Ionizing radiation is produced by unstable atoms. Unstable atoms differ from stable atoms because they have an excess of energy or mass or both.

- Unstable atoms are said to be radioactive. In order to reach stability, these atoms give off, or emit, the excess energy or mass. These emissions are called radiation.
Heat Transfer

ALPHA PARTICLE
BETA PARTICLE
NEUTRON
Types or Products of Ionizing Radiation

α  β  γ or X-ray

neutron

Heat Transfer
Radioactive Atom

Ionizing Radiation

alpha particle

beta particle

gamma ray

X-ray

Heat Transfer
• The electro-magnetic waves vary in their length and frequency along a very wide spectrum.
<table>
<thead>
<tr>
<th>Source</th>
<th>Frequency in hertz (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rays</td>
<td>10^22</td>
</tr>
<tr>
<td>X-rays</td>
<td>10^20</td>
</tr>
<tr>
<td>Ultraviolet radiation</td>
<td>10^18</td>
</tr>
<tr>
<td>Visible light</td>
<td>10^16</td>
</tr>
<tr>
<td>Infrared radiation</td>
<td>10^14</td>
</tr>
<tr>
<td>Microwaves</td>
<td>10^12</td>
</tr>
<tr>
<td>Microwaves</td>
<td>10^10</td>
</tr>
<tr>
<td>Radio waves</td>
<td>10^8</td>
</tr>
<tr>
<td>Very low frequency (VLF)</td>
<td>10^6</td>
</tr>
<tr>
<td>Extremely low frequency (ELF)</td>
<td>10^4</td>
</tr>
<tr>
<td>Direct Current</td>
<td>10^2</td>
</tr>
<tr>
<td>Power-frequency EMFs, 50 or 60 Hz</td>
<td>10^0</td>
</tr>
<tr>
<td>X-rays, about 1 billion billion Hz, can penetrate the body and damage internal organs and tissues by damaging important molecules like DNA. This is called “ionization.”</td>
<td></td>
</tr>
</tbody>
</table>
Types of Radiation

• Radiation is classified into:
  —Ionizing radiation
  —Non-ionizing radiation
Ionizing Versus Non-ionizing Radiation

- **Ionizing Radiation**
  - Higher energy electromagnetic waves (gamma) or heavy particles (beta and alpha).
  - High enough energy to pull electron from orbit.

- **Non-ionizing Radiation**
  - Lower energy electromagnetic waves.
  - Not enough energy to pull electron from orbit, but can excite the electron.
Ionizing Radiation

• Definition:

“It is a type of radiation that is able to disrupt atoms and molecules on which they pass through, giving rise to ions and free radicals.”
Ionizing radiation
A radiation is said to be ionizing when it has enough energy to eject one or more electrons from the atoms or molecules in the irradiated medium. This is the case of α and β radiations, as well as of electromagnetic radiations such as gamma radiations, X-rays and some ultra-violet rays. Visible or infrared light are not, nor are microwaves or radio waves.
Primary Types of Ionizing Radiation

- Alpha particles
- Beta particles
- Gamma rays (or photons)
- X-Rays (or photons)
- Neutrons
Types and Characteristics of Ionizing Radiation

Alpha Particles

Alpha Particles: 2 neutrons and 2 protons
They travel short distances, have large mass
Only a hazard when inhaled
• **Alpha Particles (or Alpha Radiation):** Helium nucleus (2 neutrons and 2 protons); +2 charge; heavy (4 AMU). Typical Energy = 4-8 MeV; **Limited range** (<10cm in air; 60µm in tissue); High LET (QF=20) causing heavy damage (4K-9K ion pairs/µm in tissue). Easily shielded (e.g., paper, skin) so an internal radiation hazard. Eventually lose too much energy to ionize; become He.
Beta Particles: Electrons or positrons having small mass and variable energy. Electrons form when a neutron transforms into a proton and an electron or:
Beta Particles: High speed electron ejected from nucleus; -1 charge, light 0.00055 AMU; Typical Energy = several KeV to 5 MeV; Range approx. 12'/MeV in air, a few mm in tissue; Low LET (QF=1) causing light damage (6-8 ion pairs/µm in tissue). Primarily an internal hazard, but high beta can be an external hazard to skin. In addition, the high speed electrons may lose energy in the form of X-rays when they quickly decelerate upon striking a heavy material. This is called Bremsstralung (or Breaking) Radiation. Aluminum and other light (<14) materials are used for shielding.
Heat Transfer
Gamma Rays

Gamma Rays (or photons): Result when the nucleus releases energy, usually after an alpha, beta or positron transition
X-Rays

X-Rays: Occur whenever an inner shell orbital electron is removed and rearrangement of the atomic electrons results with the release of the elements characteristic X-Ray energy
• **X- and Gamma Rays:** X-rays are photons (Electromagnetic radiations) emitted **from electron orbits. Gamma rays** are photons emitted **from the nucleus**, often as part of radioactive decay. Gamma rays typically have higher energy (Mev's) than X-rays (KeV's), but both are unlimited.
Neutrons

Neutrons: Have the same mass as protons but are uncharged
## Radiation from Natural Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>mrem/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic rays</td>
<td>28</td>
</tr>
<tr>
<td>The earth</td>
<td>26</td>
</tr>
<tr>
<td>Radon</td>
<td>200</td>
</tr>
<tr>
<td>The human body</td>
<td>25</td>
</tr>
<tr>
<td>Building materials</td>
<td>4</td>
</tr>
</tbody>
</table>
## Radiation from Manmade Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>mrem/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>90</td>
</tr>
<tr>
<td>Fallout</td>
<td>5</td>
</tr>
<tr>
<td>Consumer products</td>
<td>1</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>0.3</td>
</tr>
</tbody>
</table>
QUANTIFICATION OF RADIATION

• A. Quantifying Radioactive Decay
• B. Quantifying Exposure and Dose
A. Quantifying Radioactive Decay

Measurement of **Activity** in disintegrations per second (dps);

- 1 **Becquerel** (Bq) = 1 dps;
- 1 **Curie** (Ci) = 3.7 x 10^10 dps;
- Activity of substances are expressed as activity per weight or volume (e.g., Bq/gm or Ci/l).
B. Quantifying Exposure and Dose

- **Exposure**: Roentgen (R) = amount of X or gamma radiation that produces ionization resulting in 1 electrostatic unit of charge in 1 cm³ of dry air. Instruments often measure exposure rate in mR/hr.

- **Absorbed Dose**: rad (Roentgen absorbed dose) = absorption of 100 ergs of energy from any radiation in 1 gram of any material; 1 Gray (Gy) = 100 rads = 1 Joule/kg; Exposure to 1 Roentgen approximates 0.9 rad in air.

- **Biologically Equivalent Dose**: Rem (Roentgen equivalent man) = dose in rads x QF, where QF = quality factor. 1 Sievert (Sv) = 100 rems.
Half Life Calculation

Half-Life

The time required for the amount of radioactive material to decrease by one-half

Activity


\[ N_t = N_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} \]

Heat Transfer
Ionizing Radiation at the Cellular Level

- Causes breaks in one or both DNA strands or;
- Causes Free Radical formation
Exposure Limits

- **OSHA Limits**: Whole body limit = 1.25 rem/qtr or 5 rem (50 mSv) per year.
- Hands and feet limit = 18.75 rem/qtr.
- Skin of whole body limit = 7.5 rem/qtr.
- Total life accumulation = $5 \times (N-18)$ rem where $N = \text{age}$. Can have 3 rem/qtr if total life accumulation not exceeded.
- Note: New recommendations reduce the 5 rem to 2 rem.
# External/Internal Exposure Limits for Occupationally Exposed Individuals

## Annual Dose Limits

<table>
<thead>
<tr>
<th></th>
<th>Adult (&gt;18 yrs)</th>
<th>Minor (&lt; 18 yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whole body</strong>*</td>
<td>5000 mrem/yr</td>
<td>500 mrem/yr</td>
</tr>
<tr>
<td><strong>Lens of eye</strong></td>
<td>15000 mrem/yr</td>
<td>1500 mrem/yr</td>
</tr>
<tr>
<td><strong>Extremities</strong></td>
<td>50000 mrem/yr</td>
<td>5000 mrem/yr</td>
</tr>
<tr>
<td><strong>Skin</strong></td>
<td>50000 mrem/yr</td>
<td>5000 mrem/yr</td>
</tr>
<tr>
<td><strong>Organ</strong></td>
<td>50000 mrem/yr</td>
<td>5000 mrem/yr</td>
</tr>
</tbody>
</table>

*Effective dose equivalent*
Community Emergency Radiation

Hazardous Waste Sites:

• Radiation above background (0.01-0.02 m rem/hr) signifies possible presence which must be monitored. Radiation above 2 m rem/hr indicates potential hazard. Evacuate site until controlled.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Typical Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking</td>
<td>280 millirem/year</td>
</tr>
<tr>
<td><strong>Radioactive materials use in a UM lab</strong></td>
<td>&lt;10 millirem/year</td>
</tr>
<tr>
<td>Dental x-ray</td>
<td>10 millirem per x-ray</td>
</tr>
<tr>
<td>Chest x-ray</td>
<td>8 millirem per x-ray</td>
</tr>
<tr>
<td>Drinking water</td>
<td>5 millirem/year</td>
</tr>
<tr>
<td>Cross country round trip by air</td>
<td>5 millirem per trip</td>
</tr>
<tr>
<td>Coal Burning power plant</td>
<td>0.165 millirem/year</td>
</tr>
</tbody>
</table>
• **HEALTH EFFECTS**

• *Generalizations:* Biological effects are due to the ionization process that destroys the capacity for cell reproduction or division or causes cell mutation. A given total dose will cause more damage if received in a shorter time period. A **fatal dose** is (600 R)

• *Acute Somatic Effects:* Relatively immediate effects to a person acutely exposed. Severity depends on dose. Death usually results from damage to bone marrow or intestinal wall. Acute **radio-dermatitis** is common in radiotherapy; chronic cases occur mostly in industry.
<table>
<thead>
<tr>
<th>ACUTE DOSE (RAD) EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0-25</strong></td>
</tr>
<tr>
<td><strong>25-50</strong></td>
</tr>
<tr>
<td><strong>50-100</strong></td>
</tr>
<tr>
<td><strong>150-300</strong></td>
</tr>
<tr>
<td><strong>300-500</strong></td>
</tr>
<tr>
<td><strong>&gt; 500</strong></td>
</tr>
</tbody>
</table>
• **Delayed Somatic Effects**: Delayed effects to exposed person include: Cancer, leukemia, cataracts, life shortening from organ failure, and abortion. Probability of an effect is proportional to dose (no threshold). Severity is independent of dose. Doubling dose for cancer is approximately 10-100 rems.

• **Genetic Effects**: Genetic effects to off-spring of exposed persons are irreversible and nearly always harmful. Doubling dose for mutation rate is approximately 50-80 rems. (Spontaneous mutation rate is approx. 10-100 mutations per million population per generation.)
• **Critical Organs**: Organs generally most susceptible to radiation damage include: Lymphocytes, bone marrow, gastro-intestinal, gonads, and other fast-growing cells. The central nervous system is relatively resistant. Many nuclides concentrate in certain organs rather than being uniformly distributed over the body, and the organs may be particularly sensitive to radiation damage, e.g., isotopes of iodine concentrate in the thyroid gland. These organs are considered "critical" for the specific nuclide.
Non-ionizing Radiation

• Definition:

“ They are electromagnetic waves incapable of producing ions while passing through matter, due to their lower energy.”
- All earth surface system components emit radiation---the sun and the earth are the components we are most interested in.

- The sun emits radiation composed of high energy infrared radiation, visible light, and ultraviolet radiation collectively known as shortwave radiation (SW).

- The earth emits radiation composed of lower energy infrared radiation collectively known as long-wave radiation (LW).
Heat Transfer
Path of incoming solar radiation

- **Incoming Solar Radiation**
  - 4% Reflected Upward
  - 16% Absorbed by Gases and Dust
  - 21% Direct Radiation Absorbed
  - 6% Radiation Scattered Downward
  - 20% Radiation Reflected Downward
  - 3% Absorbed by Clouds
  - 19% Absorbed in the Atmosphere
  - 30% Lost to Space

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Albedo: a measure of how well a surface reflects insolation
Examples on Non-ionizing Radiation Sources

- Visible light
- Microwaves
- Radios
- Video Display Terminals
- Power lines
- Radiofrequency Diathermy (Physical Therapy)
- Lasers

Heat Transfer
Other Manmade Sources of Non-Ionizing Radiation
Heat Transfer
Effects

- Radiofrequency Ranges (10 kHz to 300 GHz)
  - Effects only possible at ten times the permissible exposure limit
  - Heating of the body (thermal effect)
  - Cataracts
  - Some studies show effects of teratogenicity and carcinogenicity.
RADIATION CONTROLS

• A. Basic Control Methods for External Radiation

  ● Decrease Time
  ● Increase Distance
  ● Increase Shielding
• **Time**: Minimize time of exposure to minimize total dose. Rotate employees to restrict individual dose.

• **Distance**: Maximize distance to source to maximize attenuation in air. The effect of distance can be estimated from equations.

• **Shielding**: Minimize exposure by placing absorbing shield between worker and source.
B. Monitoring

• *Personal Dosimeters*: Normally they do not prevent exposures (no alarm), just record it. They can provide a record of **accumulated exposure** for an individual worker over extended periods of time (hours, days or weeks), and are small enough for measuring localized exposures Common types: Film badges; Thermoluminescence detectors (TLD); and pocket dosimeters.
Heat Transfer
Heat Transfer
• Direct Reading Survey Meters and Counters: Useful in identifying source of exposures recorded by personal dosimeters, and in evaluating potential sources, such as surface or sample contamination, source leakage, inadequate decontamination procedures, background radiation.

Common types:

• Alpha → Proportional or Scintillation counters
  Beta, gamma → Geiger-Mueller or Proportional counters
  X-ray, Gamma → Ionization chambers
  Neutrons → Proportional counters
Heat Transfer
• **Continuous Monitors**: Continuous direct reading ionization detectors (same detectors as above) can provide read-out and/or alarm to monitor hazardous locations and alert workers to leakage, thereby preventing exposures.

• **Long-Term Samplers**: Used to measure average exposures over a longer time period. For example, charcoal canisters or electrets are set out for days to months to measure radon in basements (should be <4 pCi/L).
Elements of Radiation Protection Program

• Monitoring of exposures: Personal, area, and screening measurements; Medical/biologic monitoring.
• Task-Specific Procedures and Controls: Initial, periodic, and post-maintenance or other non-scheduled events. Engineering (shielding) vs. PPE vs. administrative controls. Including management and employee commitment and authority to enforce procedures and controls.
• Emergency procedures: Response, "clean-up", post clean-up testing and spill control.
• Training and Hazard Communications including signs, warning lights, lockout/tagout, etc. Criteria for need, design, and information given.
• Material Handling: Receiving, inventory control, storage, and disposal.
Thank You