Energy & Heat Transfer

Lecture 6

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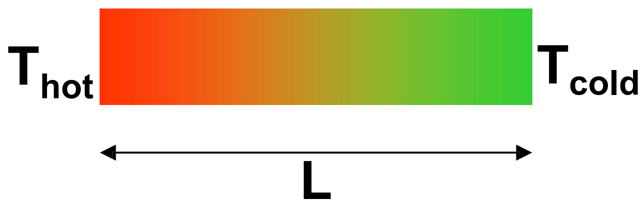
Heat Transfer Modes

Conduction



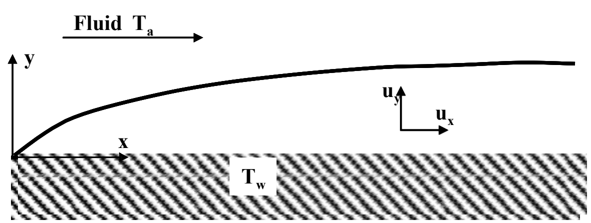
- Fourier Law

$$\dot{Q} = -kA\frac{\Delta T}{\Delta x}\,[W]$$

Thermal Conductivity [W/m.K]
Material properties

Cross-Sectional Area $[m^2]$

Convection



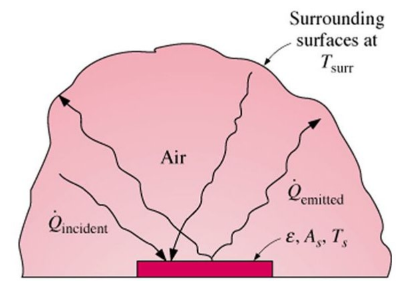
- Newton's law of cooling

$$\dot{Q} = hA(T_w - T_a)\,[W]$$

Convective Heat Transfer Coefficient [W/m^{2}K]
Flow dependent

- Natural Convection
- Forced Convection

Radiation



- Stefan-Boltzmann law

$$\dot{Q} = \varepsilon\sigma A(T_s^4 - T_\infty^4)[W]$$

Emissivity

Stefan-Boltzmann constant

$$\sigma = 5.670 \times 10^{-8}\,\frac{W}{m^2K^4}$$

Learning objectives lecture 6

- Problem Solving Approach
- Energy Balance
- Surface Energy Balance
- Combined Heat Transfer Examples

Problem Solving Approach

Step 1: Problem Statement

Step 2: Schematic

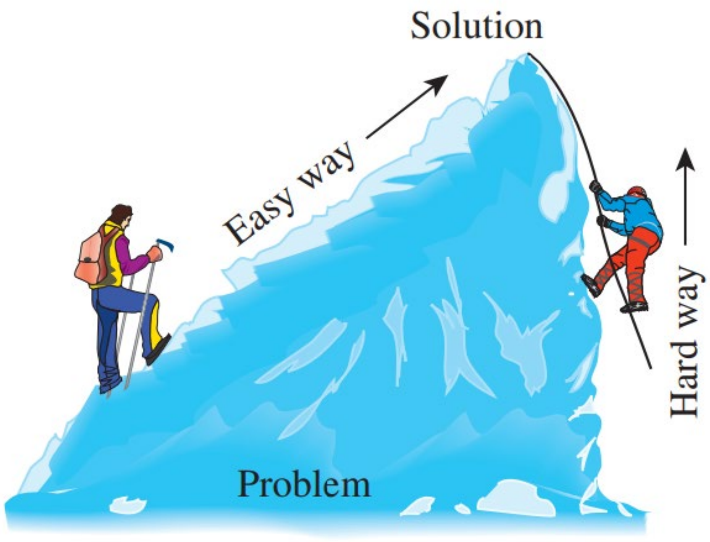
Step 3: Assumptions

Step 4: Physical Laws

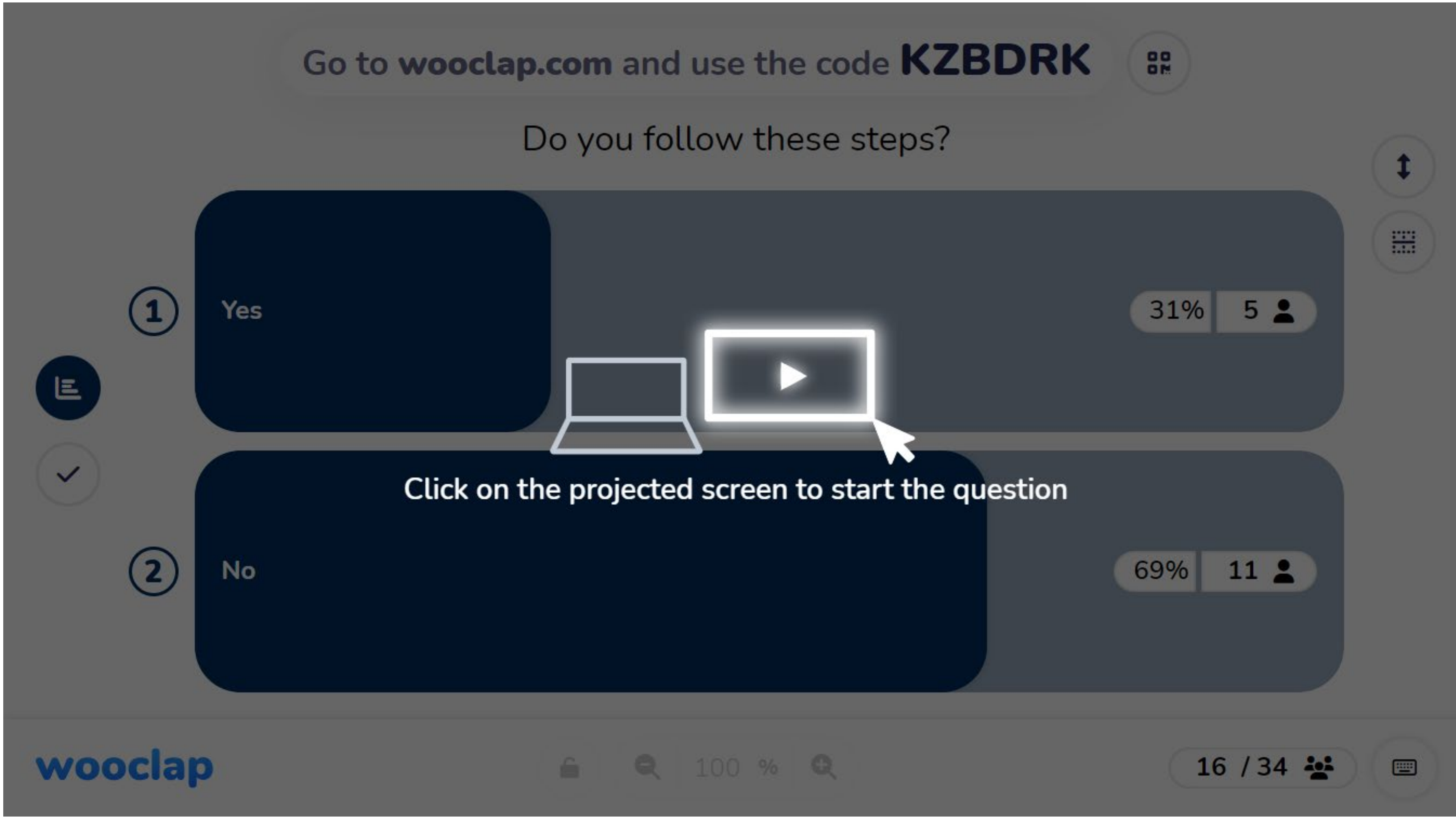
Step 5: Properties

Step 6: Calculations

Step 7: Reasoning, Verification, and Discussion




How to participate?
Click on the projected screen to start the question
Copy participation link
wooclap
100 %
34



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Do you follow these steps?
1
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100 %
16 / 34

Learning objectives lecture 6

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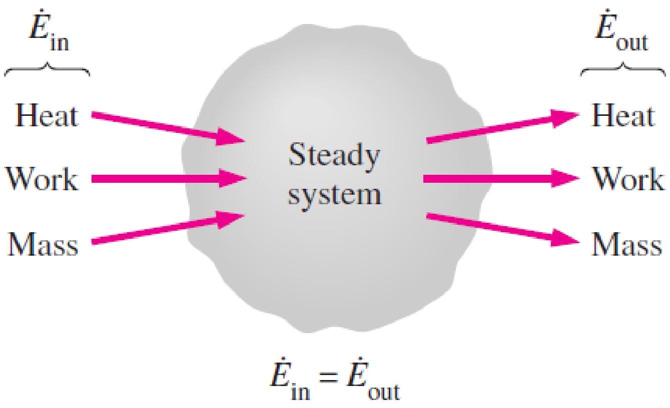
First Law of Thermodynamics

$$\begin{pmatrix}\text{Total energy} \\ \text{entering the} \\ \text{system}\end{pmatrix} - \begin{pmatrix}\text{Total energy} \\ \text{leaving the} \\ \text{system}\end{pmatrix} = \begin{pmatrix}\text{Change in the} \\ \text{total energy of} \\ \text{the system}\end{pmatrix}$$

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal} \\ \text{kinetic, potential, etc., energies}}}$$

ENERGY BALANCE



$$\underbrace{\dot{E}_{in}}_{\substack{\text{Rate of net energy transfer in}\\ \text{by heat, work, and mass}}} = \underbrace{\dot{E}_{out}}_{\substack{\text{Rate of net energy transfer out}\\ \text{by heat, work, and mass}}}$$

In heat transfer analysis, we are usually interested only in the forms of energy that can be transferred as a result of a temperature difference, that is, heat or thermal energy.

$$\underbrace{Q_{in} - Q_{out}}_{\substack{\text{Net heat}\\ \text{transfer}}} + \underbrace{E_{gen}}_{\substack{\text{Heat}\\ \text{generation}}} = \underbrace{\Delta E_{\text{thermal, system}}}_{\substack{\text{Change in thermal}\\ \text{energy of the system}}}$$

LEARNING OBJECTIVES LECTURE 6

- Problem Solving Approach
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- Surface Energy Balance
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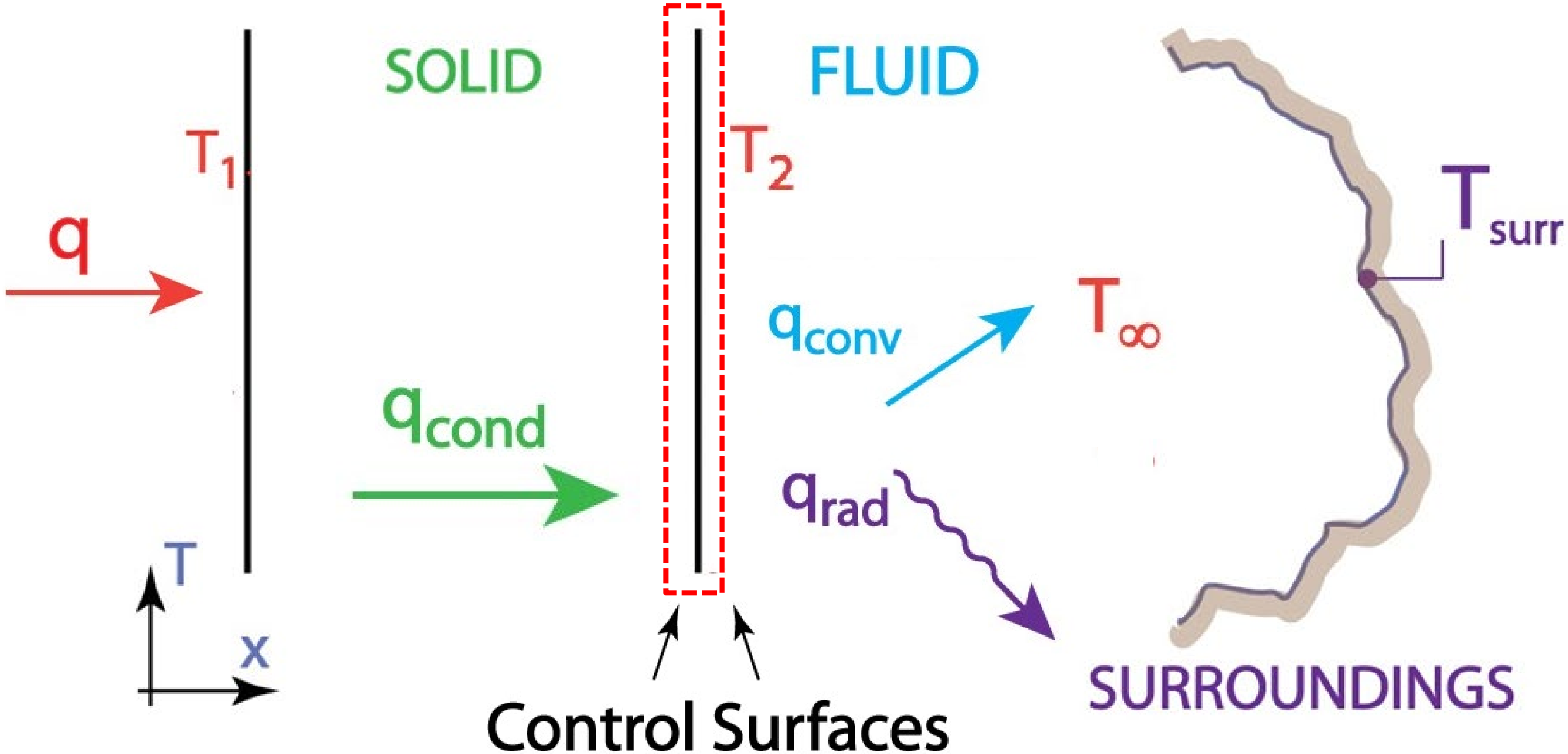
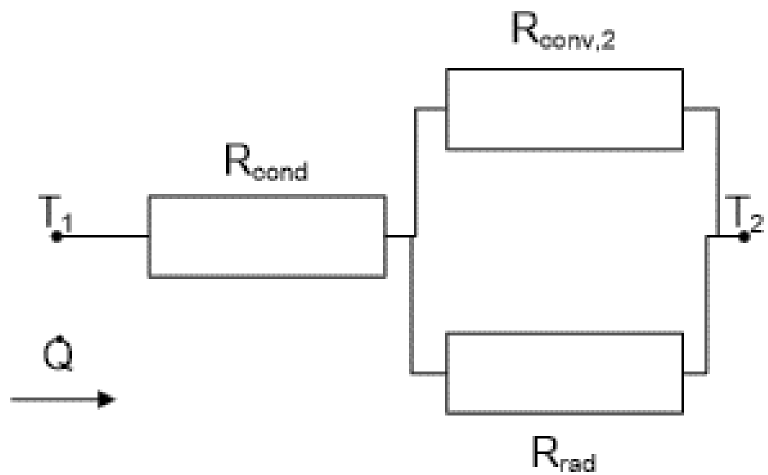
Surface Energy Balance



Surface Energy Balance

$$\dot{q}_{Cond} = \dot{q}_{Conv} + \dot{q}_{rad}$$



$$\Rightarrow \dot{Q} = h_{tot} A \Delta T \quad \text{with} \quad h_{tot} = h_{conv} + h_{rad}$$

$$h_{rad} = \varepsilon \cdot \sigma \cdot (T_s^2 + T_\infty^2) \cdot (T_s + T_\infty)$$

Go to **wooclap.com** and use the code **KZBDRK**

A person standing in a room loses heat to the air in the room by convection and to the surrounding surfaces by radiatio...

	Answer	%	Votes
1	0.008 W/ m 2 ·K	8%	1
2	3.0 W/ m 2 ·K	0%	0
3	5.5 W/ m 2 ·K	58%	7
4	8.3 W/ m 2 ·K	0%	0
5	10.9 W/ m 2 ·K	33%	4

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Learning objectives lecture 6

- Problem Solving Approach
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Step by Step Plan

Conduction:

1. Schematic (Steady state)

2. Negligible heat losses (insulation, adiabatic,..)

3. Geometry (flat plate, cylinder,…)

4. Arrangement of the layers

5. Resistance network

6. Calculation of resistances

7. Calculation of overall resistance

8. Calculation of heat flow

9. Calculation of temperatures for different layers

Radiation:

1. Schematic (Steady state)

2. Negligible Radiations

3. Surrounding Temperature

4. Calculation of heat flow

Convection:

1. Schematic

2. Force of natural convection?

3. Geometry

4. Finding the film temperature

5. Finding ingredients from Table

6. Calculation of dimensionless numbers

7. Calculation of characteristic length

8. Finding correlations from tables to calculate Nu

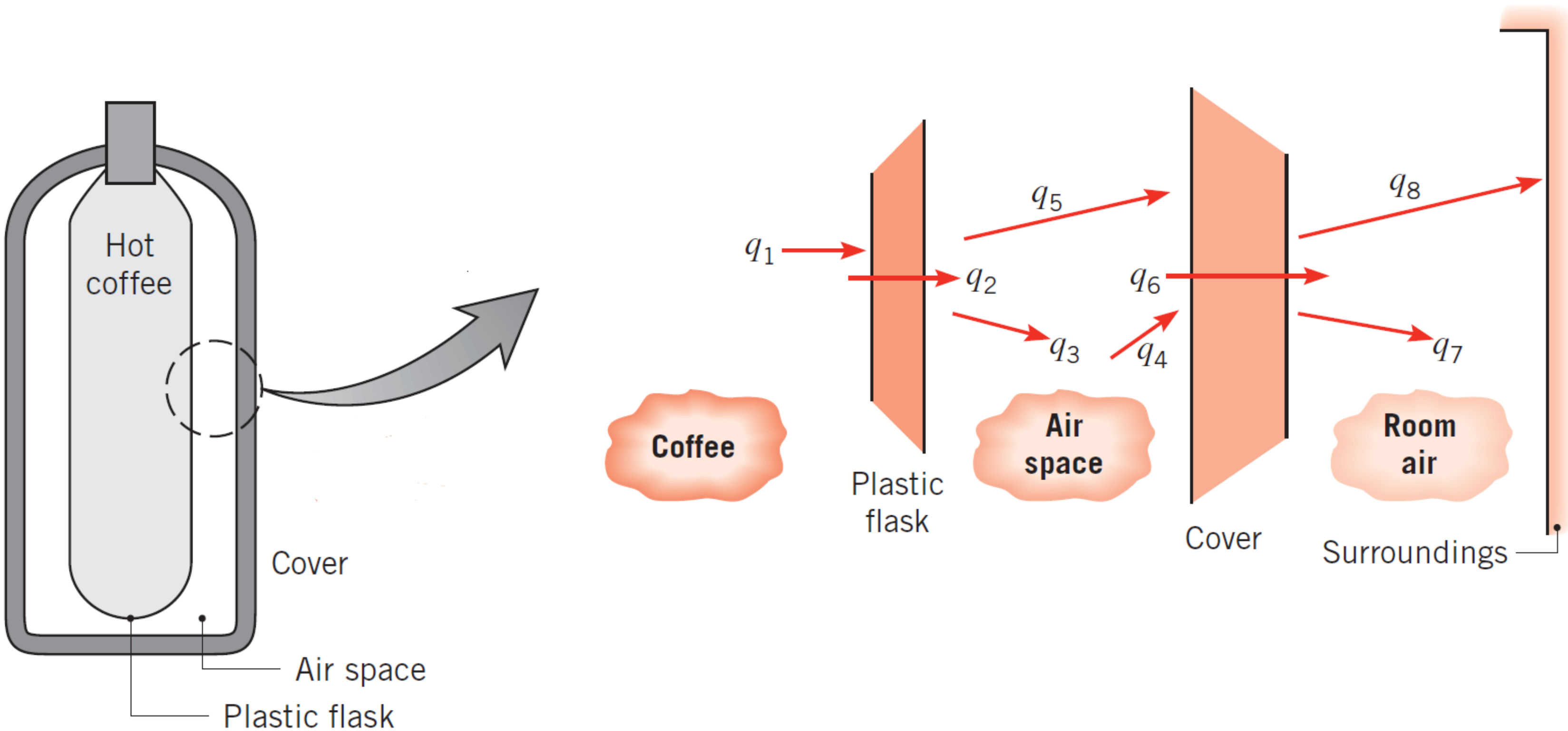
9. Calculation of h

10. Calculation of heat flow

EXAMPLE (1)

Known: ***Hot coffee is separated from its cooler surroundings by a plastic flask, an air space, and a plastic cover.***

Find: ***Relevant heat transfer processes.***



Example (1)

Pathways for energy transfer from the coffee are as follows:

q_1: free convection from the coffee to the flask.

q_2: conduction through the flask.

q_3: free convection from the flask to the air.

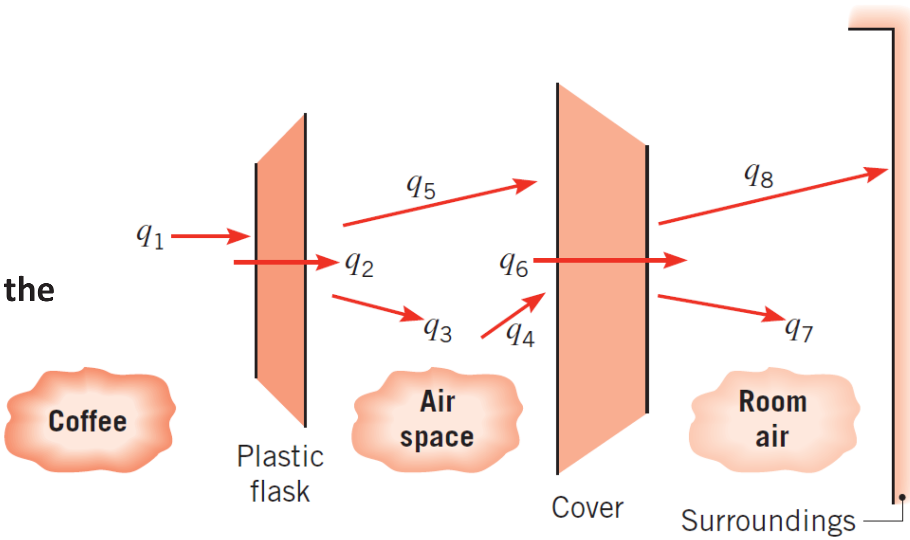
q_4: free convection from the air to the cover.

q_5: net radiation exchange between the outer surface of the flask and the inner surface of the cover.

q_6: conduction through the cover.

q_7: free convection from the cover to the room air.

q_8: net radiation exchange between the outer surface of the cover and the surroundings.



Resistance Network ????

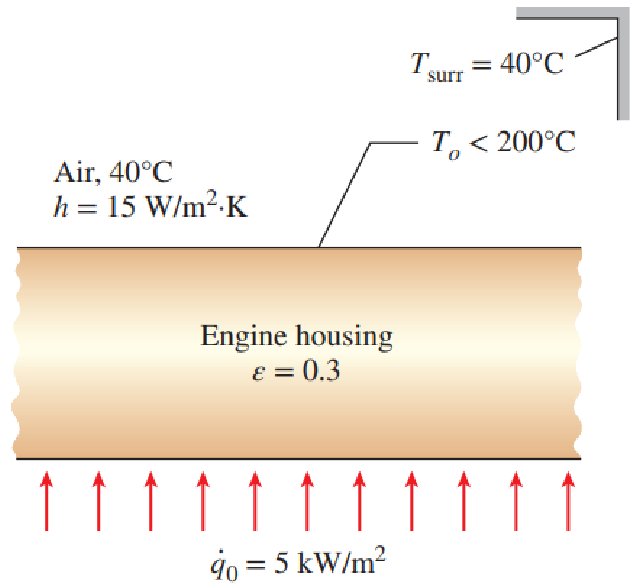
Comments: Design improvements are associated with

(1) use of aluminized (low emissivity) surfaces for the flask and cover to reduce net radiation

(2) evacuating the air space or using a filler material to retard free convection.

Example (2)

Oil leakage and spillage on hot engine surfaces can create fire hazards. Some engine oils have an autoignition temperature above 250° C. When oil leakage comes in contact with a hot engine surface that has a higher temperature than its autoignition temperature, the oil can ignite spontaneously. Consider the outer surface of an engine situated in a place where there is a possibility of being in contact with oil leakage. The engine surface has an emissivity of 0.3, and when it is in operation, its inner surface is subjected to 5 kW/m² of heat flux .The engine is in an environment where the ambient air and surrounding temperature is 40° C, while the convection heat transfer coefficient is 15 W/m² ·K. To prevent a fire hazard, the temperature of the engine surface should be kept below 200° C. Determine whether oil on the engine surface is at a risk of autoignition. If there is a risk of autoignition, discuss a possible prevention measure that can be implemented.



Example (2)

Assumptions:

1 -Steady operating conditions exist.

2 -The surrounding surfaces are at the same temperature as the ambient air.

3- Heat conduction through the engine housing is one-dimensional.

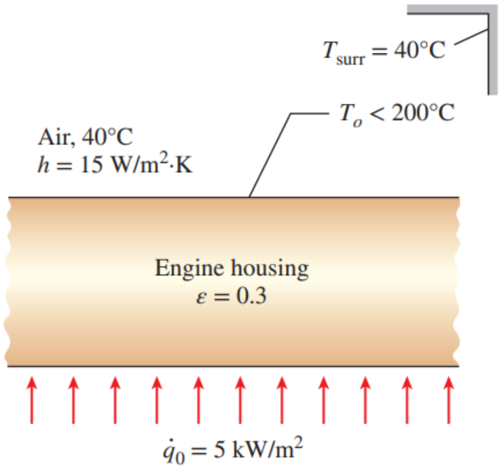
4 -The engine inner surface is subjected to uniform heat flux.

Properties :

- **Emissivity of the engine surface is given as ε = 0.3.**

Analysis :

When in operation, the inner surface of the engine is subjected to a uniform heat flux, which is equal to the sum of heat fluxes transferred by convection and radiation on the outer surface.



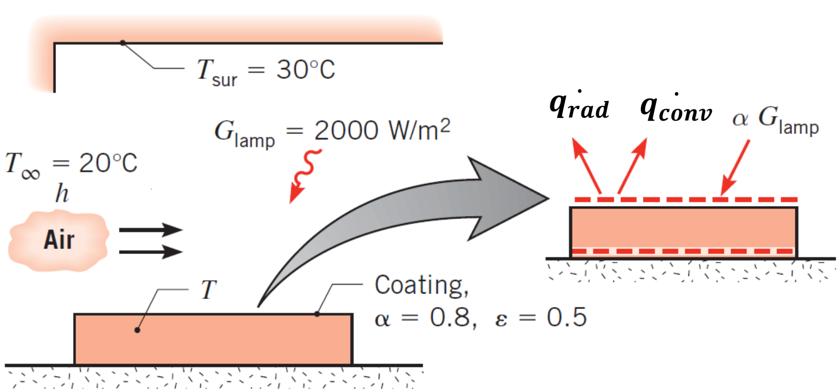
$$\dot{q}_0 = h(T_o - T_\infty) + \varepsilon\sigma\left(T_o^4 - T_{surr}^4\right)$$

EXAMPLE (3)

The coating on a plate is cured by exposure to an infrared lamp providing a uniform irradiation of 2000 W/m^2. It absorbs 80% of the infrared irradiation and has an emissivity of 0.50. It is also exposed to an airflow and large surroundings for which temperatures are 20° C and 30° C, respectively.

1. If the convection coefficient between the plate and the ambient air is 15 W/m2 · K, what is the cure temperature of the plate?
2. The final characteristics of the coating, including wear and durability, are known to depend on the temperature at which curing occurs. An airflow system is able to control the air velocity, and hence the convection coefficient, on the cured surface . What value of h would provide a cure temperature of 50° C?

Schematic:



Example (3)

Assumptions:

1. Steady-state conditions.

2. Negligible heat loss from back surface of plate.

3. Plate is small object in large surroundings, and coating has an absorptivity of $\alpha_{sur} = \varepsilon = 0.5$ with respect to irradiation from the surroundings.

Analysis:

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = 0 \quad \Longrightarrow \quad \mathrm{G}.\,\alpha_{sur} - \dot{\mathrm{q}}_{\mathrm{rad}} - \dot{\mathrm{q}}_{\mathrm{conv}} = 0$$

$$(\alpha G)_{\text{lamp}} - h(T - T_{\infty}) - \varepsilon\sigma(T^4 - T_{\text{sur}}^4) = 0$$

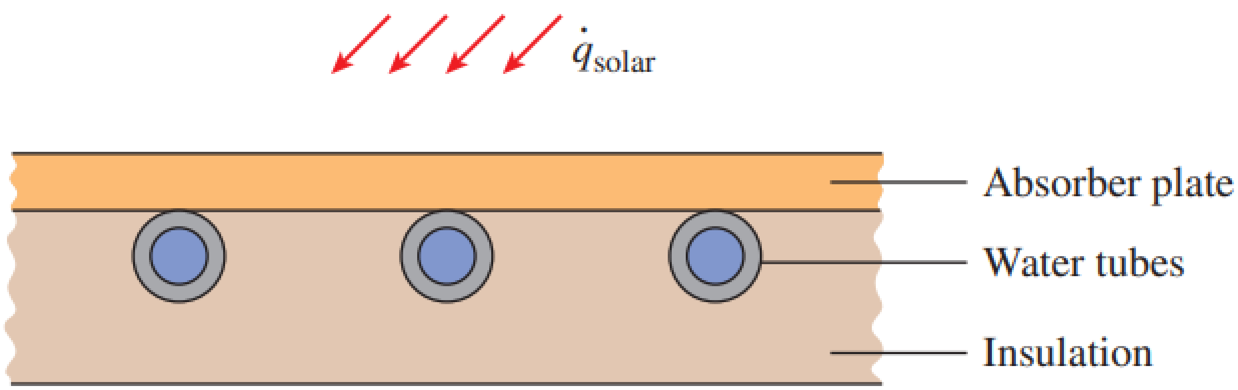
$0.8 \times 2000\ \mathrm{W/m^2} - 15\ \mathrm{W/m2 \cdot K}(T - 293)\ \mathrm{K} - 0.5 \times 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}\ (T^4 - 303^4)\ \mathrm{K^4} = 0$

and solving by trial-and-error, we obtain :

$T = 377\ \mathrm{K} = 104^{\circ}\ \mathrm{C}$ $\qquad$ $h(T = 50^{\circ}\ \mathrm{C}) = 51.0\ \mathrm{W/m^2 \cdot K}$

Example (4)

A flat-plate solar collector is used to heat water by having water flow through tubes attached at the back of the thin solar absorber plate. The absorber plate has a surface area of 2 m^2 with emissivity and absorptivity of 0.9. The surface temperature of the absorber is 35° C, and solar radiation is incident on the absorber at 500 W/m^2 with a surrounding temperature of 0° C. The convection heat transfer coefficient at the absorber surface is 5 $W/m^2 \cdot K$, while the ambient temperature is 25° C. Net heat absorbed by the solar collector heats the water from an inlet temperature (T_{in}) to an outlet temperature (T_{out}). If the water flow rate is 5 g/s with a specific heat of 4.2 kJ/kg·K, determine the temperature rise of the water.



EXAMPLE (5)

A photovoltaic panel of dimension 2 m × 4 m is installed on the roof of a home. The panel is irradiated with a solar flux of GS = 700 W/m^2, oriented normal to the top panel surface. The absorptivity of the panel to the solar irradiation is $\alpha_S = 0.83$, and the efficiency of conversion of the absorbed flux to electrical power is $\eta = P/\alpha_S G_S A = 0.553 - 0.001\ \mathrm{K}^{-1} T_p$, where T_p is the panel temperature expressed in kelvins and A is the solar panel area. The panel emissivity is $\varepsilon = 0.90$.

Determine the electrical power generated for

(a) a still summer day, in which $T_{sur} = T_\infty = 35^\circ$ C, $h = 10$ W/m$^2 \cdot$ K

(b) a breezy winter day, for which $T_{sur} = T_\infty = -15^\circ$ C, $h = 30$ W/m$^2 \cdot$ K.