INTERNAL COMBUSTION ENGINES

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Lecture # 12 (Heat transfer in Engines)

HEAT TRANSFER IN ENGINES

- Heat dissipation is probably one of the most important considerations in engine design.
- An internal combustion engine creates enough heat to destroy itself. Without an efficient cooling system, we would not have the vehicles we do today.
- The original radiators were simple networks of round copper or brass tubes that had water flowing through them by convection.
- Not long after that, as engines grew larger and hotter, companies began to add fans for a constant flow of air over the radiator cores.
- These more efficient cooling systems eventually added a pump to push the water through the cooling tubes.
- All in all, the car radiator is a simple and lasting technology

I. ENERGY DISTRIBUTION

The amount of energy (power) available for use in an engine is

$$\dot{W} = \dot{m}_f Q_{\mathrm{HV}} \tag{1}$$

where

$\dot{m}_f$ = fuel flow rate into the engine
Q_{HV} = heating value of the fuel

The mass flow of fuel is limited by the mass flow of air that is needed to react with the fuel. Brake thermal efficiency gives the percentage of this total energy that is converted to useful output at the crankshaft:

$$(\eta_t)_{\mathrm{brake}} = \dot{W}_b / \dot{m}_f Q_{\mathrm{HV}} \eta_c \tag{2}$$

where

η_t = thermal efficiency
η_c = combustion efficiency
$\dot{W}_b$ = brake power

I. ENERGY DISTRIBUTION

The rest of the energy can be divided into heat losses, parasitic loads, and energy that is lost in the exhaust flow.

$$\text{Power generated} = \dot{W}_{\text{shaft}} + \dot{Q}_{\text{exhaust}} + \dot{Q}_{\text{loss}} + \dot{W}_{\text{acc}} \tag{3}$$

where

$\dot{W}_{\text{shaft}}$ = brake output power off of the crankshaft

$\dot{Q}_{\text{exhaust}}$ = energy lost in the exhaust flow

$\dot{Q}_{\text{loss}}$ = all other energy lost to the surroundings by heat transfer

$\dot{W}_{\text{acc}}$ = power to run engine accessories

1. ENERGY DISTRIBUTION

Depending on the size and geometry of an engine, as well as on how it is being operated, the shaft power output is

$$\dot{W}_{\text{shaft}} \approx 25\text{–}40\%$$

CI engines are generally on the high end of this range, and SI engines are on the lower end. Energy lost in exhaust flow is

$$\dot{Q}_{\text{exhaust}} \approx 20\text{–}45\%$$

A greater percentage of energy is lost in the exhaust of SI engines because of their higher exhaust temperatures. Lost exhaust energy is made up of two parts: enthalpy (heat) and chemical energy. When the engine is running rich at full load, chemical energy makes up about half of the exhaust loss. Under many operating conditions, lost exhaust energy exceeds the brake power output of the engine. Other heat losses are

$$\dot{Q}_{\text{loss}} \approx 10\text{–}35\%$$

I. ENERGY DISTRIBUTION

For many engines, the heat losses can be subdivided:

$$\dot{Q}_{\text{loss}} = \dot{Q}_{\text{coolant}} + \dot{Q}_{\text{oil}} + \dot{Q}_{\text{ambient}}$$

With CI engines on the high end, heat flow to the coolant is about

$$\dot{Q}_{\text{coolant}} \approx 10\text{–}30\%$$

At high load, energy lost to the coolant can amount to about half of the brake power output, increasing to about twice the brake power output at low load. Depending on the type of oil and engine speed,

$$\dot{Q}_{\text{oil}} \approx 5\text{–}15\%$$

Losses directly to the surroundings are

$$\dot{Q}_{\text{ambient}} \approx 2\text{–}10\%$$

Friction losses are on the order of

$$\dot{W}_{\text{friction}} \approx 10\%$$

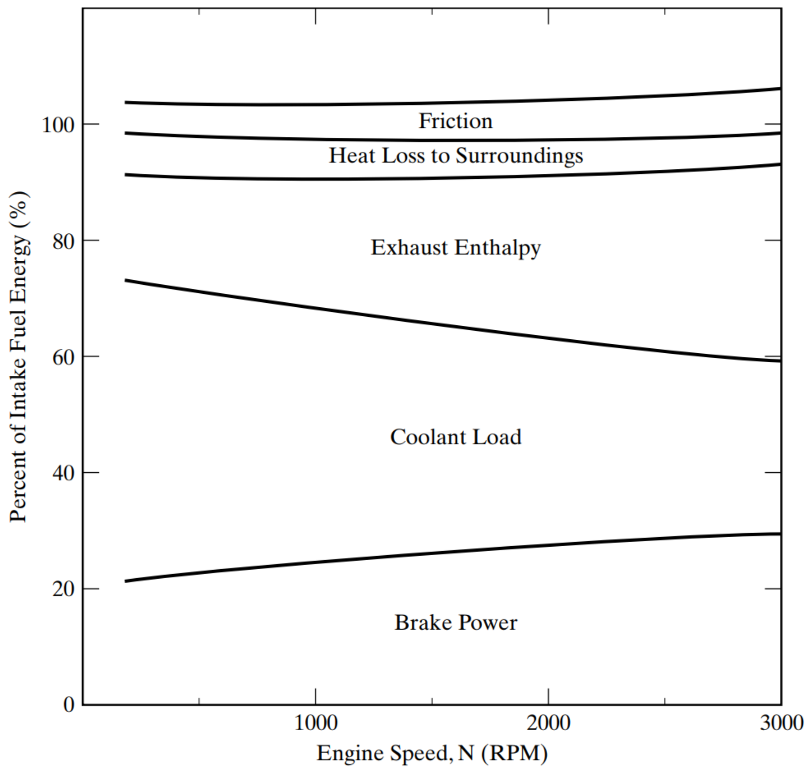


FIGURE 1

Distribution of energy in a typical SI engine as a function of engine speed. Friction losses, which are generally on the order of 10%, add to other heat losses and make the total energy distribution greater than 100%.

2. ENGINE TEMPERATURE

Engine Warmup

- As a cold engine heats up to steady-state temperature, thermal expansion occurs in all components.
- The magnitude of this expansion will be different for each component, depending on its temperature and material.
- Engine bore limits the expansion of pistons.
- In cold weather, the startup time can be as high as 20—30 minutes.
- Some parts of the engine reach steady state much sooner and some do not.
- Fairly, normal conditions may be experienced within few minutes, but it can take as long as an hour to reach optimum fuel consumption rates.
- Engines are built to operate best at steady-state conditions.
- Full power and optimum fuel economy may not be realized until this condition is reached.

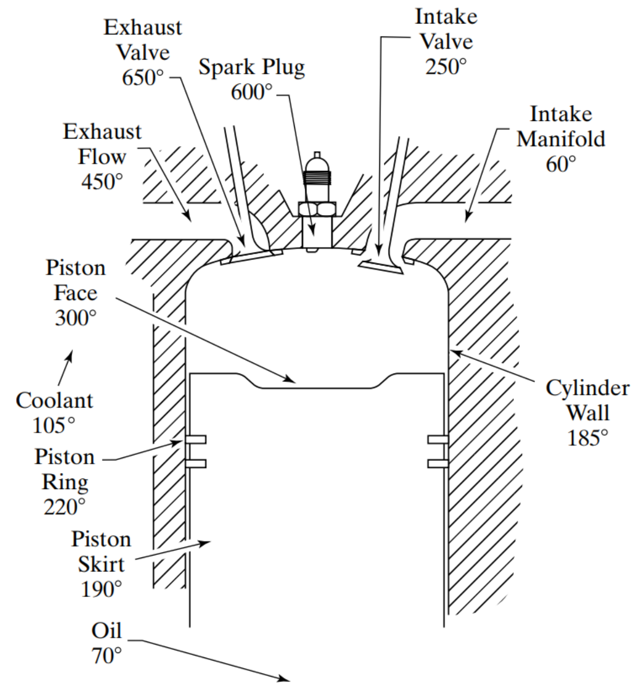


FIGURE 2

Typical temperature values found in an SI engine operating at normal steady state conditions. Temperatures are in degrees C.

2. ENGINE TEMPERATURE

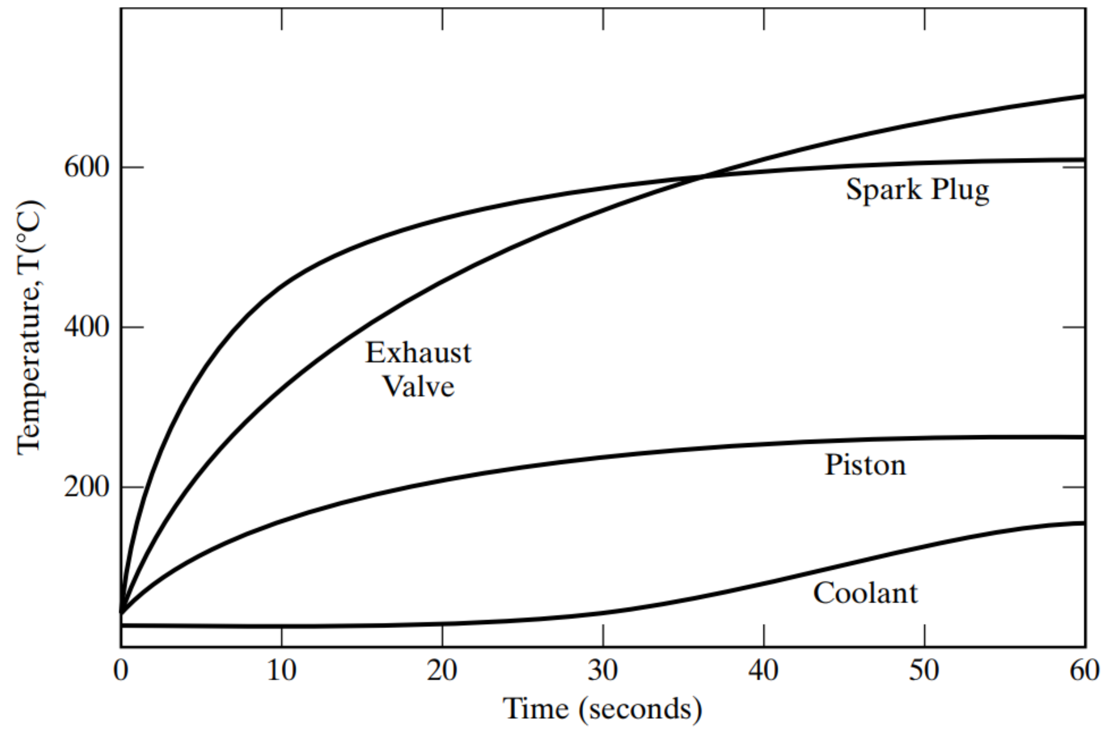


FIGURE 5

Temperatures of engine components of a typical SI engine as a function of time after cold start-up.

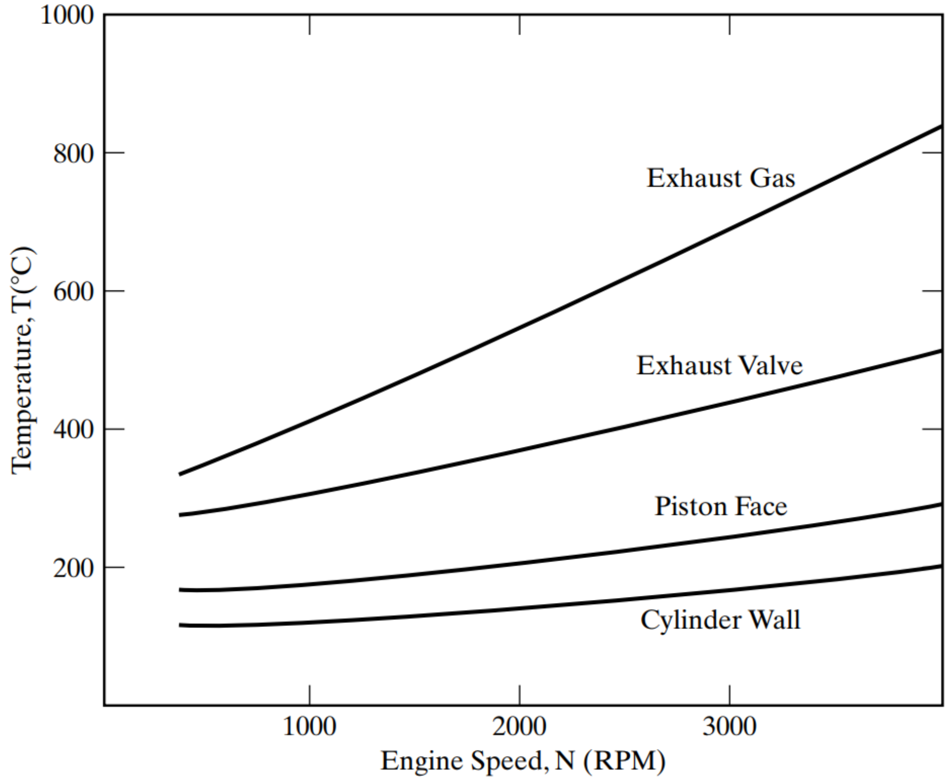


FIGURE 12

Engine temperatures as a function of engine speed for a typical SI engine.

3. AIR COOLED ENGINES

- Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.
- In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc.
- Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air.
- The amount of heat dissipated to air depends upon :

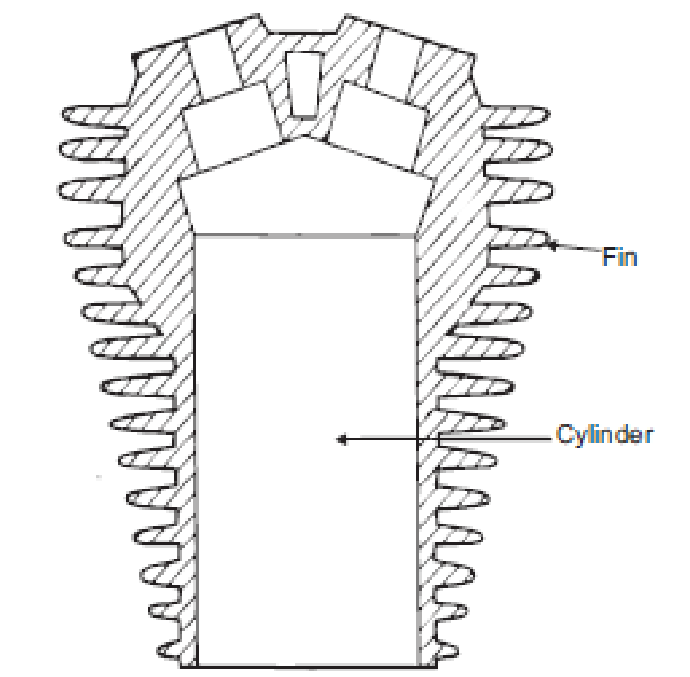
  (a) Amount of air flowing through the fins.

  (b) Fin surface area.

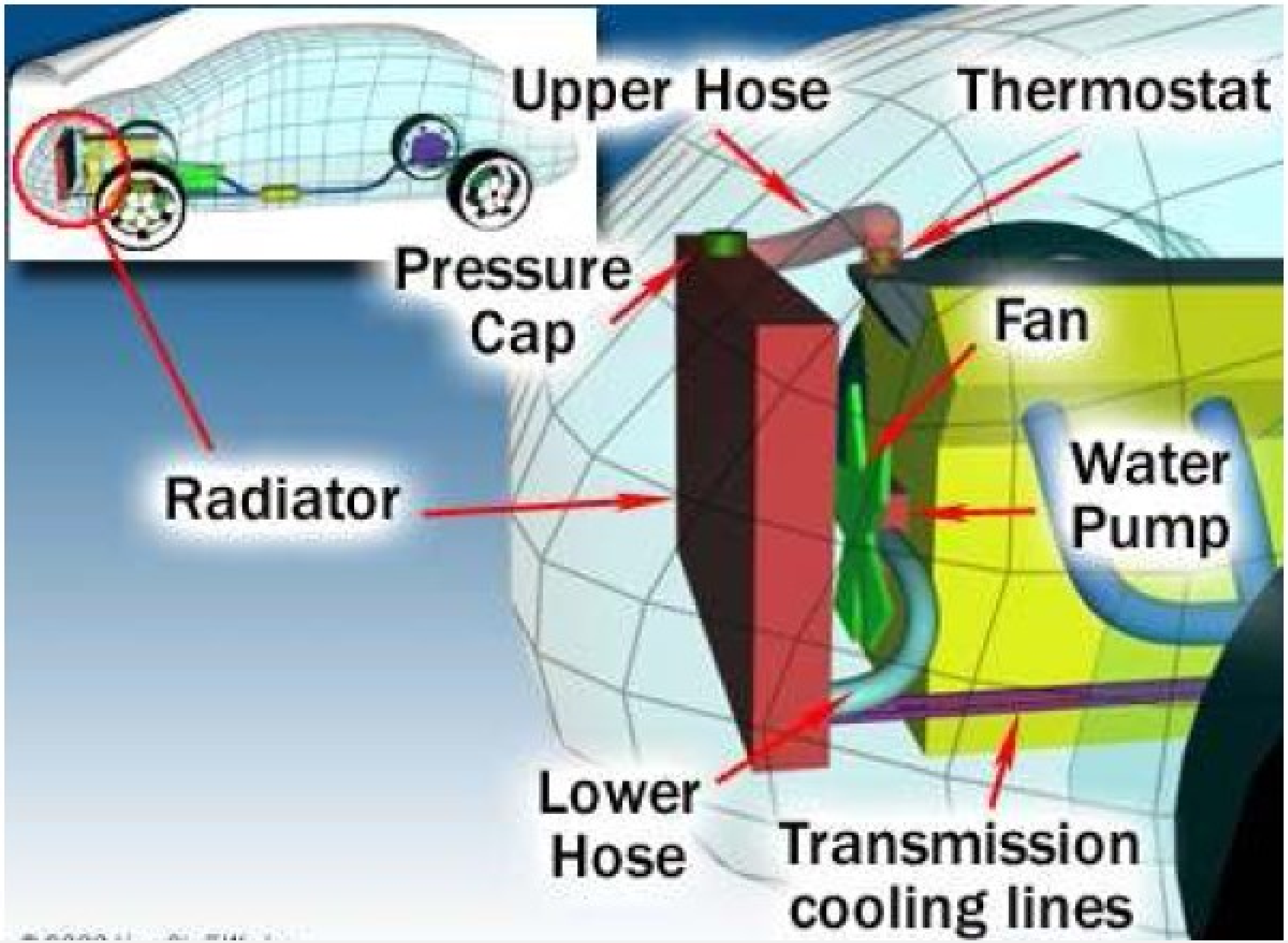
  (c) Thermal conductivity of metal used for fins

3. AIR COOLED ENGINES

Finned Engine Cylinder



4. LIQUID-COOLED ENGINES



4. LIQUID-COOLED ENGINES

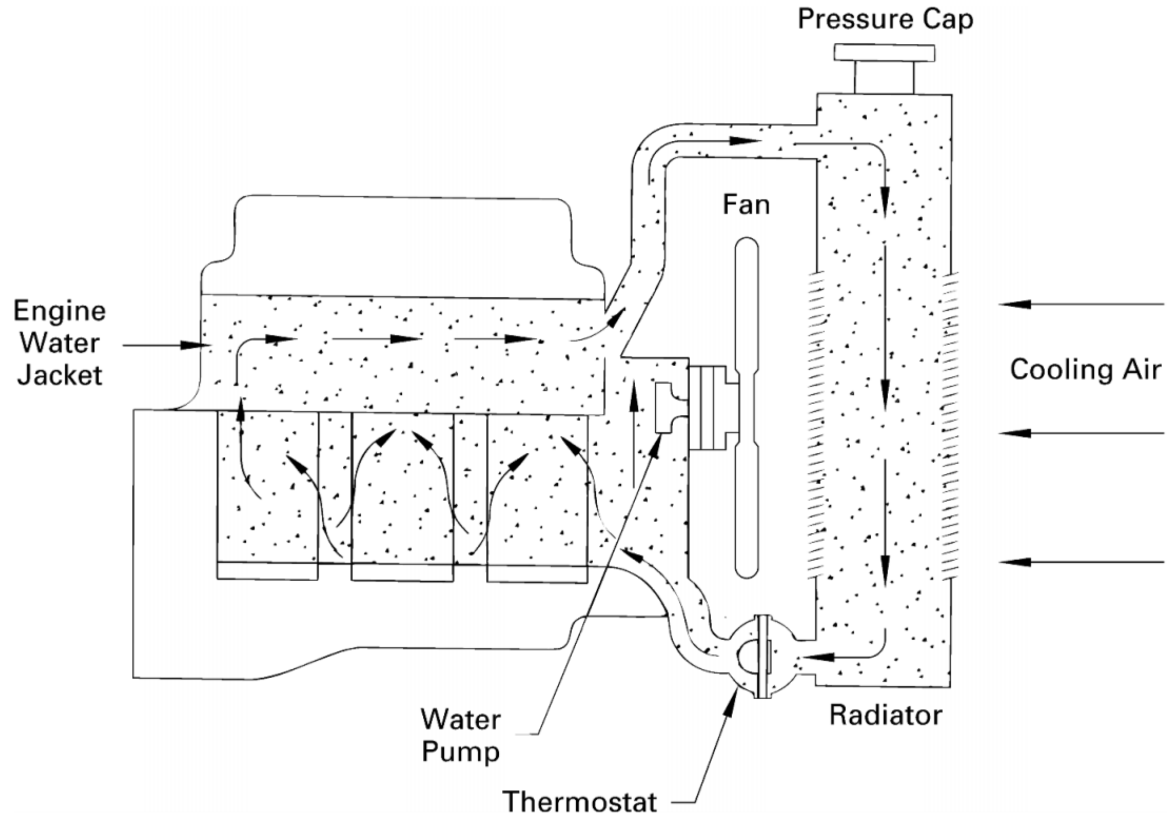


FIGURE 15

Radiator of a liquid-cooled engine used to remove heat from the coolant loop of the engine. A radiator is a liquid-to-air heat exchanger generally mounted in front of the engine on an automobile. Liquid flow is supplied by the engine water pump, while air flow is a result of the forward motion of the automobile, assisted by one or more fans. Adapted from [81].

4. LIQUID-COOLED ENGINES

When compared with liquid-cooled engines, air-cooled engines have the following advantages:

(1) lighter weight,

(2) less costly,

(3) no coolant system failures (e.g., water pump, hoses),

(4) no engine freeze-ups, and

(5) faster engine warm-up.

Disadvantages of air-cooled engines are that they:

(1) are less efficient,

(2) are noisier, with greater air flow requirements and no water jacket to dampen noise,

(3) need a directed air flow and finned surfaces.

5. HEAT TRANSFER IN COMBUSTION CHAMBERS

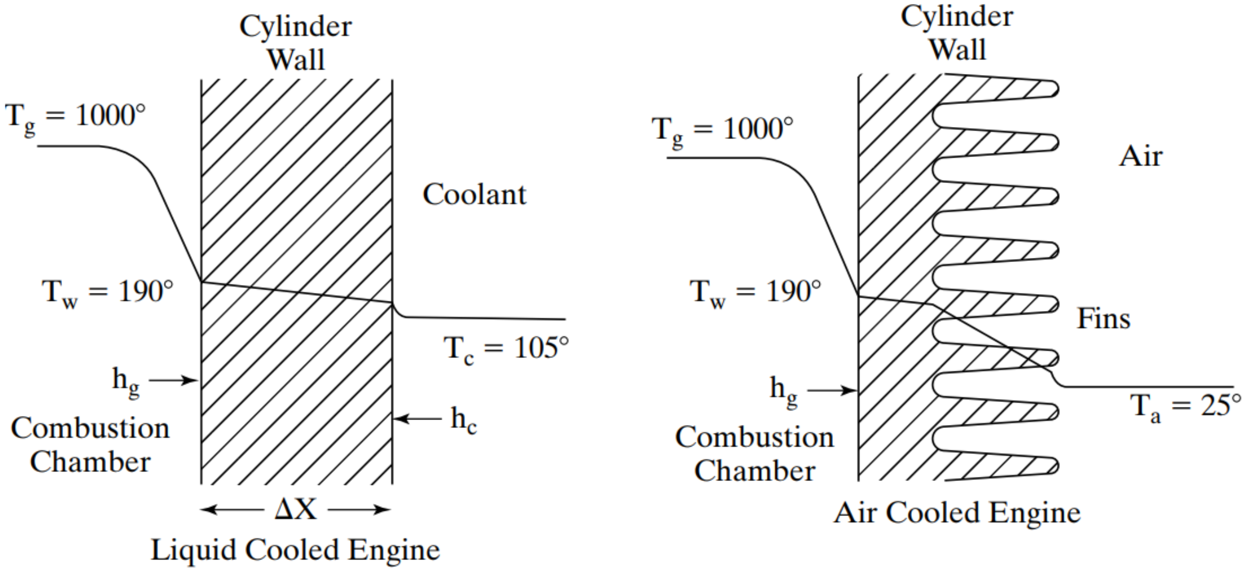


FIGURE 7

Heat transfer through the combustion chamber cylinder wall of an IC engine. The cylinder gas temperature T_g and convection heat transfer coefficient h_g vary over large ranges for each engine cycle, while the coolant temperature T_c (or air temperature T_a) and heat transfer coefficient h_c are fairly constant. As a result of this, heat conduction is cyclic for a small depth into the cylinder wall on the combustion chamber side. Temperatures are in degrees C.

T_g = gas temperature in the combustion chamber
T_c = coolant temperature
h_g = convection heat transfer coefficient on the gas side
h_c = convection heat transfer coefficient on the coolant side
Δx = thickness of the combustion chamber wall
k = thermal conductivity of the cylinder wall

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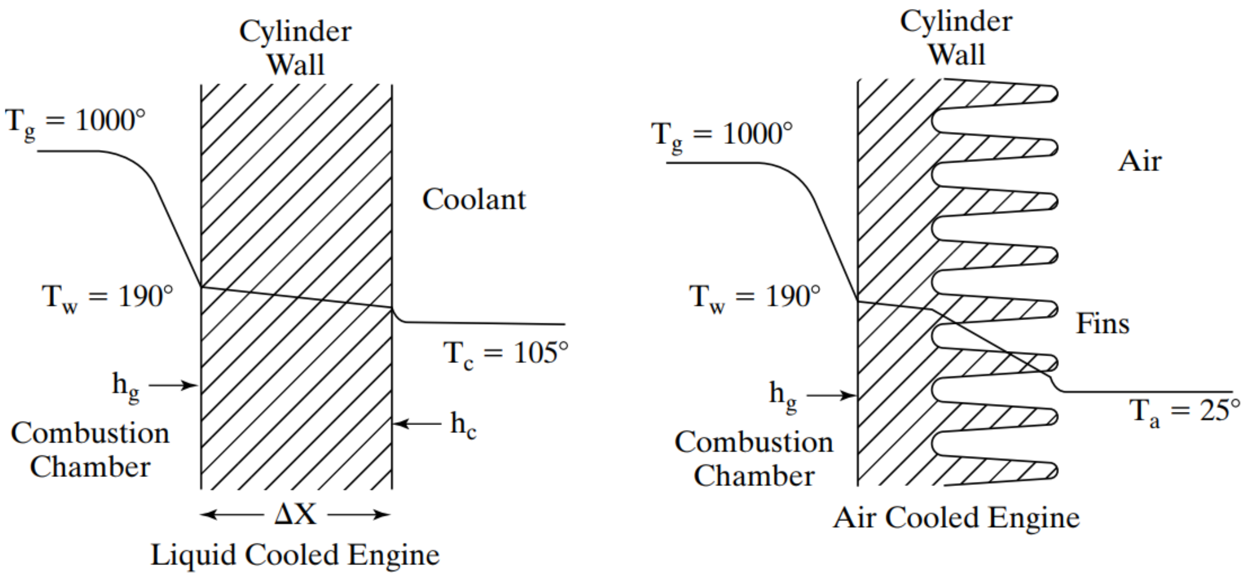

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Figure 7 shows heat transfer through a cylinder wall. Heat transfer per unit surface area will be

$$\dot{q} = \dot{Q}/A = (T_g - T_c)/[(1/h_g) + (\Delta x/k) + (1/h_c)] \qquad (5)$$

T_g = gas temperature in the combustion chamber
T_c = coolant temperature
h_g = convection heat transfer coefficient on the gas side
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k = thermal conductivity of the cylinder wall

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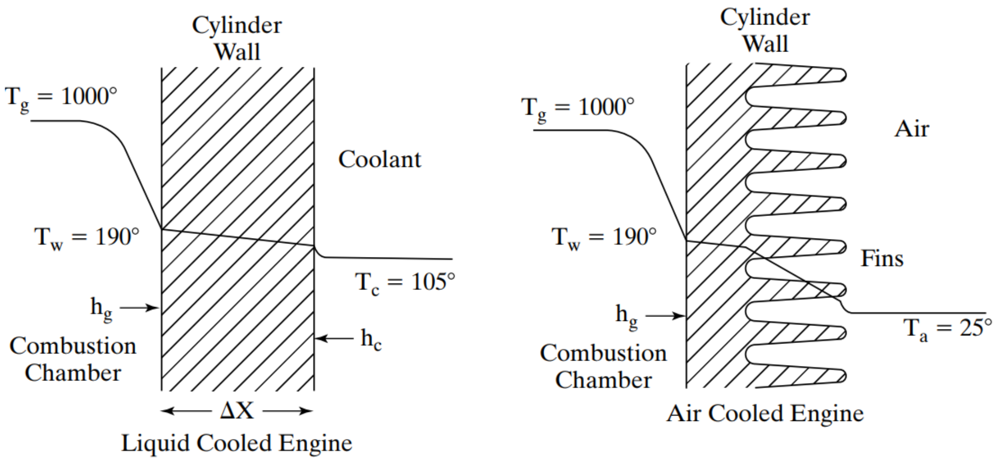

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Radiation heat transfer between cylinder gas and the combustion chamber walls is

$$\dot{q} = \dot{Q}/A = [\sigma(T_g^4 - T_w^4)]/\{[(1 - \epsilon_g)/\epsilon_g] + [1/F_{1-2}] + [(1 - \epsilon_w)/\epsilon_w]\} \qquad (9)$$

where

T_g = gas temperature
T_w = wall temperature
σ = Stefan–Boltzmann constant
ϵ_g = emissivity of gas
ϵ_w = emissivity of wall
F_{1-2} = view factor between gas and wall

END OF THE LECTURE

QUIZ 2

QUIZ 2

As a three-cylinder, 1.5 liter, two-stroke cycle, spark ignition engine runs at 3400 RPM, there are 0.000440 kg of gases trapped in the each cylinder during the cycle. This includes 4.60% exhaust residual from the preceding cycle. At this condition, the engine has a trapping efficiency $\lambda_{te} = 0.760$.

Calculate:

(a) delivery ratio.
(b) charging efficiency.
(c) scavenging efficiency.
(d) relative charge.

$$\lambda_{dr} = m_{mi}/V_d\rho_a$$
$$\lambda_{ce} = m_{mt}/V_d\rho_a$$

$$\lambda_{te} = m_{mt}/m_{mi} = \lambda_{ce}/\lambda_{dr}$$
$$\lambda_{se} = m_{mt}/m_{tc}$$
$$\lambda_{rc} = m_{tc}/V_d\rho_a = \lambda_{ce}/\lambda_{se}$$