Module 4- Thermal Engineering

NOV 20

1 A brick wall 250mm thick is faced with concrete 50mm thick. The wall is 10m long and 5m high. The temperature of the exposed brick face is 300^{0}C and that of concrete is 50^{0}C. Thermal conductivities of brick and concrete is 0.69W/m.^{0}K and 0.93W/m. ^{0}K Determine: (i) Heat loss per hour (ii) Interface temperature.

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2 (a) A brick wall 250 mm thick is faced with concrete 50 mm thick. If the temperature of the exposed brick face is 30°C and that of concrete is 5°C, determine the heat lost per hour, through a wall 10m long and 5m high. Also determine the interface temperature (Given K_{brick} = 0.69 W/m°K, $K_{concrete}$ = 0.93 W/m°K).

3 (b) A single acting air compressor has a cylinder of 200 mm diameter and 300 mm stroke and runs at 150 rpm. Suction pressure and temperature are 1 bar absolute and 15°C respectively. Delivery pressure is 10 bar absolute. Calculate work done per cycle and power required to drive the compressor. Assume the law of compression to be PV^{12} = constant. Neglect clearance volume.

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4 (b) The inside and outside surfaces of a window glass are at 20°C and −5°C respectively. If the glass is 1000mm × 500mm in size and 15 mm thick with thermal conductivity of 0.78W/mK. Determine the heat loss through the glass over a period of 2 hours. 8

5 (b) Find the amount of work required to compress and discharge 1m^3 of air at 15°C and 1 bar to 7 bars absolute. When compression is isothermal. Take R = 0.29kJ/kgK.

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6 (a) A single cylinder, single acting reciprocating air compressor has a cylinder diameter 150 mm and a stroke of 250 mm. Air is drawn in the cylinder at a pressure of 1 bar and a temperature of 15°C. It is then compressed to 6 bar. If the compressor speed is 120 rpm calculate,

(i) mass of air compressed per cycle

(ii) Work required per cycle

(iii) Power required to drive the compressor, if compression is adiabatic

(iv) Volumetric efficiency

Assume γ, = 1.4 and R = 0.290 KJ/KgK 8

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7 (a) A single stage reciprocating compressor is required to compress 1 kg of air from 1 bar to 4 bar. Initial temperature is 27°C. Compare the work requirement on following cases.

(i) Isothermal compression

(ii) Compression with $PV^{1.2}$ = constant

(iii) Isentropic compression (Assume R = 287 KJ/KgK). 8

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8 (b) A single acting single cylinder air compressor is required to compress 1 kg of air from 100 KPa to 400 KPa isothermally. The initial temperature of air is 27°C. Calculate the power required to drive the compressor, if speed of compressor is 100 rpm. Take characteristic gas constant for air as 0.287 KJ/Kgk.

9 X (a) Heat is conducted through a composite plate composed of two parallel plates of different materials A and B of thermal conductivities 134 w/m-k and 60 w/m-k and thickness 36mm and 42mm respectively. The temperature of outer surface of slab A and that of B are 96°C and 8°C respectively. Find the rate of heat transfer and inter face temperature, if the cross sectional area of plate across direction of heat flow is 10 m^2.

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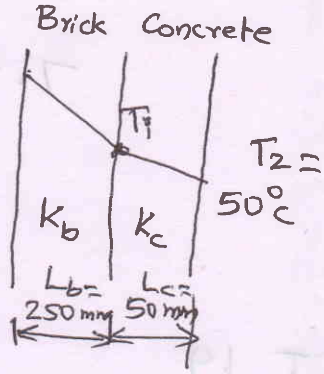
10 (b) A wall is made up of two layers of bricks each 150mm thick with a 40mm air space between them. Coefficients of thermal conductivities are :
(i) inside brick = 0.69W/mK, (ii) Air = 0.0605 W/mK, (iii) Outside brick = 1.038W/mK. The wall is 6.15m long and 5.5m high. Determine the heat loss/hour through the wall, if inside face temperature is 24°C and outside temperature is 7°C. 8

11 (b) A single stage single acting air compressor has a cylinder of 200mm diameter and 300mm stroke and runs at 150 RPM. If the suction pressure and temperature are 1 bar absolute and 15°C respectively and the delivery pressure 10 bar absolute. Calculate the power required to drive the compressor. Assume the law of compression to be $pV^{1.2}$ = constant.

Module 4 – Thermal Engineering

NOV 20

1. Given Data



$L_b = 250\ mm = 0.25\ m$

$L_c = 50\ mm = 0.05\ m$

$k_b = 0.69\ W/mK$

$k_c = 0.93\ W/mK$

$A = 10\ m \times 5\ m = 50\ m^2$

$T_1 = 300°c \qquad T_2 = 50°c.$

$\dot{\phi} = ? \qquad T_i = ?$

$$\phi = \frac{T_1 - T_2}{\frac{L_b}{k_b A} + \frac{L_c}{k_c A}} = \frac{300 - 50}{\frac{0.25}{0.69 \times 50} + \frac{0.05}{0.93 \times 50}}$$

$$= 30042\ W = 30.042\ kW$$

$$= 30.042\ kJ/s = 108151\ kJ/h$$

To get interface temperature

$$\frac{T_1 - T_i}{\frac{L_b}{k_b A}} = \frac{T_i - T_2}{\frac{L_c}{k_c . A}}$$

$$\Rightarrow \frac{300 - T_i}{(0.25/0.69)} = \frac{T_i - 50}{\left(\frac{0.05}{0.93}\right)}$$

$$300 - T_i = 6.7391\,T_i - 336.955$$

$$7.7391\,T_i = 636.955$$

$$T_i = \underline{\underline{82.3^\circ C}}$$

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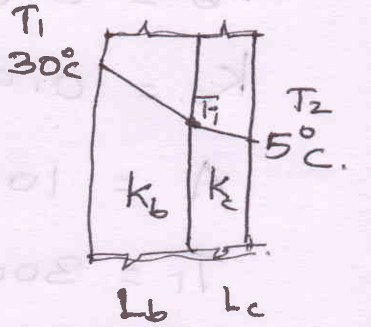
(2) Given Data



$A = 10m \times 5m = 50\ m^2$

$T_1 = 30^\circ c \qquad T_2 = 5^\circ c$

$L_b = 0.25\,m \qquad L_c = 0.05\,m$

$k_b = 0.69\ W/mK \qquad k_c = 0.93\ W/mK$

$$\dot{Q} = \frac{T_1 - T_2}{\frac{L_b}{k_b \cdot A} + \frac{L_c}{k_c \cdot A}} = \frac{30 - 5}{\frac{0.25}{0.69 \times 50} + \frac{0.05}{0.93 \times 50}}$$

$$= 3004\ W = 3.004\ kW$$

$$= 3.004\ kJ/s = \underline{\underline{10814.4\ kJ/h}}$$

To get interface temperature.

$$\frac{T_1 - T_i}{\frac{L_b}{k_b \cdot A}} = \frac{T_i - T_2}{\left(\frac{L_c}{k_c \cdot A}\right)} \Rightarrow \frac{30 - T_i}{\left(\frac{0.25}{0.69}\right)} = \frac{T_i - 5}{\left(\frac{0.05}{0.93}\right)}$$

$$30 - T_i = 6.7391\ T_i - 33.6955$$

$$7.7391\ T_i = 63.6955$$

$$T_i = \frac{63.6955}{7.7391} = \underline{\underline{8.23\ ^\circ C}}$$

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3. Given Data

$D = 200$ mm $\quad L = 300$ mm

$N = 150$ rpm $\quad P_1 = 1$ bar $= 100$ kPa

$T_1 = 15^\circ C \quad P_2 = 10$ bar $= 10^3$ kPa

$W = ? \quad P = ? \quad n = 1.2$

Theoretical Swept Volume of cylonder

$$V_1 = \frac{\pi}{4} D^2 L = \frac{\pi}{4} \times 0.2^2 \times 0.3 = 0.00942\ m^3$$

$$W = \frac{n}{n-1} \cdot P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{1.2}{1.2-1} \times 100 \times 0.00942 \left[\left(\frac{10}{1} \right)^{\frac{1.2-1}{1.2}} - 1 \right]$$

$$= 2.644\ kJ$$

Power required, $P = \frac{W \times N}{60} = \frac{2.644 \times 150}{60}$

$$= \underline{\underline{6.61}}\ kW$$

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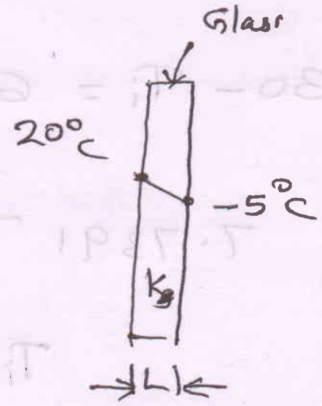
4 Given Data

$k_g = 0.78 \ W/mK$

$L = 15 \ mm = 0.015 \ m$

$A = 1000 \ mm \times 500 \ mm$

$= 1 \ m \times 0.5 \ m = 0.5 \ m^2$



Time $t = 2$ ~~hours~~. $T_1 = 20°C$ $T_2 = -5°C$.

~~Heat~~ transfer rate $\dot{\phi} = \dfrac{T_1 - T_2}{\dfrac{L}{kA}}$

$$= \frac{20 - (-5)}{\dfrac{0.015}{(0.78 \times 0.5)}} = \frac{25}{\left(\dfrac{0.015}{0.78 \times 0.5}\right)}$$

$= 650 \ W = 0.65 \ kW = 0.65 \ kJ/s.$

∴ Heat loss in 2 hrs.

$Q = \dot{\phi} \times t = 0.65 \ kJ/s \times 2 \ hrs.$

$= 0.65 \times 2 \times 3600 = \underline{\underline{4680 \ kJ}}$

5 Given Data $P_1 = 1 \ bar$ $V_1 = 1 m^3$

$T_1 = 15°C$ $P_2 = 7 \ bar$

$W = P_1 V_1 \ln\left(\dfrac{P_2}{P_1}\right) = 100 \times 1 \times \ln\left(\dfrac{7}{1}\right)$

$= \underline{\underline{194.59 \ kJ}}$

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6 Given Data $d = 150\ mm = 0.15 m$ $L = 0.25 m$

$P_1 = 1$ bar $T_1 = 15^\circ c$ $P_2 = 6$ bar

$N = 120$ rpm. $\gamma = 1.4$ $R = 0.29\ kJ/kg\cdot k$

$m = ?$ $W = ?$ $P = ?$ $\eta_V = ?$

Swept Volume, $V_s = \frac{\pi}{4} d^2 L$

$= \frac{\pi}{4} \times 0.15^2 \times 0.25$

$= \cancel{0.00}\ 4.418 \times 10^{-3}$

(i) mass of air $m = \frac{P_1 V_1}{R T_1}$

$= \frac{1 \times 10^5 \times 4.418 \times 10^{-3}}{290 \times (15 + 273)}$

$= 5.29 \times 10^{-3}$ kg.

(ii) Work required $W = \frac{\gamma}{\gamma - 1} \times m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$

$= \frac{1.4}{1.4 - 1} \times 5.29 \times 10^{-3} \times 290 \times 288 \left[\left(\frac{6}{1} \right)^{\frac{1.4 - 1}{1.4}} - 1 \right]$

$= 1033.8\ J/cycle.$

$= 1.0338\ kJ/cycle$

(iii) Power required $P = \frac{W \times N}{60}$

$$= \frac{1.0338 \times 120}{60} = 2.068 \text{ kW}$$

(ii) Volumetric efficiency.

Since Free air conditions are not given it is assumed that $P_a = 1.01325 \times 10^5$ N/m² and $T_a = 15°C$.

$$\therefore \frac{P_a V_a}{T_a} = \frac{P_1 V_1}{T_1}$$

$$\therefore V_a = V_1 \times \frac{P_1}{P_a} \times \frac{T_a}{T_1}$$

$$= 4.418 \times 10^{-3} \times \frac{1 \times 10^5}{1.01325 \times 10^5} \times \frac{288}{288}$$

$$= 4.36 \times 10^{-3} \text{ m}^3$$

$$\eta_v = \frac{V_a}{V_s} = \frac{4.36 \times 10^{-3} \text{ m}^3}{4.418 \times 10^{-3}} = 98.69\%$$

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7 Given Data $m = 1$ kg $P_1 = 1$ bar $= 100$ kPa

$P_2 = 4$ bar $= 400$ kPa $T_1 = 27°C = 300$ K

$R = 287$ J/kg.K $n = 1.2$

(i) isothermal Compression

$$W_{Isothermal} = P_1 V_1 \ln \frac{P_2}{P_1} = mRT_1 \ln \frac{P_2}{P_1}$$

$$= 1 \times 287 \times 300 \times \ln \frac{4}{1}$$

$$= 119360 \text{ J} = \underline{\underline{119.36}} \text{ kJ}$$

(ii) Compression with $PV^{1.2} = \text{Constant}$.

$$W_{polytropic} = \frac{n}{n-1} \times mRT_1 \times \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{1.2}{1.2-1} \times 1 \times 287 \times 300 \left[\left(\frac{4}{1}\right)^{\frac{1.2-1}{1.2}} - 1 \right]$$

$$= 134275 \text{ J} = \underline{\underline{134.28}} \text{ kJ}$$

(iii) Isentropic compression.

$$W_{isentropic} = \frac{\gamma}{\gamma-1} \times mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$= \frac{1.4}{1.4-1} \times 1 \times 287 \times 300 \left[\left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}} - 1 \right]$$

$$= 146454 \text{ J} = 146.45 \text{ kJ}$$

$$\therefore W_{isothermal} < W_{polytropic} < W_{isentropic}$$

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8 Given Data $m = 1 kg$ $P_1 = 100 kPa$

$P_2 = 400 kPa$ ~~$T_1 = T_2$~~ $T =$ Constant.

$T_1 = 27°C$ $N = 100$ rpm.

$R = 0.287$ kJ/kg.K.

$$W = mRT_1 \ln \frac{P_2}{P_1}$$

$$= 1 \times 0.287 \times (27+273) \ln \left(\frac{400}{100}\right)$$

$$= 119.36 \text{ kJ}$$

Power required $P = \frac{W \times N}{60}$

$$= \frac{119.36 \times 100}{60}$$

$$= 198.93 \text{ kW}$$

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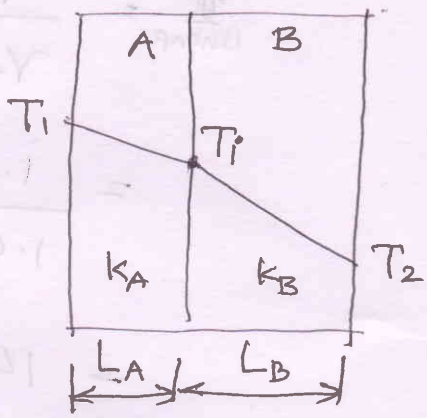
9 Given Data



$A = 10 m^2$

$T_1 = 96°C$

$T_2 = 8°C$

$k_A = 134$ W/mK

$k_B = 60$ W/mK

$L_A = 36$ mm $= 0.036$ m

$L_B = 42$ mm $= 0.042$ m.

Rate of heat transfer

$$\Phi = \frac{T_1 - T_2}{\frac{L_A}{k_A \cdot A} + \frac{L_B}{k_B \cdot A}} = \frac{96 - 8}{\frac{0.036}{134 \times 10} + \frac{0.042}{60 \times 10}}$$

$$= 908475 \text{ W} = \underline{\underline{908.48 \text{ kW}}}.$$

$$= 908.48 \text{ kJ/s}$$

To get interface temperature

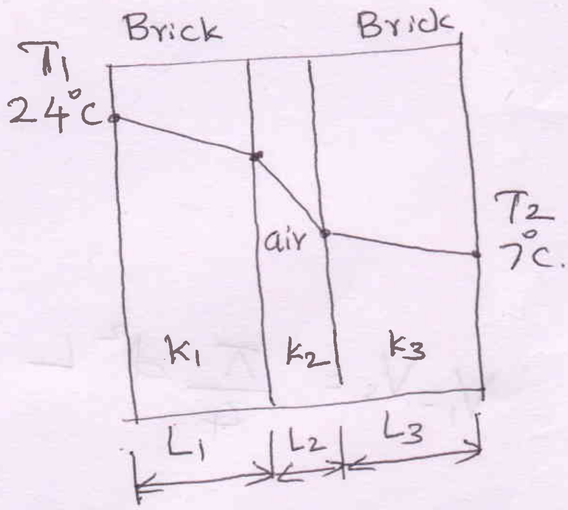
$$\Phi = k_A \cdot A \frac{(T_1 - T_i)}{L_A}$$

$$908475 = 134 \times 10 \times \frac{(96 - T_i)}{0.036}$$

$$T_i = \underline{\underline{71.59}} \ ^\circ C$$

APR 17

10 Given Data



$T_1 = 24^\circ C$ $\quad T_2 = 7^\circ C.$

$k_1 = 0.69$ W/mK

$k_2 = 0.0605$ W/mK

$k_3 = 1.038$ W/mK

$A = 6.15 \text{ m} \times 5.5 \text{ m}$

$L_1 = L_3 = 0.15 \text{ m}, \ L_2 = 0.04 \text{ m}$

$$\dot{Q} = \frac{T_1 - T_2}{\frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{L_3}{k_3 A}} = \frac{T_1 - T_2}{\frac{1}{A}\left[\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3}\right]}$$

$$= \frac{24 - 7}{\frac{1}{6.15 \times 5.5}\left[\frac{0.15}{0.69} + \frac{0.04}{0.0605} + \frac{0.15}{1.038}\right]}$$

$$= 562.07 \; J/s.$$

$$= 562.07 \times \frac{3600}{1000} \; kJ/hr$$

$$= \underline{2023.45 \; kJ/h}$$

APR 17

11 Given Data $d = 200\,mm = 0.2\,m$

$L = 300\,mm = 0.3\,m$

$N = 150\,rpm$

$P_1 = 1\,bar \quad T_1 = 15°C$

$P_2 = 10\,bar$

$n = 1.2$

$$V_1 = V_s = \frac{\pi}{4} d^2 L = \frac{\pi}{4} \times 0.2^2 \times 0.3 = \underline{9.425 \times 10^{-3}\,m^3}$$

$$W = \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W = \frac{1.2}{1.2-1} \times 100 \times 9.425 \times 10^{-3} \left[\left(\frac{10}{1}\right)^{\frac{1.2-1}{1.2}} - 1 \right]$$

$$= 2.645 \ \cancel{kW} \ kJ/cycle$$

Power required $P = \dfrac{W \times N}{60}$

$$= \frac{2.645 \times 150}{60}$$

$$= \underline{\underline{6.61 \ kW}}$$