

1. A counter current single shell and tube heat exchanger is used to cool engine oil with water in a laboratory test rig. The water flow rate is 7 litres per minute, and the engine oil flow rate is 1 litre per minute. The c_p of the oil is 2,100 J/kgK, and the density is 810 kg/m³.
 - (a) What are the capacity rates of the oil and water streams? [2]
 - (b) Given that the oil enters at 125°C and is required to leave at 60°C, and that the water enters at 12°C, what is the exit temperature of the water? [2]
 - (c) What is the LMTD for this exchanger? [4]
 - (d) Given that the overall heat transfer coefficient is 900 W/m²K, what surface area is required in order for the exchanger to fulfil the requirement? [5]

2. A pipe in a central heating circuit contains water at 70°C flowing at 5 litres per minute. The internal diameter is 10 mm and the external diameter is 12 mm. Given the thermal resistance on the outside of the tube is 4.423 K/W per m, and the external air temperature is 15°C.
 - (a) What is the bulk velocity of the water? [2]
 - (b) What is the Reynolds number? [2]
 - (c) Using the correlation $Nu = 0.023Re^{0.8}Pr^{0.4}$, what is Nu? [4]
 - (d) If the wall thermal resistance by conduction is negligible, what is the heat transfer to the air? [5]

3. A UK based power station burns coal with an ultimate analysis of 72% carbon, 14% hydrogen, 9% ash, and 5% oxygen. The burner brings in air with 5% excess above stoichiometric combustion to maintain clean combustion. The combustion of coal is complete, and the gas stream leaves the boiler at 150°C. The plant engineers require the following information:
 - (a) The air to fuel ratio by mass [4]
 - (b) Mass fraction of the exhaust gas stream [5]
 - (c) Apparent specific heat capacity at constant pressure of the dry gas mixture at 300K [4]

Answers:

1: oil 28.3 W/K, water 490 W/K, 15.8°C, 74.6°C, 0.028 m²

2: 1.06 m/s, 26500, 115, 12.4 W per m length of pipe.

3: 13.47, 0.201/0.011/0.787, 0.998 kJ/kgK

1a) $\dot{C} = \dot{m} c_p$ water: from tables $\rho = \frac{1}{v} = \frac{1}{0.0010012} = 998 \text{ kg/m}^3$
at 20°C?

$c_p = 4.18 \text{ kJ/kgK}$

$\dot{M} = \frac{0.007 \times 998}{60} = 0.116 \text{ kg/s}$ $\dot{C} = 0.116 \times 4.18 = 0.486 \text{ kW/K}$

oil $\dot{M} = \frac{0.001 \times 800}{60} = 0.0135 \text{ kg/s}$

$\dot{C} = 0.0135 \times 2.1 = 0.028 \text{ kW/K}$

b) $\dot{C}_o \Delta T_o = \dot{C}_w \Delta T_w \rightarrow 0.028 \times (125 - 60) = 0.486 \times (T_{w2} - 12)$
 $T_{w2} = 15.8^\circ\text{C}$

c) LMTD = $\frac{\Delta T_{END1} - \Delta T_{END2}}{\ln \frac{\Delta T_{END1}}{\Delta T_{END2}}} = \frac{(125 - 15.8) - (60 - 12)}{\ln \frac{(125 - 15.8)}{(60 - 12)}} = \frac{61.2}{0.82} = 74.6^\circ\text{C}$

It's a ΔT in K or $^\circ\text{C}$ is same - relative not absolute

d) $\dot{Q} = UA \Delta T_M$ correction factor assumed = 1

$\dot{C}_o \Delta T_o = UA \Delta T_M \rightarrow 0.028 (125 - 60) \times 10^3 (\text{W}) = 900 \times A \times 74$
 $\rightarrow A = 0.028 \text{ m}^2$

2a) use $(\dot{V}) = (\text{vel}) \times \text{Area}_{\text{cross section}}$ $\text{vel} = \frac{(0.005)}{60} / \pi \times 0.005^2 = 1.06 \text{ m/s}$

b) $Re = \frac{\rho u d}{\mu}$ take values for water at 70°C $\rho = \frac{1}{v} = \frac{1}{0.00073} = 978 \text{ kg/m}^3$
 $\mu = 400 \times 10^{-6} \text{ kg/ms}$
 $= \frac{978 \times 1.06 \times 0.01}{400 \times 10^{-6}} = 25917$

c) Take Pr at 70°C $Pr = 2.53$

$Nu = 0.023 (25917)^{0.8} (2.53)^{0.4} = 113$

d) Find the R_{th} for inside = $\frac{1}{hA} = \frac{1}{Nu} \times \frac{d}{k}$

Take k at 70°C $k_f = 0.662 \text{ W/mK}$

$h = \frac{113 \times 0.662}{0.01} = 7493 \text{ W/m}^2\text{K}$

Since no pipe length is specified, assume it is for 1m as done for the outer surface in the question.

$$\therefore R_{TH, INNER} = \frac{1}{7498 \times \pi \times 0.01 \times 1} = 4.25 \times 10^{-3} \text{ K/Wm.}$$

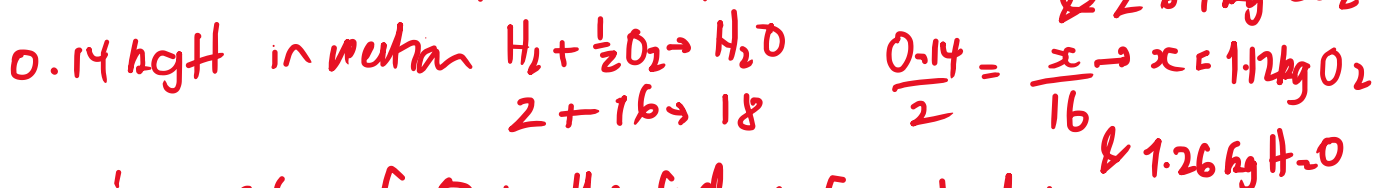
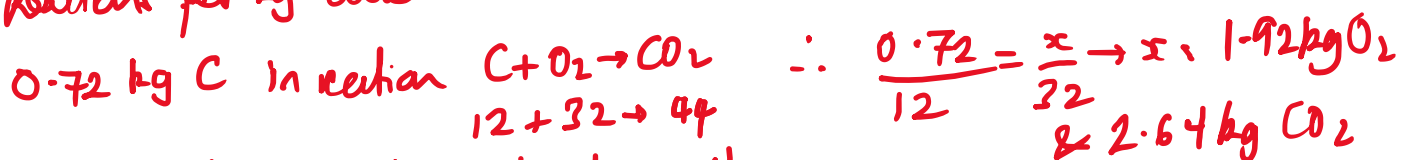
So total R_{TH} when pipe wall conduction has no R_{TH} is:

$$\sum R_{TH} = 4.25 \times 10^{-3} + 4.423 = 4.427 \text{ K/W (little resistance on inner surface)}$$

\therefore Heat transfer is

$$\dot{Q} = UA\Delta T \text{ or } \frac{\Delta T}{\sum R_{TH}} = \frac{(70-15)}{4.427} = 12.42 \text{ W/m. } \checkmark$$

3a) Products per kg coal



There is 0.05 kg of O in the fuel, so for stoichiometric O_2 need is $1.92 + 1.12 - 0.05 = 2.99 \text{ kg } O_2$

But there is 5% excess, so $2.99 \times 1.05 = 3.14 \text{ kg}$

Air to fuel ratio is $\frac{(3.14 \times 4.29)}{1} = 13.47$

using the 3.29 ratio of $\frac{N_2}{O_2}$ by mass (Grawi)

plus the 1.0 for the O_2 in the air

b) Exhaust DRY gas stream is

	m_i	m_i/m
CO ₂	2.64	0.201
N ₂	10.33	0.787
O ₂	0.15	0.011
	<u>13.12</u>	

WET case

CO ₂	2.64	0.184
H ₂ O	1.26	0.088
N ₂	10.33	0.718
O ₂	<u>0.15</u>	0.010
	14.38	