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/m^3.

   (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/m^{2}K, 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 analysisof 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 m^2

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 at 20°C? $\rho = \frac{1}{v_f} = \frac{1}{0.0010018} = 998 \, kg/m^3$

$c_p = 4.18 \, kJ/kg K$.

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

oil $\dot{m} = \frac{0.001}{60} \times 810 = 0.0135 \, kg/s$

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

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

$T_{w2} = 15.8°C$

c) LMTD COUNTER FLOW $= \frac{\Delta T_{END\,1} - \Delta T_{END\,2}}{\ln \frac{\Delta T_{END\,1}}{\Delta T_{END\,2}}} = \frac{(125-15.8)-(60-12)}{\ln \frac{(125-15.8)}{(60-12)}} = \frac{61.2}{0.82} = 74°C$

It's a ΔT so K or °C is same - relative not absolute

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

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

$\rightarrow A = 0.028 \, m^2$.

2a) use $(\dot{Vol}) = (vel)$ Area cross section $vel = \left(\frac{0.005}{60}\right) / \pi \times 0.005^2 = 1.06 \, m/s$

b) $Re = \frac{\rho u d}{\mu}$ take values for water at 70°C $\rho = \frac{1}{v_f} = \frac{1}{0.001023} = 978 \, kg/m^3$

$\mu = 400 \times 10^{-6} \, kg/ms$

$= \frac{978 \times 1.06 \times 0.01}{400 \times 10^{-6}} = 25917$

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 $= \frac{1}{hA}$ & $Nu = \frac{hd}{k}$

Take K at 70°C $k_f = 0.662 \, W/mK$ $h = \frac{113 \times 0.662}{0.01} = 7493 \, W/m^2K$

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

$\therefore \quad R_{TH,INNER} = \frac{1}{7493 \times \pi \times 0.01 \times 1} = 4.25 \times 10^{-3}$ K/W m.

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

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

3a) Reactions per kg coal

0.72 kg C in reaction $C + O_2 \rightarrow CO_2$ $\quad 12 + 32 \rightarrow 44$ $\quad \therefore \frac{0.72}{12} = \frac{x}{32} \rightarrow x = 1.92 \text{ kg } O_2$ & 2.64 kg CO_2

0.14 kg H in reaction $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ $\quad 2 + 16 \rightarrow 18$ $\quad \frac{0.14}{2} = \frac{x}{16} \rightarrow x = 1.12 \text{ kg } O_2$ & 1.26 kg H_2O

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

But there is 5% excess, so $2.99 \times 1.05 = 3.14$ 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 (Given)

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
	13.12	

WET case

CO_2	2.64	0.184
H_2O	1.26	0.088
N_2	10.33	0.718
O_2	0.15	0.010
	14.38	