Section A

All questions worth 3 marks each in section A

1. This is determined by the reaction constant, K, from the tables. When $K \leq 0.001$, we expect that the products are < 0.1 % of the gas mix in the reaction $\frac{1}{2}N_2 + \frac{1}{2}O_2 \rightarrow NO$

ie. $\ln 0.001 = -6.9$.

In tables, this is T = 1200 → 1400K range.

2. $\Delta\tilde{h}_{fo}\ H_2O_{VAP} = -241830$ kJ/kmol.

$\Delta\tilde{h}_{fo}\ H_2O_{liq} = -285820$ kJ/kmol

The difference is : $-285820 - {}^{-}241830 = -43990$ kJ/kmol.

This is at 1bar and 298.15 K.

At this T, $\Delta h_{fg}\ H_2O = 2441.8$ kJ/kg

∴ for 1 kmol $18 \times 2441.8 = \underline{43952}$ kJ/kmol.

∴ This is the difference accounted for.

3 NSFEE from formula sheet :

$$\dot{Q} + \dot{W} + p\frac{dV}{dt} = \sum \dot{m}_o\left(h_o + \frac{c_o^2}{2} + gz_o\right) - \sum \dot{m}_i\left(h_i + \frac{c_i^2}{2} + gz_i\right) + \frac{d}{dt}m_{cv}\left(u_{cv} + \frac{c_{cv}^2}{2} + gz_{cv}\right)$$

$\dot{Q} = 0$ (insulated)

$p\frac{dV}{dt} = 0$ (rigid)

$\dot{m}_i = 0$ (flow only out)

$c^2/2$ term 0 (negligible)

gz term 0 (negligible).

$$\dot{W} = \sum \dot{m}_o h_o + \frac{dm_{cv}}{dt} \cdot u_{cv}$$

4. Two benefits of de-aerator:
   i) it acts as an open feed heater, raising feed water temp prior to boiler ∴ raising η_{TH}.
   ii) it does what its name says - removes air and other non-condensable gases which migrate into the LP condenser.

5. Approach temperature is the temperature difference ~~in temperature~~ between the super-heated steam on the vapour power cycle and the incoming hot gases impinging on the SH. heat exchanger.
   Pinch point is the difference in temperature between the saturated water in the economiser, and the hot gases passing the economiser heat exchanger at that point.

6. Irreversibility = Exergy ~~out~~ in - Exergy ~~in~~ out
   Exergy in is the work in the turbine
   Exergy out is the actual generator output power.
   i.e. $(h_{in} - h_{out})$ is Exergy out
   $= (3200 - 2300)\ kJ/kg = 900\ kJ/kg$.
   Power out is $900 \times 0.95 = 855$
   $\therefore \dot{I} = 45\ kJ/kg$.

7. Oxy-fuel is a combustion method to reduce CO_2 release. Oxygen is generated by refrigeration process on site and is burnt with the fuel in a stream of CO_2 from exhaust to reduce flame temperature. Exhaust has H_2O and CO_2 ∴ CO_2 can be captured.

8. ^{238}U is the only radioactive isotope with a half life sufficient that it has not decayed completely since ~~the~~ when it was formed at the beginning of the universe. It contains ^{235}U in the deposits which is fissile - i.e. ~~emits neutrons spontaneously and~~ has a fission cross section of significant magnitude to initiate fission.

9. BWR is controlled on high power by moderation with water flow - more water promotes higher power; and it is controlled by control rods on lower power which can be inserted from above absorbing thermal neutrons and arresting fission.

10. 0.4MeV convert to J then to V

$1\,eV = 1.602\,176\,46 \times 10^{-19}\,J$

$\therefore 0.4 \times 10^{6}\,eV = 6.4 \times 10^{-14}\,J$

$m_n = 1.674\,927\,28 \times 10^{-27}\,kg$

$\therefore \frac{1}{2} m_n V^2 = 6.4 \times 10^{-14}$

$\Rightarrow V = 8.748 \times 10^{6}\,m/s.$

11. a) The stoichiometric equation for this is:

$$H_2 + CO_2 \rightarrow H_2O + CO$$

Dissociation produces:

$$H_2 + CO_2 \rightarrow \alpha H_2 + \alpha CO_2 + (1-\alpha)H_2O + (1-\alpha)CO$$

Using the formula:

$$K^{\Theta} = \frac{(x_c)^c (x_d)^d}{(x_a)^a (x_b)^b}\left(\frac{p_{total}}{p^{\Theta}}\right)^{c+d-a-b}$$

$$K^{\Theta} = \frac{(x_{H2O})^c (x_{CO})^d}{(x_{CO2})^a (x_{H2})^b}\left(\frac{p_{total}}{p^{\Theta}}\right)^{c+d-a-b}$$

With the appropriate values from the formula, and remembering to clearly show what happens to the pressure term, by substituting the values of x according to the molar quantities and the values of a-d from the stoichiometric equation molar quantities:

$$K^{\Theta} = \frac{(1-\alpha)^1 (1-\alpha)^1}{(\alpha)^1 (\alpha)^1}\left(\frac{p_{total}}{p^{\Theta}}\right)^{1+1-1-1} = \frac{1-2\alpha+\alpha^2}{\alpha^2}$$

Clearly showing that the pressure term drops out because of the stoichiometric balance in this case.

b) At one bar, and any pressure, the reaction equilibrium constant is:

$$K^{\Theta} = \frac{1-2\alpha+\alpha^2}{\alpha^2}$$

Therefore, for α=0.5:

$$K^{\Theta} = \frac{1-1+0.25}{0.25} = 1$$

[5]

The values presented in the tables are ln K, which is:

$$\ln K^{\Theta} = \ln 1 = 0$$

[2]

This value occurs in the tables on p.21 between the temperatures of 1000 and 1200 K therefore interpolate:

$$\frac{T-1000}{1200-1000} = \frac{0-(-0.366)}{0.311-(-0.366)}$$

Therefore temperature is 1108 K. [5]

Due to the pressure term being cancelled by the balance of the stoichiometric equation, this will also be the temperature at which the dissociation is 50% at 20 bar. [3]

c) Using Hess's Law:

$$H_2 + CO_2 \rightarrow \alpha H_2 + \alpha CO_2 + (1-\alpha)H_2O + (1-\alpha)CO$$

The enthalpy of formation for each constituent are:

$$0 - 393520 \rightarrow 0.5 \times 0 + 0.5 \times -393520 + 0.5 \times -241830 + 0.5 \times -110530$$

[6]

Difference between left and right side of equation is -372940-(-393520)=+20,580 kJ/kmol [3], i.e. a slightly endothermic result [1].

12 a) Compressor exit temperature: 10 marks available

Use $\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n\eta_{oc}}}$ $T_2 = 300 \times (10.5)^{\frac{0.4}{1.4\times0.9}} = 632\,K$. [4]

Temperature at entry to turbine

[2] formula

Use $T_{af} = T_0 - \frac{m_f . \Delta h_0}{\sum m_i c_{pi}}$ & $\sum m_i c_{pi} = m.\bar{c}_p$

per kmol CH_4 = $632 - \frac{802310}{454 \times 1.319} = 1972\,K$ [5]

∴ Assumption is valid. [1]

[1] each value in formula

b) Cycle η 15 marks available

Use $\eta_{cycle} = \frac{\dot{W}_T - \dot{W}_C}{\dot{Q}} = \frac{\dot{m}_T(T_3 - T_4) - \dot{m}_C(T_2 - T_1)}{\dot{m}_T(T_3 - T_2)}$ [1]

with negligible $\dot{m}_f$, $\dot{M}_T = \dot{M}_C$ [1]

Using c_p on each valid

Turbine exhaust Temp:

Use $\frac{T_4}{T_3} = \left(\frac{p_4}{p_3}\right)^{\frac{0.4\times0.9}{1.4}}$ → $T_4 = 1972\left(\frac{1.01325+0.02}{10.5-0.5}\right)^{0.257}$ [6]

$= 1100\,K$

[1] w_T [1] w_C [1] result

∴ $\eta_{cycle} = \frac{(1972-1100)-(632-300)}{1972-632} = \frac{872-332}{1340} =$ 0.46 [3]

[2] formula [1] Q

Specific work out put:

Use $W_T - W_C$ for 1 kg of air: $872 - 332 = 540$ kJ/kg. [2]

c) Equation for combustion: 10 marks available

$CH_4 + 3.2O_2 + 3.76\times3.2N_2 \rightarrow CO_2 + 2H_2O + 1.2O_2 + 3.76\times3.2N_2$

∴ AFR = $\frac{3.2\times32 + 3.76\times3.2\times28}{16} = \frac{102+337}{16} = 27.4$. [6]

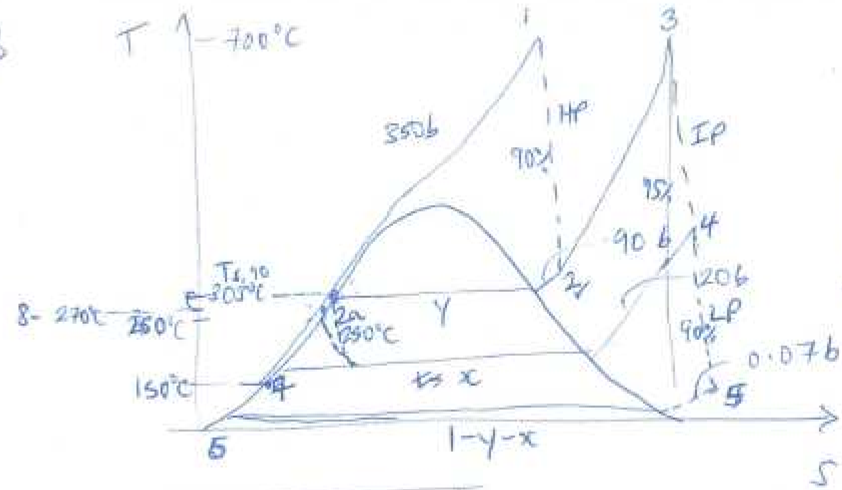
∴ $\dot{m}_f = \frac{\dot{M}_a}{27.4} = \frac{9}{27.4} = 0.329$ kg/s. [2]

Alternative longer method of FAR valid

Since this is only $\frac{0.329}{27.4+0.329} = 0.012$ or 1.2 % of mass, it is a reasonable assumption to neglect it in part b) [2]

13

Part a) 18 marks available



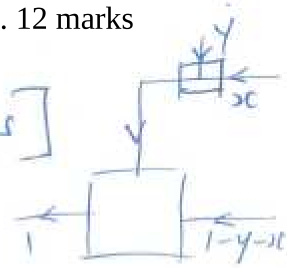
$s_0 = 0.224$ kJ/kg K
$h_0 = 62.9$ kJ/kg
$T_0 = 288$ K.

Point	h kJ/kg	s kJ/kg K	ε	Ė per kg/s boiler feed.	
1	3709	6.459	1850	1850	0.734 / 3238
2'	3238	6.459			
2	3285	6.523	1407	1407	0.285
3	3874	7.220	1796	1350	0.599
4'	3313	7.220			
4	3341	7.250	1255	943	0.853
5'	2240	7.250			
5	2351	7.57	172	116	
2a	1087	2.797			
7	640	1.860			
6	163	0.559	3.6	2.4	
8	1185	2.976			

[1 MARK EACH h&s]

i.e. 12 marks

Open feed heater:

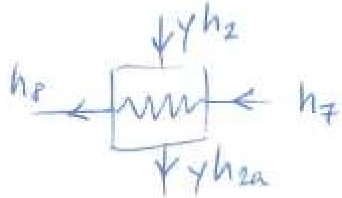


[2] $\dot{m}\,y\cdot h_{2a} + \dot{m}\,x\,h_4 + \dot{m}(1-y-x)h_6 = \dot{m}\,h_7$

$y\cdot 1087 + x\,3341 + (1-y-x)163 = 640$

+1 formula

Closed feed heater:



[2] $y(h_2 - h_{2a}) = h_8 - h_7$

$y(3285 - 1087) = 1185 - 640$

$y = 0.248$

& from previous equation:

$0.248 \times 1087 + 3341x + (1 - 0.248 - x)163 = 640$

$(3341 - 163)x = 640 - 270 - 123$

[1] $\rightarrow x = \frac{247}{3178} = 0.078.$

Part b) 17 marks available

c) Exergy into a turbine is the steam exergy change

[3] ∴ For HP (1850 − 1407) = 443 kJ/kg of boiler feed

[3] For IP (1350 − 943) = 407 kJ/kg of boiler feed

[3] For LP (943 − 116) = 827 kJ/kg of boiler feed.

Exergy destroyed in the condenser is the change from steam to water:

[2] (116 − 2.4) = 114 kJ/kg of boiler feed

The energy lost in the condenser is Δh

(2351 − 163) × (1 − 0.248 − 0.078)

[3] = 1475 kJ/kg of boiler feed.

Energy loss >> Exergy lost illustrating low quality of the energy.

[3]

Marked out of 11 in section a)

14 (a) $C + O_2 \rightarrow CO_2$

Energy per kmol from tables of combustion enthalpy: -393520 kJ/kmol

$\therefore$ Energy per mol of C is -393520 J/mol.

In 1 mol there is N_A C atoms.

$N_A = 6.022 \times 10^{23}$

$\therefore$ Energy per atom:

$\frac{-393520}{6.022 \times 10^{23}} = 6.535 \times 10^{-19}$ J/atom. [6]

eV per J $1.602\,176\,46 \times 10^{-19}$ J

$\therefore$ per atom

$\frac{6.535}{1.60217646} = \underline{4.07 \text{ eV}}.$

Energy of a thermal neutron is $\underline{0.025 \text{ eV}}$. [5]

Marked out of 11 in section b)

b) $\lambda = \frac{h}{p} = \frac{hc}{\sqrt{T^2 + 2TM_0c^2}}$

T is k.e. $= (0.025 \times 1.602 \times 10^{-19}) = 4 \times 10^{-21}$ J.

$M_n = 1.674\,927\,28 \times 10^{-27}$ kg

$C = 2.997\,924\,58 \times 10^8$ m/s

$$\therefore \lambda = \frac{6.626 \times 10^{-34} \times 2.997 \times 10^8}{\sqrt{(4 \times 10^{-21})^2 + 2 \times 4 \times 10^{-21} \times 1.675 \times 10^{-27} \times (2.998 \times 10^8)^2}}$$

$$= \frac{1.986 \times 10^{-25}}{\sqrt{1.6 \times 10^{-41} + 1.204 \times 10^{-30}}} = \frac{1.986 \times 10^{-25}}{1.097 \times 10^{-15}}$$

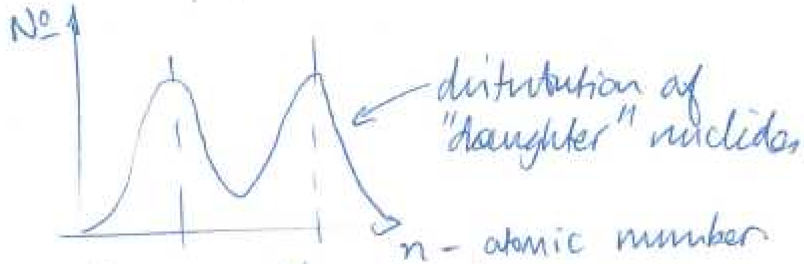
[7]

$= 1.810 \times 10^{-10}$ m.

This is of the order of cross section of a fission cross section & $\therefore$ likely to interact. [4]

Marked out of 13 in section c)

9) A fission reaction may produce a number of alternative nuclide pairs in a binary split. On ~~average~~ ensemble these produce a population distribution like this:



[5]

[2] There are mostly promptly released neutrons. released ~~very~~ nearly instantaneously. But some of the neutron population is produced by decay

[3] of some daughter nuclides, which occur some time after fission. The full population of neutrons is dependent on these delayed neutrons to make up

[3] a full count for critical condition, and the delay is the source of control of the fission rate.