National Exams May 2014

04-Chem-A1 Process Balances and Chemical Thermodynamics

<u>Three Hour Duration</u>

<u>NOTES:</u>

1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.

3) This is an open-book exam.

4) Any non-communicating calculator is permitted.

5) The examination is in four parts – Part A (Questions 1 and 2), Part B (Questions 3 and 4), Part C (Questions 5 and 6), and Part D (Questions 7 and 8). Answer **ONE** question from Part A, **ONE** question from Part B, **ONE** question from Part C, and **ONE** question from Part D. **FOUR** questions constitute a complete paper.

6) The question chosen from Part A is worth 20%, the question chosen from Part B is worth 30%, the question chosen from Part C is worth 20%, and the question chosen from Part A is worth 30%.

PART A: ANSWER ONE OF QUESTIONS 1-2

Note: Four questions constitute a complete paper
(with one from Part A, one from Part B, one from Part C, and one from Part D)

1) A system combining a solid-oxide fuel cell with a gas turbine has been proven to achieve higher operating efficiencies at high pressures. The exhaust gases from the fuel cell enter a steam turbine as shown in Figure 1. Determine the shaft work done by the turbine.

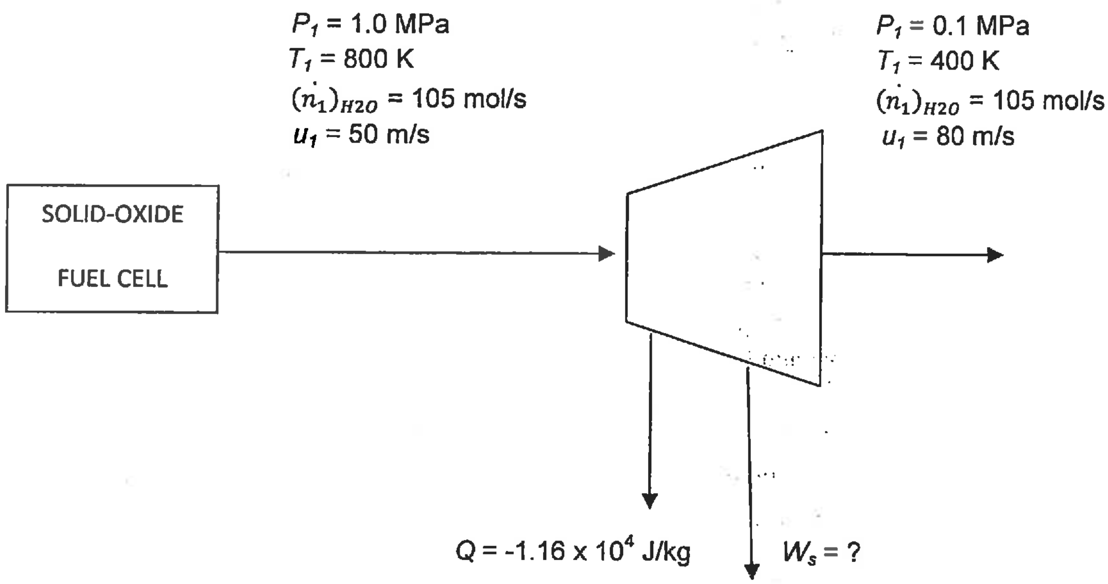

Figure 1

2) Hydrogen can be produced by steam-methane reforming. The feed to this process is heated to a temperature of 450°C, as shown in Figure 2, before it enters the reaction chamber. What is the required flow rate of each gas if the heater consumes 2.5 kW of power in bringing the reaction gases to the operating conditions? The feed to the reaction chamber has a 3:1 molar ratio of steam to methane.

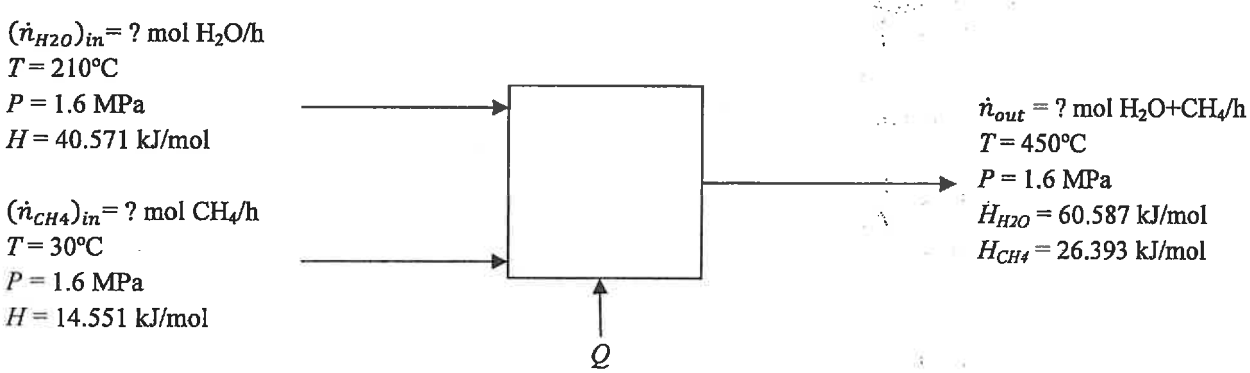

Figure 2

PART B: ANSWER ONE OF QUESTIONS 3-4

Note: Four questions constitute a complete paper
(with one from Part A, one from Part B, one from Part C, and one from Part D)

3) The process flow diagram for a factory producing a protein called casein is shown in Figure 3.

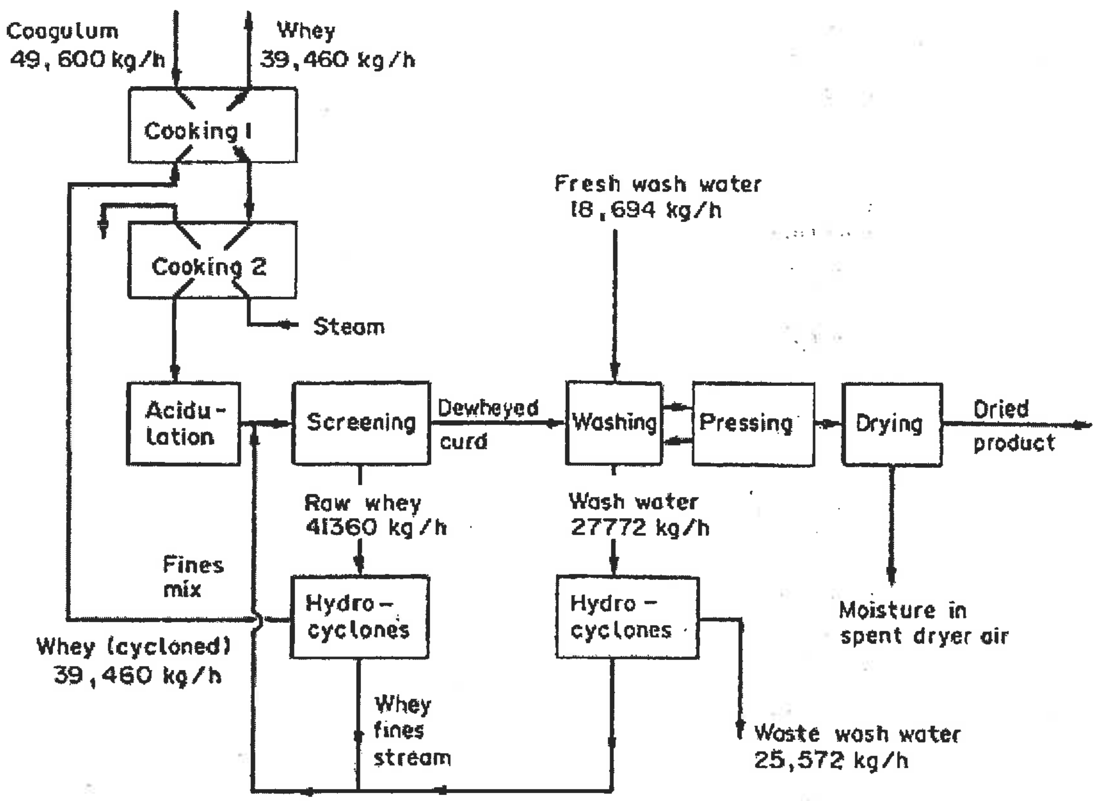

Figure 3

The raw material (coagulum) containing casein and lactose is passed through two cookers and acidified. This precipitates the casein as a solid mass known as a "curd." In this form, the casein is removed from the whey (the leftover water with dissolved sugars such as lactose, as well as some soluble proteins) by screening, and is then washed and dried. The casein fines (very small particles of casein suspended in the raw whey and in the wash water) are removed by hydrocyclones, and recycled to be mixed with the heated coagulum just before screening. The cycloned whey is used for heating in the first cooker and steam in the second cooker by indirect heating. The casein and lactose contents of the various streams were determined, and these values are given in Table 1.

Table 1

	% Composition on Wet Weight Basis		
	Casein	Lactose	Moisture
Coagulum	2.76	3.68	
Raw whey from screening	0.012	4.1	
Whey (cycloned)	0.007		
Wash water	0.026	0.8	
Waste wash water	0.008		
Dried product			11.9

Assume that lactose is completely soluble in all solutions. Also assume that concentrations in the fines streams and wastes streams from the hydrocyclones are the same. Assume that there is little or no casein removed from the whey cyclones.

a) What is the composition of the dewheyed curd leaving the screening process before it enters the washing process?
b) What is the composition of the dried product?

4) Synthesis gas (a mixture of CO and H_2) is produced in a coal gasification process at a pressure of 27 bar and a temperature of 260°C. This syngas stream will be mixed with steam before entering a hydrogen-shift reactor to produce more hydrogen. A diagram of this process is shown in Figure 4. Determine the unknown flow rates $\dot{n}_2$ and $\dot{n}_3$.

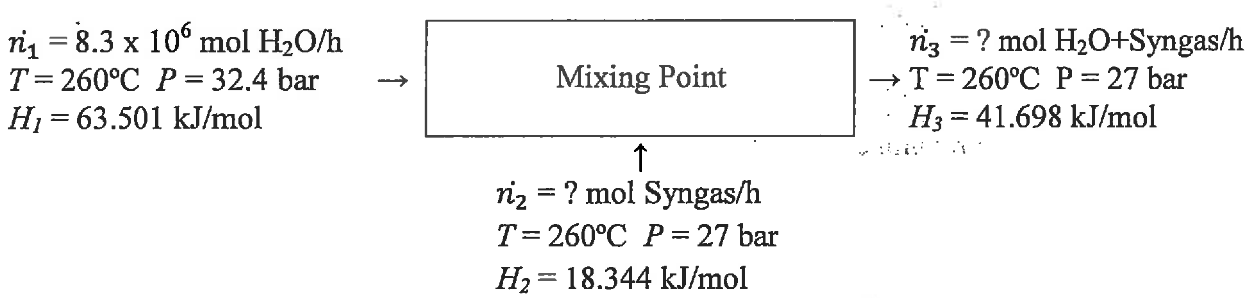

Figure 4

PART C: ANSWER ONE OF QUESTIONS 5-6

Note: Four questions constitute a complete paper
(with one from Part A, one from Part B, one from Part C, and one from Part D)

5) A gas mixture consisting of 70 mol% methane and 30 mol% nitrogen is compressed reversibly and isothermally from 10 bar to 100 bar at 250 K. The flow rate is 0.2 m^3/min.

a) Determine the rate of heat transfer.
b) Determine the power requirement assuming that the gas mixture is an ideal solution.

6) Oxygen that is initially at a pressure of 13.8 MPa and a temperature of 15.5°C is throttled in a steady-flow process to a pressure of 1.38 MPa. If the throttling valve is well-insulated, i.e. the process is adiabatic, what is the final temperature of the oxygen. State all assumptions that you make.

PART D: ANSWER ONE OF QUESTIONS 7-8

Note: Four questions constitute a complete paper
(with one from Part A, one from Part B, one from Part C, and one from Part D)

7) This problem concerns a mixture of benzene (1) and acetonitrile (2).

Antoine equations:

$$\log_{10} P_1^{sat} = 4.01814 - \frac{1203.835}{T-53.226} \qquad \log_{10} P_2^{sat} = 4.27873 - \frac{1355.374}{T-37.853}$$

$$P_1^{sat}, P_2^{sat} = [\text{bar}] \qquad T = [\text{K}]$$

Activity coefficient correlations:

$$ln\gamma_1 = x_2^2 \qquad ln\gamma_2 = x_1^2$$

a) If the liquid composition of the mixture is 20 mole% benzene and 80 mole% acetonitrile, what is its pressure if the bubble point is 20°C? What is the composition of the vapour in equilibrium with the liquid at this temperature?

b) What would be the composition of the liquid and the vapour for a mixture at equilibrium that boils at 45°C under a pressure of 0.32 bar?

c) If the vapour-phase composition is 15 mole% benzene and 85 mole% acetonitrile, calculate the dew point temperature at a pressure of 0.22 bar.

8) The following gas-phase reaction is proposed as a means of producing ethylene in the absence of a petroleum feedstock (the hydrogen can be obtained through the hydrolysis of water):

$$2CO_2 + 6H_2 \leftrightarrow C_2H_4 + 4H_2O$$

a) For $T = 800$ K and $P = 1$ bar, calculate the value of the equilibrium constant K and the % conversion of CO_2.

b) For $T = 800$ K and $P = 100$ bar, calculate the value of the equilibrium constant K and the % conversion of CO_2. Treat the gas mixture as an ideal solution.