



UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: MAY/ JUNE 2025

COURSE AND CODE: MASS AND ENERGY BALANCES ENCH2MB

DURATION: 2 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER/S: Mrs N Maseko
Dr J Pocock

INTERNAL MODERATOR: Dr M Lasich

EXTERNAL MODERATOR: Dr K Osman

INSTRUCTIONS:

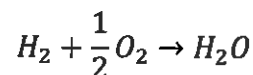
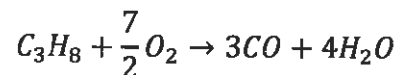
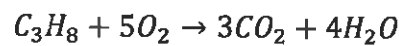
1. **ALL** questions should be attempted. Answer in **INK**.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. **Two answer books are provided. Label them Book A and Book B. Answer Section A in Book A and Section B in Book B.**
5. This examination question paper, together with all associated diagrams, **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

A mixture of 75 mole % propane and 25 mole % hydrogen is burned with 25 % excess air. Fractional conversions of 90 % of propane and 85 % of the hydrogen are achieved; of the propane that reacts, 95 % reacts to form CO₂ and the balance reacts to form CO. The hot combustion product gas passes through a boiler in which heat transferred from the gas converts boiler feedwater into steam. The following chemical reactions take place:



- (a) Assuming a basis of 100 mol feed gas, draw and fully label a flowchart. Include all stream information for each stream (4)
- (b) Carry out a degree of freedom analysis (5)
- (c) Calculate the molar fraction of CO in the stack gas (13)
- (d) The CO in the stack gas is a pollutant. Its concentration can be decreased by increasing the percent excess air fed to the furnace. State at least one cost of doing so. (*Hint:* The heat released by the combustion goes into heating the combustion products; the higher the combustion product temperature, the more steam is produced.) (2)

QUESTION 2

Three hundred litres of a mixture containing 65 wt% butanol and 35 wt% water (mixture specific gravity = 0.927) and a quantity of a 30 wt% butanol and 70 wt% water (mixture SG=0.872) are blended to produce a mixture containing 40 wt% ethanol.

- a) Draw and label a flowchart of the mixing process and conduct a degree of freedom analysis

(6)

- b) Calculate the required volume of the 30 wt% butanol mixture

(5)

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SECTION B

QUESTION 3

An air-conditioner is being used to cool an office building during the summer in Johannesburg. The air entering the air-conditioner is at 30°C with a 60% relative humidity. The thermostat on the air-conditioning system is set to deliver saturated air to the office at 18°C. To cool the open plan office, 20m³/minute of the cool saturated air is supplied. Determine:

- a. The amount of condensate that needs to be removed from the air-conditioning system in kg/hr. (8)
- b. The amount of heat removed from the air per second in kW. (12)

DATA:

The specific heat capacity of liquid water can be taken as 4.19 kJ/kg.K

A psychrometric chart is provided on page 6.

TOTAL /20/

QUESTION 4

A pump is being used to transport 1kg/s of a hot liquid product from a distillation column to storage. The liquid leaves the accumulator (where it is at rest, ie. has no initial velocity) at a height of 10m above ground level at 85°C. As the liquid may become too viscous (thus increasing frictional energy losses), the pipeline to the storage tank has heat losses of 16kW along the length of the pipe. The storage unit inlet is 5m above ground level. The liquid leaves the pipe into the storage unit where it can also be taken to be at rest (ie. no velocity). If the pump is supplying 4.8kW of shaft work, what is the final temperature of the liquid product as it reaches the storage tank?

DATA:

Specific Heat Capacity of the liquid = 3.58 kJ/kg.K

The Gravitational Constant $g = 9.81 \text{ m/s}^2$

TOTAL /10/

QUESTION 5

Anhydrous hydrazine (N_2H_4) is being added to a rocket fuel tank with a volume of 50 L. The tank is maintained at a temperature of 27°C and a pressure of 5 atm. Calculate the number of moles of hydrazine in the fuel tank using:

- The Ideal Gas Equation of State (4)
- The Truncated Virial Equation of State (7)
- What is the reason for the difference between the number of moles given by the two equations of state? (4)

Data:

For Hydrazine $P_{\text{crit}} = 145 \text{ atm}$, $T_{\text{crit}} = 653\text{K}$, Pitzer acentric factor $\omega = 0.337$

The Gas Constant $R = 0.08206 \text{ L.atm/mol.K} = 8.314 \text{ m}^3.\text{Pa/mol.K}$

TOTAL /15/

QUESTION 6

One mole of an ideal gas is being subjected to the following reversible processes in an ideal internal combustion engine based upon the Otto Cycle.

- The gas is adiabatically compressed from 1 bar pressure, 28°C to 6 bar pressure, 343.4°C
 - The gas is isochorically heated to 15 bar pressure, 1267.9°C
 - The gas is adiabatically expanded to 2.5 bar pressure, 479.5°C
 - The gas is isochorically cooled back to its original temperature.
- Calculate the Work done to or by the gas for each stage of the cycle. (6)
 - Calculate the heat added or removed from the gas for each stage of the cycle. (6)
 - Determine by calculation of the internal energy over the cycle, whether the gas has returned to its initial thermodynamic state. Justify your answer. (8)

DATA: Specific Heat Capacity at Constant Volume $C_v = 1.5 R \text{ (J/mol.K)}$

The Gas Constant $R = 0.08206 \text{ L.atm/mol.K} = 8.314 \text{ m}^3.\text{Pa/mol.K}$

TOTAL /20/

Useful Equations:

Equations of State for Gases:

Ideal Gases: $\frac{P\bar{V}}{RT} = 1$

Virial Equation of State: $\frac{P\bar{V}}{RT} = 1 + \frac{B}{\bar{V}}$ Where: $B = \frac{RT_c}{P_c} (B_0 + \omega B_1)$

$$\text{And: } B_0 = 0.083 - \frac{0.422}{T_r^{1.6}}$$

$$B_1 = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$$T_r = \frac{T}{T_c} \text{ where } T, T_c \text{ are in K}$$

$$P_r = \frac{P}{P_c}$$

For reversible processes with one mole of an ideal gas:

$$\frac{PV}{RT} = 1$$

$$dU = dQ - dW$$

$$dU = C_v dT$$

$$dH = dU + d(PV)$$

$$dH = C_p dT$$

$$C_p = C_v + R$$

Isobaric Processes

$$dW = PdV$$

Isochoric Processes

$$dW = 0$$

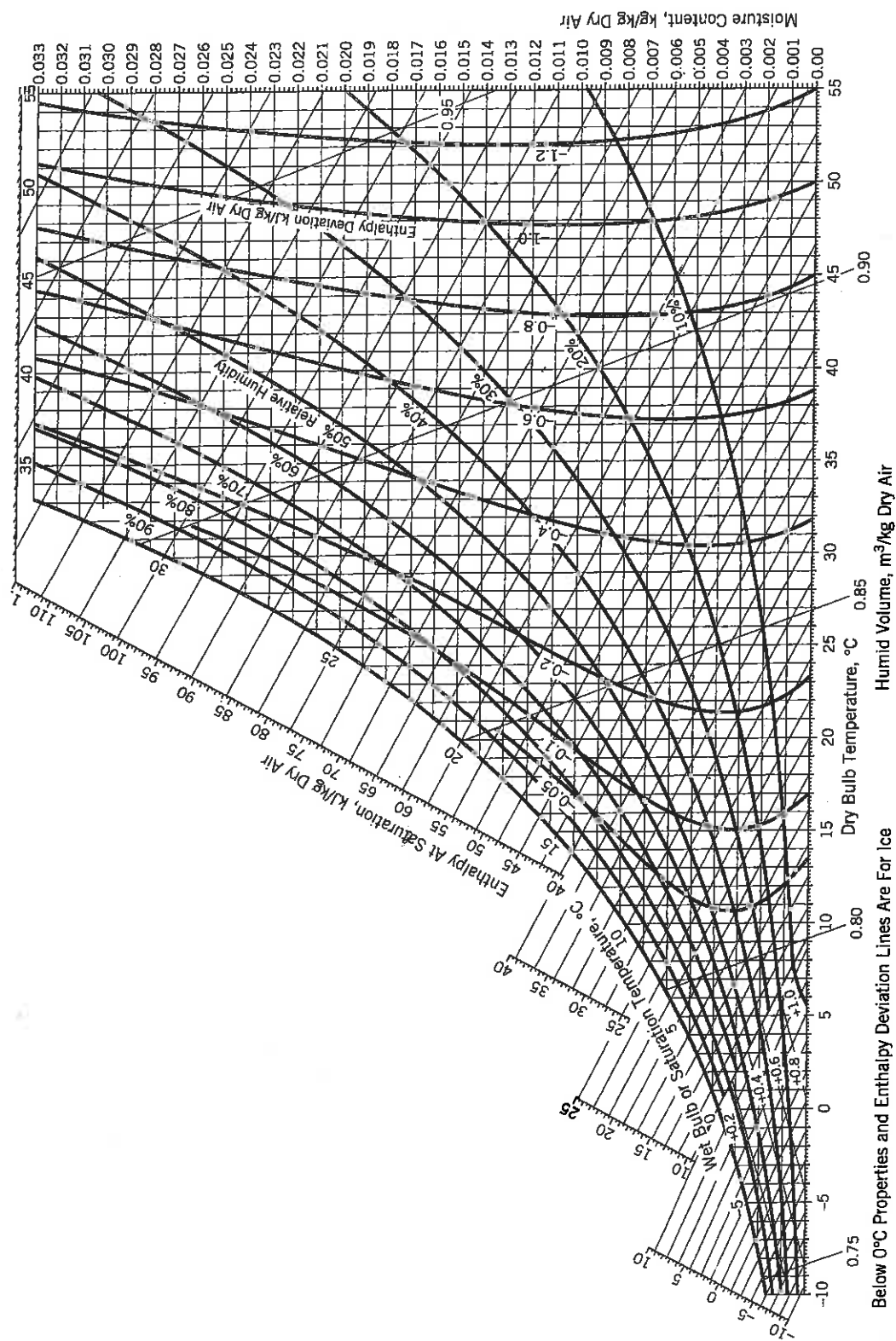
Isothermal Processes

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

Adiabatic Processes

$$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$\text{where } \gamma = \frac{C_p}{C_v}$$



Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
 Figure 8.4-1 Psychrometric chart—SI units. Reference states: H₂O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier Corporation.)