UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

EXAMINATIONS: NOVEMBER 2018

COURSE AND CODE: THERMODYNAMICS 1 ENCH2TD

DURATION: 2 HOURS

TOTAL MARKS: 100

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DR H HASHEMI

INTERNAL MODERATOR(S): MR MG NTUNKA

EXTERNAL MODERATOR: DR M LASICH

INSTRUCTIONS:

1. **ALL** questions should be attempted. **Answer in ink.**

2. Two books are provided: Label these as **Book 1 and Book 2.** Answer Section A in **Book 1 (PN)** and Section B in **Book 2 (HH).**

3. 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.

4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.

5. State all assumptions clearly.

SECTION A [BOOK 1 – PN]

QUESTION 1

i. Calculate the fugacity (bar) for ethylene at 213 K and 5 bar. Use the virial equation and the vapour pressure equation.

(9)

ii. If you have a binary mixture of ethylene at $y_{ethylene} = 0.75$ with the balance 0.25 propane, calculate the $\hat{f}_i$ in solution for ethylene. State all assumptions.

(3)

$T_c = 282.5$ K

$P_c = 50.6$ bar

$V_c = 131.1$ cm^3/mol

$Z_c = 0.281$

$\omega = 0.087$

Molecular weight = 28.0532 g/mol

Vapour pressure data

$$\log P_i^{sat}\,(bar) = A_i - \frac{B_i}{T(K) + C_i}$$

A = 3.87261

B = 584.146

C = -18.307

T_1 (K) = 149.37 (lowest temperature limit)

T_2 (K) = 188.57 (highest temperature limit)

TOTAL /12/

QUESTION 2

For the system A + B at 100 °C, the Figure 1 below shows the trend of the activity coefficients versus the mole fraction of A. The data is given in the Table 1.

Figure 1 and Table 1 are reprinted on PAGE 10 to submit with your answer book.

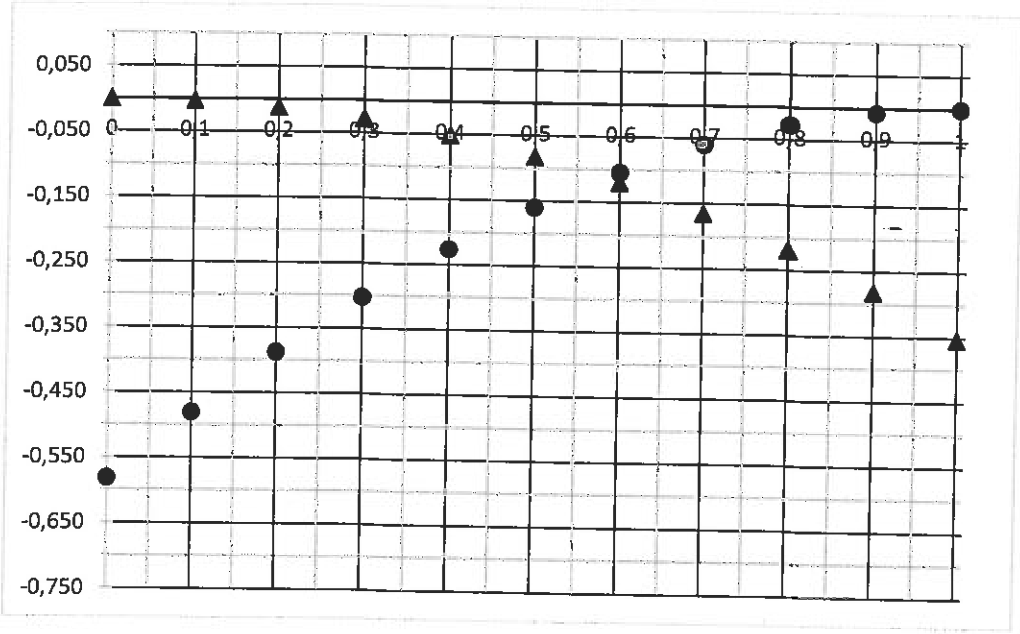

FIGURE 1. Plots of lnγ_A and lnγ_B vs. x_A. (•), lnγ_A ; (▲), lnγ_B

x_A	x_B	$ln\gamma_A$	$ln\gamma_B$
0.2	0.8	-0.387	-0.013
0.4	0.6	-0.226	-0.052
0.6	0.4	-0.104	-0.120
0.8	0.2	-0.027	-0.220

TABLE 1. lnγ_A and lnγ_B for system A (1) + B(2) at 100 °C.

QUESTION 2 cont.

i. Comment on the system behaviour from the data provided in Figure 1.

(4)

ii. Calculate G^E/RT and enter the values on the Table 1 printed on PAGE 10.

(4)

iii. Calculate and plot G^E/x_1x_2RT on the FIGURE 1 reprinted on PAGE 10. Enter the values calculated in the TABLE.

(5)

iv. Determine the γ_i^∞ for components A and B and comment on the values obtained. Why are the activity coefficients at infinite dilution important?

(5)

v. Using the information calculated, obtain an expression for G^E/RT vs x_1x_2.

(5)

TOTAL /23/

QUESTION 3

Vapour-liquid equilibrium data for the binary system octane (1) + ethylcyclohexane (2) at $P = 101.3\ kPa$ is presented in Figure 2.

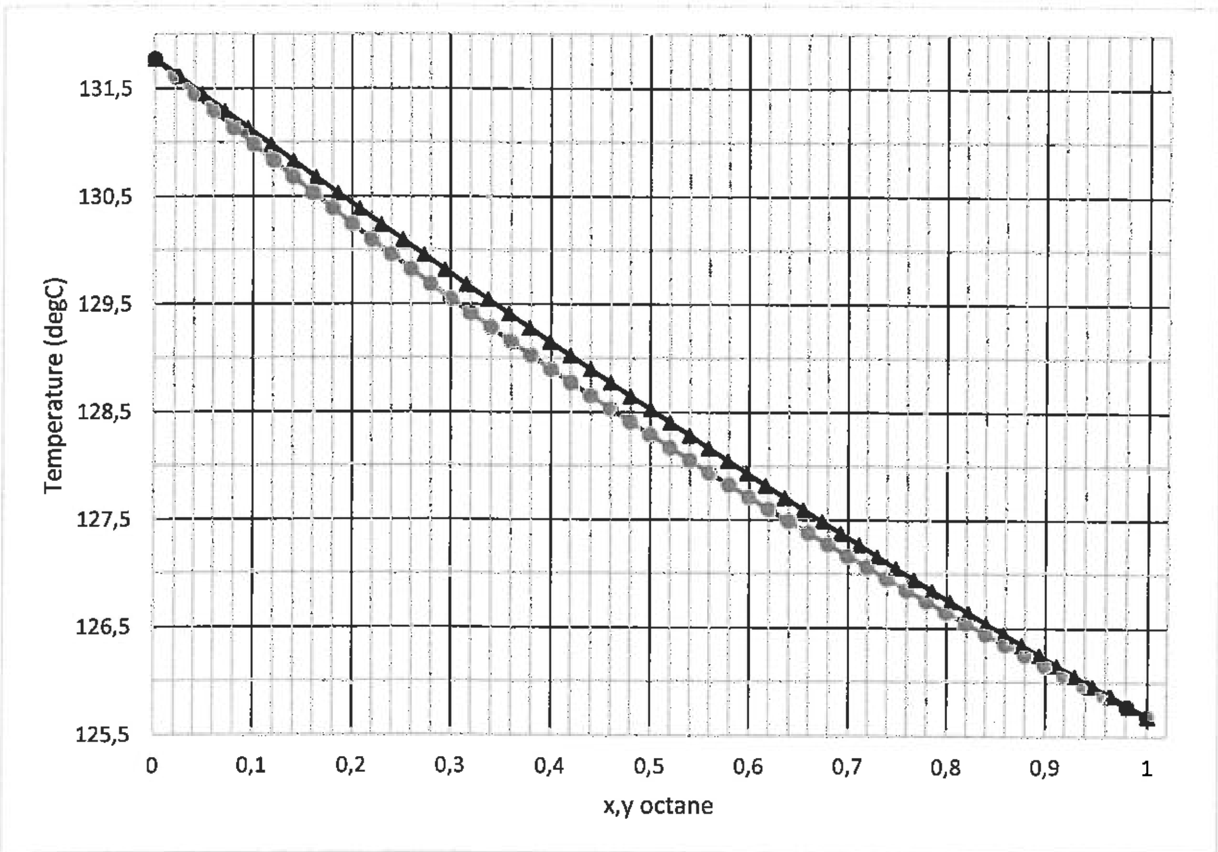

FIGURE 2. Pxy diagram for the system octane (1) + ethylcyclohexane (2) at P = 101.3 kPa.

i. Discuss the phase behaviour for the system shown in Figure 2. (4)

ii. For the equilibrium temperature of T = 126.5 °C, calculate the activity coefficients, γ_1 and γ_2. State all assumptions. (8)

iii. Comment on the values obtained in (ii). (2)

iv. Define the relative volatility, and calculate this value for the data in (ii). (4)

v. Comment on the separation of the two components studied via distillation. (2)

TOTAL /20/

DATA IS PROVIDED ON PAGE 5.

DATA

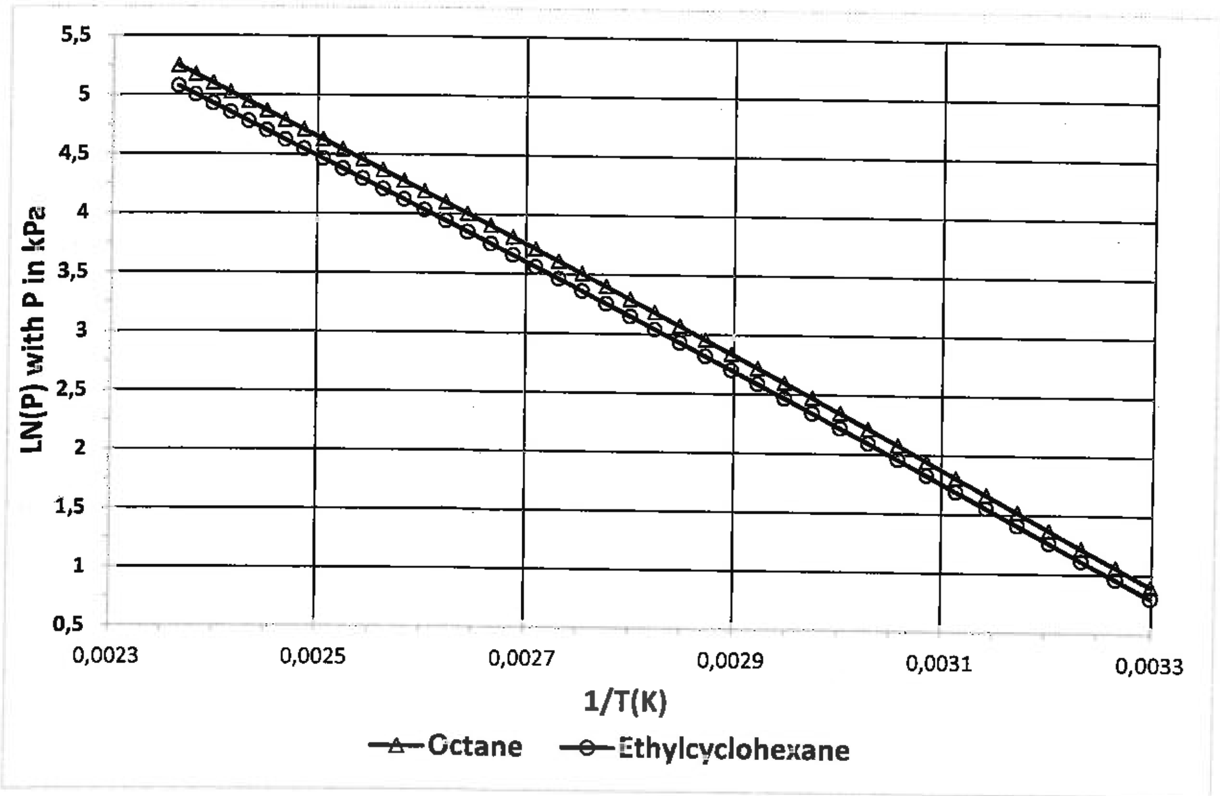

FIGURE 3. Plot of lnP versus 1/T. *[P in units of kPa and T in units of K]*

SECTION B [BOOK 2-HH]

QUESTION 4

The working fluid in the refrigeration system shown below is R-22. The refrigerant exits the evaporator at 150 kPa, and it exits the condenser as a saturated liquid at 1.4 MPa. Some of the refrigerant is bled off at state 3 and throttled to state 6 before it enters a heat exchanger. The refrigerant exits the heat exchanger at states 4 and 7. The heat exchanger is used to subcool the refrigerant before it is throttled to the evaporator pressure.

a) Determine the coefficient of performance (COP) for the refrigeration cycle. State all assumptions. (14)

b) Determine the compressor load in kW. (2)

c) What is the quality (x) of stream 5? (4)

d) Comment on the use of R-22. (3)

DATA

$\dot{m}_2 + \dot{m}_8 = 10$ kg/s	$x_3 = 0$	$P_7 = 400$ kPa
$P_1 = 150$ kPa	$P_4 = 1.4$ MPa	$x_7 = 1$
$P_2 = 1.4$ MPa	$T_4 = 6$°C	$P_8 = 1.4$ MPa
$T_2 = 90$°C	$P_5 = 150$ kPa	$T_8 = 65$°C
$P_3 = 1.4$ MPa	$P_6 = 400$ kPa	$\lvert\dot{W}_{C,1}\rvert = 565.4$ kW

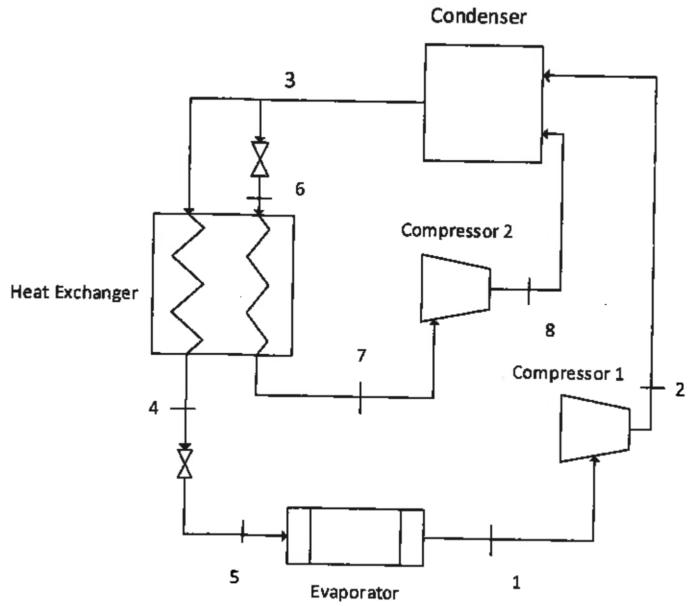

FIGURE 4.

TOTAL /23/

QUESTION 5

Methane is liquefied using the process shown in the following flowsheet. A partial set of conditions is provided in the table below. **Mark the attached chart as you use it and SUBMIT it with your exam as reprinted on PAGE 11.**

a) H_9 is saturated liquid and H_{10} is saturated vapor. The flash drum is adiabatic. Find $\dot{m}_{10}/\dot{m}_7$ and $\dot{m}_9/\dot{m}_7$.

(11)

b) Use the dotted boundary to find H_{11}.

(5)

c) Compressor II is 80% efficient. Find the work required to compress 180 kg/hr.

(4)

d) Find the heat transfer duty necessary (kJ/kg) in the condenser.

(2)

DATA

Stream No.	T (K)	P (MPa)	H (kJ/kg)
2		0.1	820
4		0.5	730
6		1.0	Sat Liq
7	140	1.0	
9		0.1	
10		0.1	

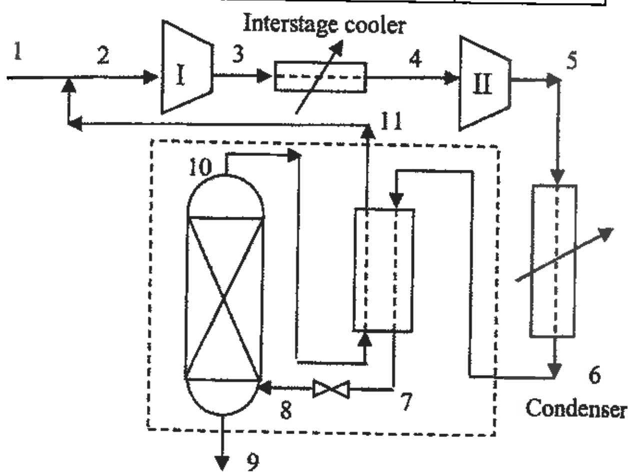

FIGURE 5

TOTAL /22/

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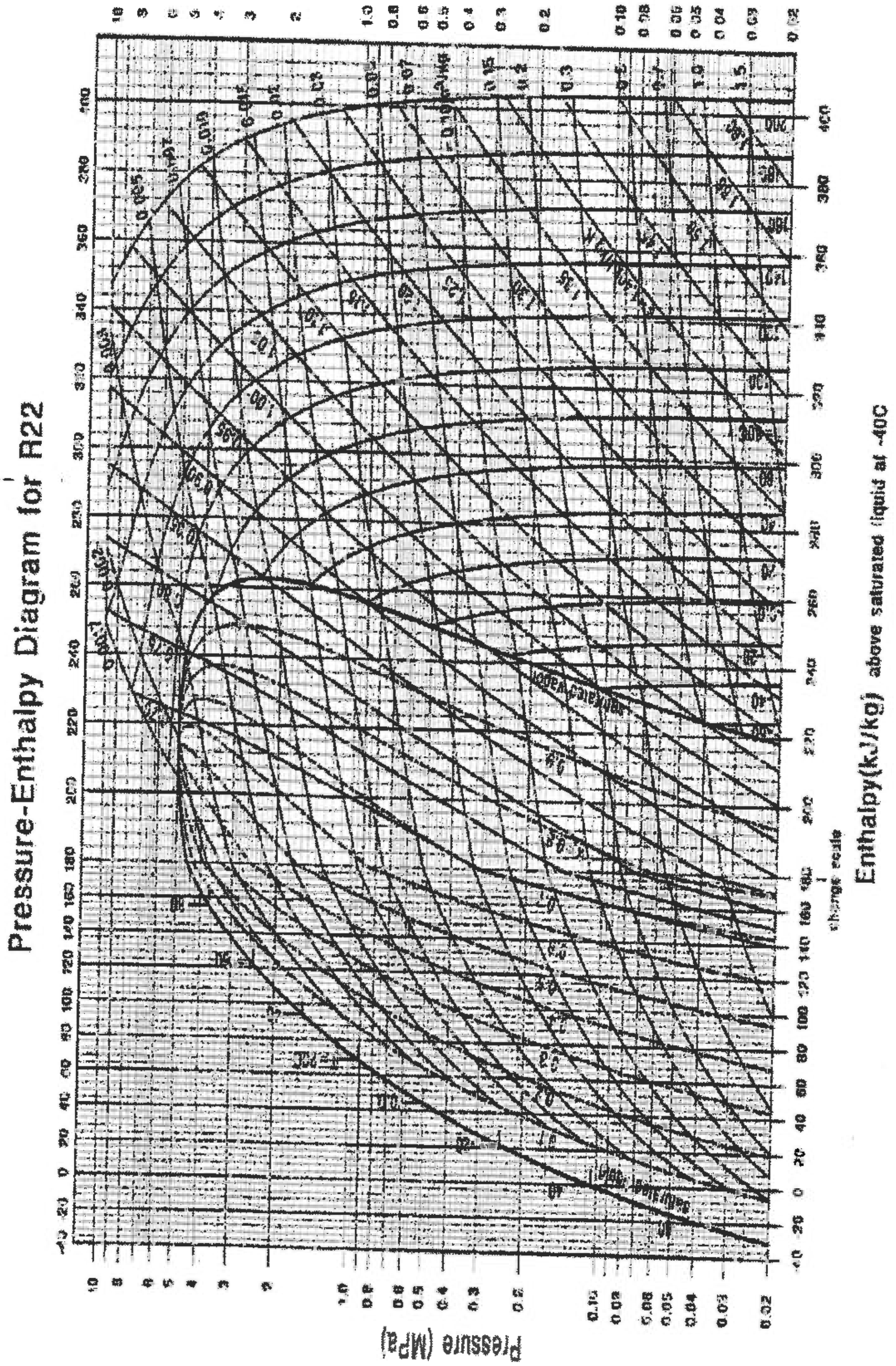

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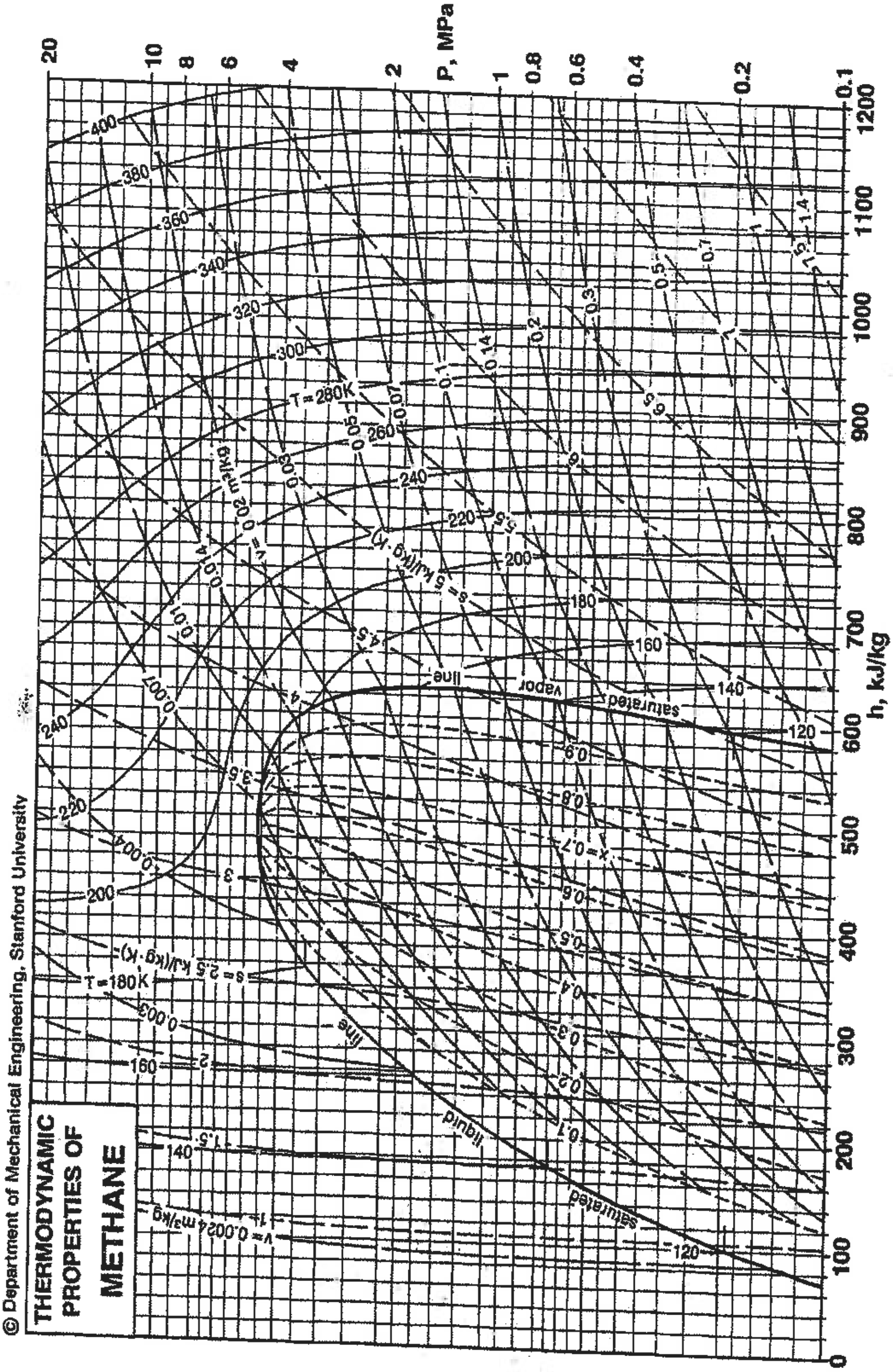


STUDENT NUMBER:

SUBMIT THIS PAGE WITH YOUR ANSWER BOOK 1.

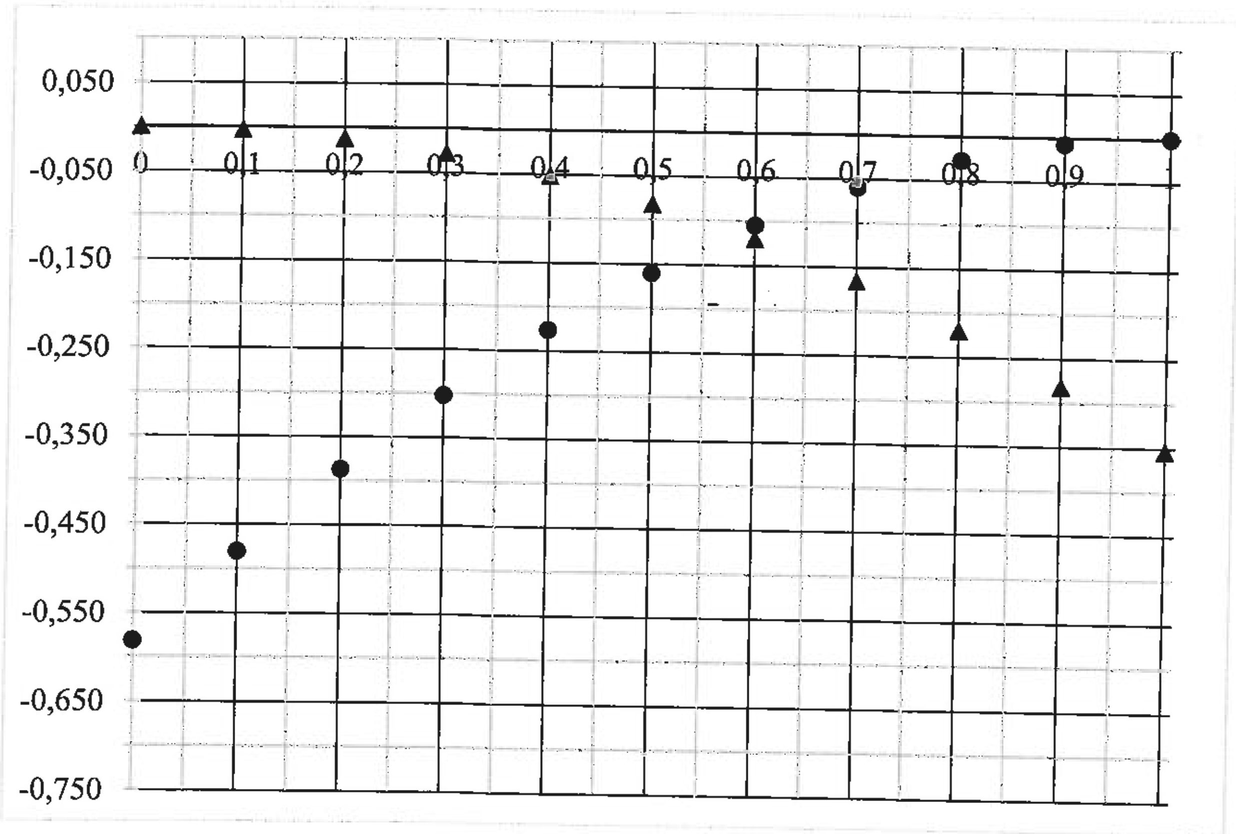


FIGURE 1. Plots of $\ln\gamma_A$ and $\ln\gamma_B$ vs. x_A. (●), $\ln\gamma_A$; (▲), $\ln\gamma_B$

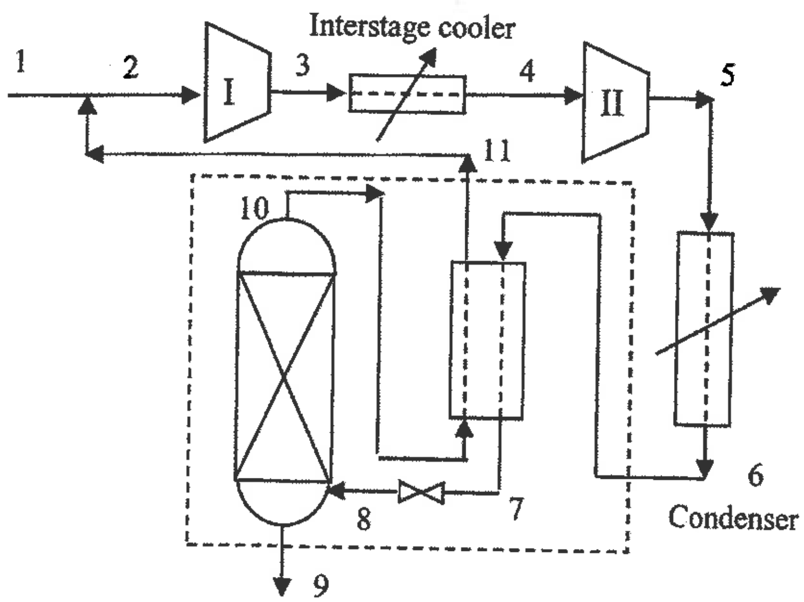
x_A	x_B	$ln\gamma_A$	$ln\gamma_B$				
0.2	0.8	-0.387	-0.013				
0.4	0.6	-0.226	-0.052				
0.6	0.4	-0.104	-0.120				
0.8	0.2	-0.027	-0.220				

TABLE 1. $\ln\gamma_A$ and $\ln\gamma_B$ for system A (1) + B(2) at 100 °C

STUDENT NUMBER:

SUBMIT THIS PAGE WITH YOUR ANSWER BOOK 2.

Stream No.	T(K)	P(MPa)	H (kJ/kg)
2		0.1	820
4		0.5	730
6		1.0	Sat Liq
7	140	1.0	
9		0.1	
10		0.1	



FORMULAE SHEET

Equations of State

Virial: $Z = 1 + B/V + C/V^2 + \ldots$

Van der Waals: $P = RT/(V - b) - a/V^2$

Carnot Engines

$\eta = 1 - T_C/T_H$

Compressors

$\Pi = [\, n/(n-1) \,] (m/M) RT_1 [\, (P_2/P_1)^{n-1/n} - 1]$

$\eta_v = 1 - c\,[\, (P_2/P_1)^{1/n} - 1]$

Adiabatic Processes

$PV^\gamma = \text{constant}$

Heat Capacity

$\langle C_P \rangle_H/R = A + (B/2)T_0(\tau + 1) + (C/3)T_0^2(\tau^2 + \tau + 1) + D/(\tau T_0^2)$

$\langle C_P \rangle_S/R = A + [BT_0 + (CT_0^2 + D/(\tau^2 T_0^2))\,(\tau+1)/2]\,(\tau - 1)/\ln(\tau)$

Generalized Correlations

$\omega = -1.0 - \log_{10}(P_r^{sat})|_{Tr=0.7}$

$Z = Z^0 + \omega Z^1$

$H^R/(RT_C) = (H^R)^0/(RT_C) + \omega(H^R)^1/(RT_C)$

$S^R/(RT_C) = (S^R)^0/(RT_C) + \omega(S^R)^1/(RT_C)$

$S^R/R = -P_r(dB^0/dT_r + \omega dB^1/dT_r)|_{Pr < 0.8}$

$dB^0/dT_r = 0.675/Tr^{2.6}$

$dB^1/dT_r = 0.722/Tr^{5.2}$

Entropy

$dS = dQ/T$

$\Delta S^{i.g.} = R\langle C_P^{i.g.} \rangle_S \ln(T_2/T_1) - R\ln(P_2/P_1)$

Universal Gas Constant

R =	$8.314\ J.K^{-1}.mol^{-1}$	$8.314\ Pa.m^3.K^{-1}.mol^{-1}$
	$8.206\times10^{-2}\ L.atm.K^{-1}.mol^{-1}$	$8.314\ Pa.m^3.K^{-1}.mol^{-1}$
	$8.314\times10^{-2}\ L.bar.K^{-1}.mol^{-1}$	$83.14\ cm^3.bar.mol^{-1}.K^{-1}$

Pitzer correlation: $B^0 = 0.083 - \frac{0.422}{T_R^{1.6}}$; $B^1 = 0.139 - \frac{0.172}{T_R^{4.2}}$; $\frac{BP_c}{RT_c} = B^o + \omega B^1$

Rackett equation: $V^{sat} = V_c Z_c^{(1-T_r)^{0.2857}}$;

Partial Molar Property for a binary system

$$\bar{M}_1 = M + x_2 \frac{dM}{dx_1}$$

$$\bar{M}_2 = M - x_1 \frac{dM}{dx_1}$$

$$\ln \phi_i = \frac{B_{ii} P}{RT}$$

$$\ln \frac{f_i}{f_i^{sat}} = \frac{V_i^L (P - P_i^{sat})}{RT}$$

$$G^{id} = \sum x_i G_i + RT \sum x_i ln x_i$$

$$S^{id} = \sum x_i S_i - R \sum x_i ln x_i$$