UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

# SCHOOL OF ENGINEERING

## EXAMINATIONS: NOVEMBER 2019

**COURSE AND CODE:** THERMODYNAMICS ENCH2TD

**DURATION:** 2 HOURS

**TOTAL MARKS:** 100

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**INTERNAL EXAMINER(S):** PROF. P. NAIDOO
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**INTERNAL MODERATOR(S):** MR M. G. NTUNKA

**EXTERNAL MODERATOR:** DR. S. IWARERE

**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 (SB)** and Section B in **Book 2 (PN).**

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 – SB]

## QUESTION 1

Ethane gas, at 35 bar and 450 K, is throttled in a steady state flow process to 1 bar.

i) Estimate the final temperature of the ethane? (11)

ii) Estimate the entropy change of the process? (4)

iii) What is the temperature change of the process if ethane is assumed to be an ideal gas? (3)

*Hint:* An iteration process with two steps is sufficient for your calculations. Use the initial guess for temperature as: 450 K. $\ll C_P^{ig} \gg_H = \ll C_P^{ig} \gg_S$

$$\frac{C_P^{ig}}{R} = A + BT + CT^2$$

$$\Delta H = \ll C_P^{ig} \gg_H (T_2 - T_1) + H_2^R - H_1^R \text{ (J/mol)}$$

$$\Delta S = \ll C_P^{ig} \gg_S ln\frac{T_2}{T_1} - Rln\frac{P_2}{P_1} + S_2^R - S_1^R \text{ (J/(mol.K))}$$

**Table 1.** Critical properties for ethane

| ***Tc* (K)** | ***Pc* (bar)** |
|---|---|
| 305.3 | 48.72 |

**Table 2.** Heat capacity's constants for ethane in ideal state.

| ***A*** | **$10^3$ *B*** | **$10^6$ *C*** |
|---|---|---|
| 1.131 | 19.225 | 5.561 |

**Table 3.** Reduced enthalpy and entropy for ethane at the pressure of **35** bar.

| ***T* (K)** | ***$H^R$/ ($RT_C$)*** | ***$S^R$/R*** |
|---|---|---|
| 450 | -0.236 | -0.090 |
| 445 | -0.244 | -0.099 |
| 440 | -0.253 | -0.105 |
| 435 | -0.261 | -0.1098 |

**TOTAL** /18/

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## QUESTION 2

A refrigeration cycle using ethylene as a refrigerant is shown in Figure 1. Stream 5 is saturated vapour at 0.2 MPa and stream 2 is saturated liquid at 0.6 MPa. The compressor is adiabatic with the efficiency of 0.85. Heat exchanger I serves to increase the temperature of stream 5 to stream 6 and decrease the temperature from 2 to 3. Stream 6 is at 220 K and 0.2 MPa. The P-H diagram for the system is provided on PAGE 7 (**FIGURE 6**).

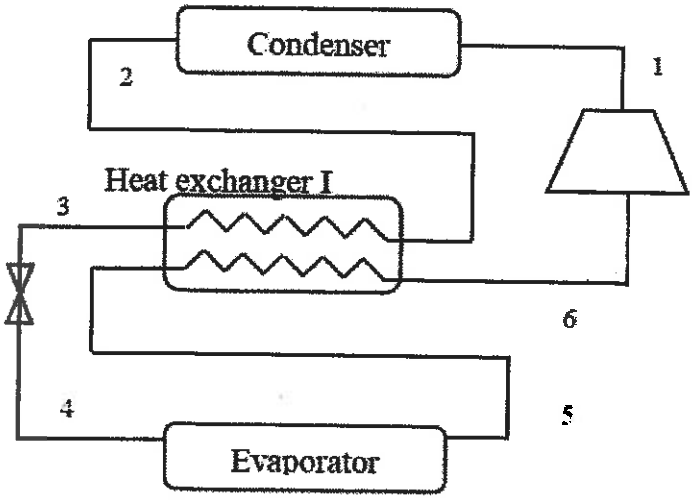



**FIGURE 1.** Refrigeration Cycle.

i) Determine the work done by the compressor per 1 kg of refrigerant in 1 second, in *kW*.

(9)

ii) Determine the enthalpy of stream 3, in *kJ/kg*.

(6)

iii) Determine the quality of stream 4 and the amount of heat transfer in the evaporator in *kJ/kg*.

(8)

iv) Mention three factors when selecting a reliable refrigerant for a refrigeration system.

(6)

v) Name two commonly used systems for absorption refrigeration?

(3)

**TOTAL** **/32/**

# SECTION B [BOOK 2-PN]

## QUESTION 3

3.1 Define the fugacity coefficient for a pure component using a numerical equation.

(2)

3.2 Using the Lee-Kesler correlation,

$$\varphi_i = \varphi_i^0(\varphi_i^1)^\omega$$

Calculate the fugacities for the species in a binary gaseous mixture of n-propane (80 mol %) and propene (20 mol%) at T = 350 K and P = 2 MPa. State all assumptions.

(14)

3.3 Comment on the assumptions made in performing the calculations in 3.2, and whether these are appropriate for the system.

(2)

The Lee-Kesler plots are provided on PAGE 8 (**FIGURE** 7).

**DATA**

**Table 4.**

| | Propane | Propene |
|---|---|---|
| Formulae | $C_3H_8$ | $C_3H_6$ |
| molecular weight | 44.10 | 42.08 |
| Tc (K) | 369.9 | 365.6 |
| Pc (bar) | 42.48 | 46.65 |
| Vc ($cm^3$/mol) | 200.0 | 188.4 |
| ω | 0.152 | 0.140 |
| $Z_c$ | 0.276 | 0.289 |

**TOTAL /18/**

## QUESTION 4

Vapour-liquid equilibrium data for the binary system n-heptane (1) + propan-2-ol (2) at $P = 101.3\ kPa$ is presented in Figure 2, and x-y plot in Figure 3.

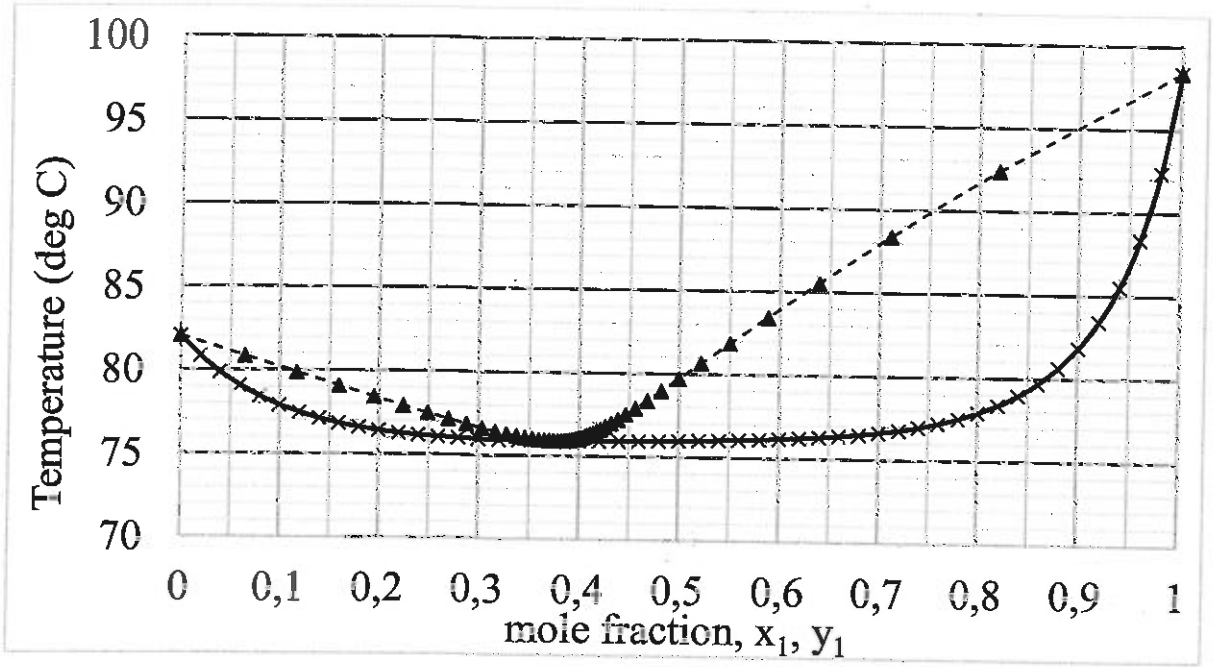



**FIGURE 2.** Txy diagram for the system n-heptane (1) + propan-2-ol (2) at P = 101.3 kPa. (-x-, T-x data; and -▲-, T-y data).

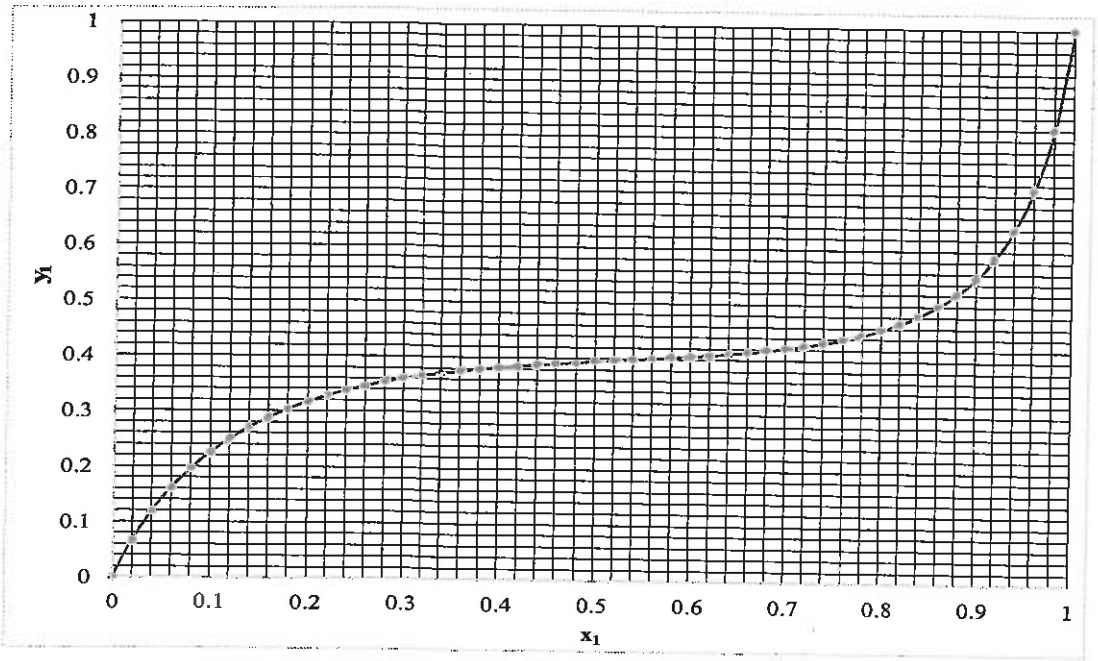



**FIGURE 3.** xy diagram for the system n-heptane (1) + propan-2-ol (2) at P = 101.3 kPa.

4.1 Describe the phase behavior taking into consideration the components in the mixture.

(6)

4.2 What is the azeotropic condition and explain the constraints this places on the separation of the components in the system?

(2)

4.3 For a mixture with overall composition, $z_1 = 0.8$ at T = 86 °C, determine the fraction of vapour present.

(4)

4.4 For the mixture in 4.3, if a stream with this composition is fed into a distillation column operating at atmospheric pressure, what are the top and bottom products and temperatures likely to be?

(4)

4.5 Consider the plot of $\gamma_i$ vs mole fraction, $x_1$ in Figure 4. Determine the infinite dilution activity coefficients for each specie. What do these values imply?

(4)

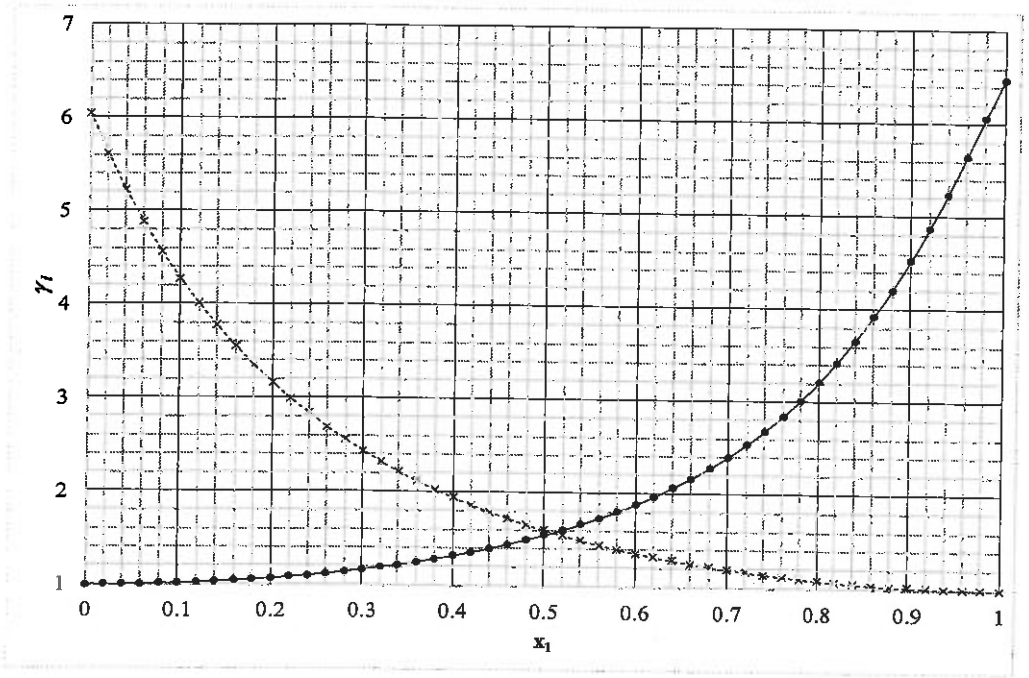



**FIGURE 4.** Plot of $\gamma_i$ vs mole fraction, $x_1$ for the system n-heptane (1) + propan-2-ol (2) at P = 101.3 kPa. (-x-, component 1; and -●-, component 2).

4.6 At a mole fraction, $x_1$ of 0.65, determine the activity coefficients for each specie. Then calculate the excess Gibbs energy, $G^E$ at 350 K.

(6)

4.7 Determine the property change of mixing, $\Delta H$ for the mixture, $x_1 = 0.65$ at 350 K.

(2)

4.8 Then calculate the property change of mixing, $\Delta G$, $S^E$ and $\Delta S$.

(4)

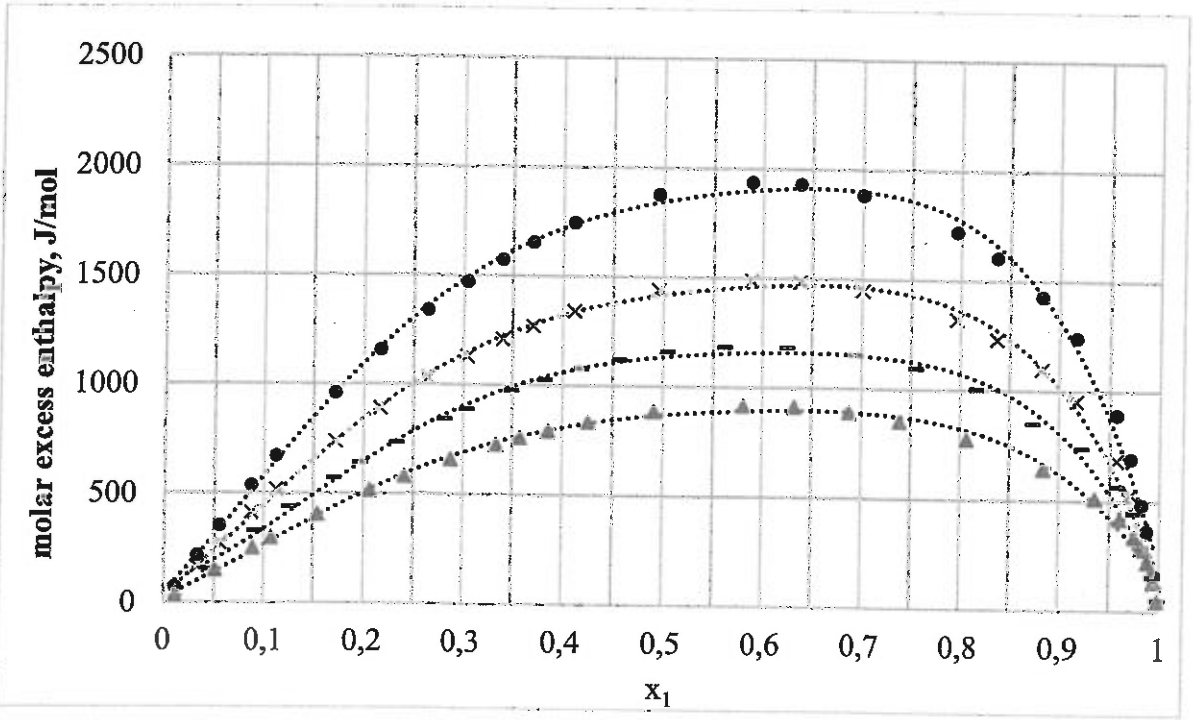
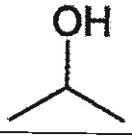



**FIGURE 5.** Plot of excess molar enthalpy for the system n-heptane (1) + propan-2-ol (2) at P = 101.3 kPa. Temperatures ▲, 303.15 K; -, 318.25 K ; X; 333.15 K; ●, 350.15 K.

**DATA**

| | ***n-Heptane*** | ***Propan-2ol*** |
|---|---|---|
| Formulae | $C_7H_{16}$ | $C_3H_8O_2$ |
| molecular weight | 100.204 | 60.096 |
| SG | 0.6882 | 0.7893 |
| $T_{boiling\ pt.,\ 1atm}$ (C) | 98.43 | 82.15 |
| Structure |  |   |

**TOTAL /32/**

STUDENT NUMBER:

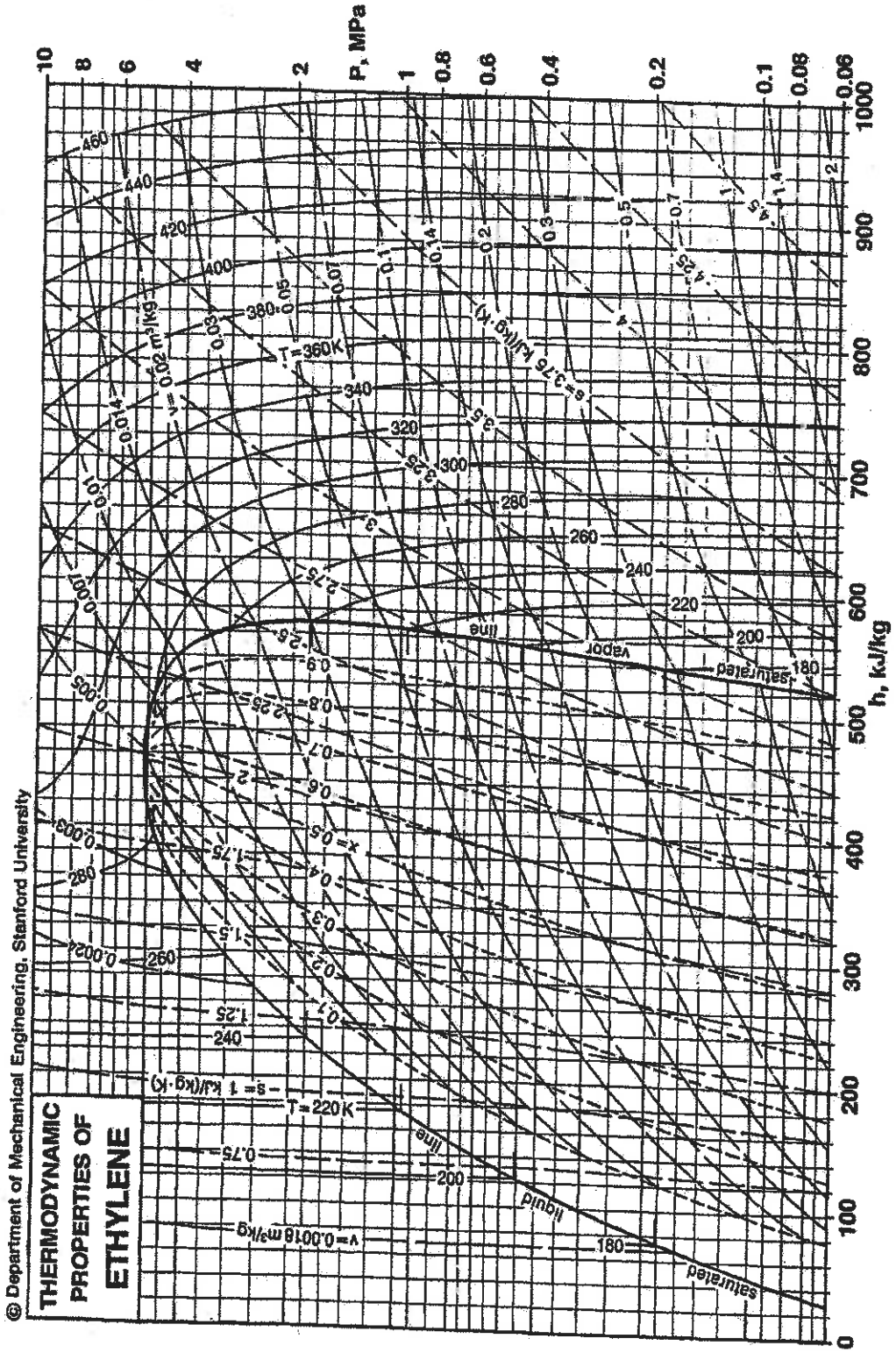



**FIGURE 6: P-H Diagram for Ethylene**

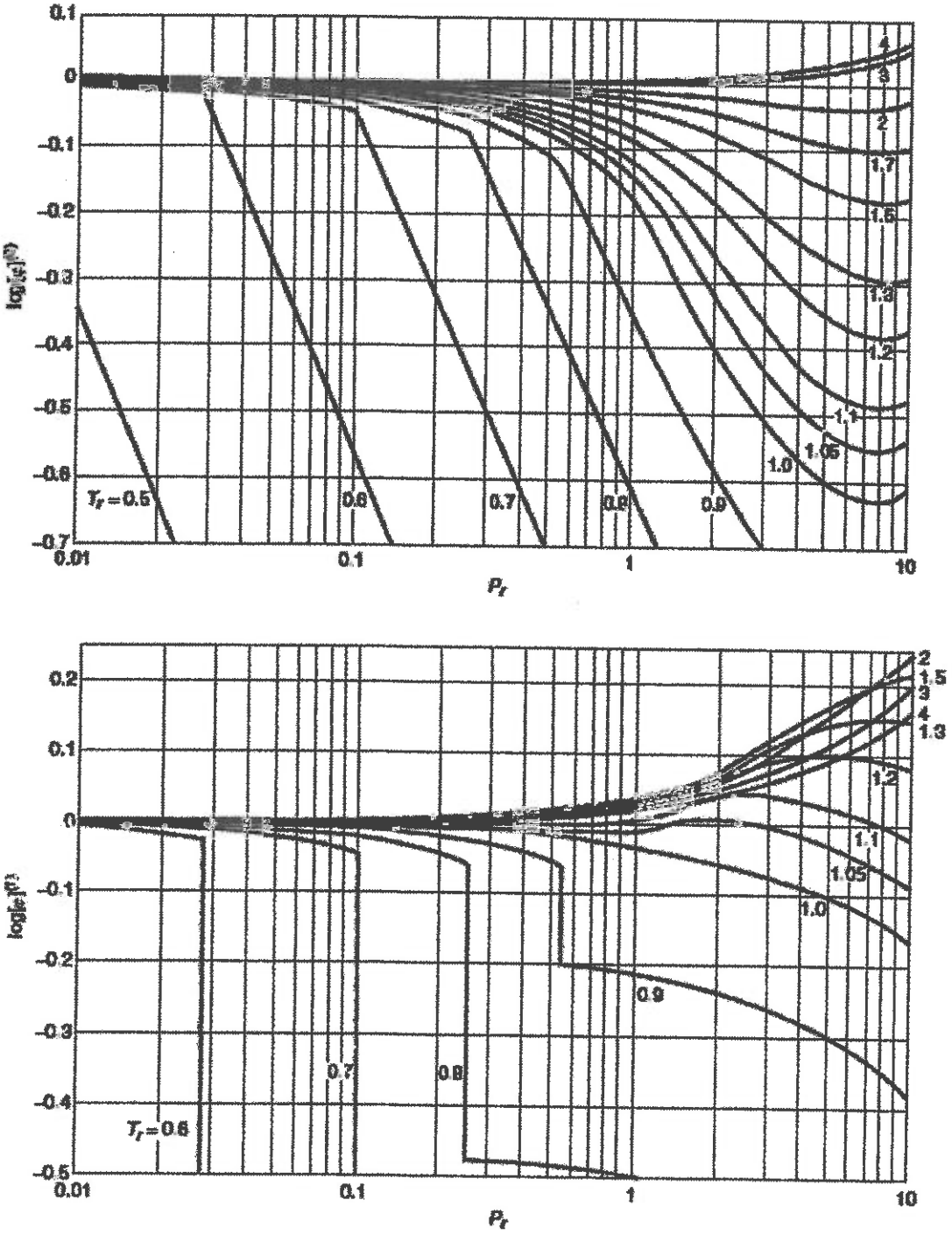



**FIGURE 7.** Fugacity coefficients based on the Lee-Kesler correlation.

# 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***

$dS = dQ/T$

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

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Universal Gas Constant

R = 8.314 $J.K^{-1}.mol^{-1}$ 8.314 $Pa.m^3.K^{-1}.mol^{-1}$

8.206x$10^{-2}$ $L.atm.K^{-1}.mol^{-1}$ 8.314 $Pa.m^3.K^{-1}.mol^{-1}$

8.314x$10^{-2}$ $L.bar.K^{-1}.mol^{-1}$ 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

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

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

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

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

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

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