Roll No.													

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

TEST 1

Sem & AY : Odd Sem. 2019-20
Course Code: PET 220
Course Name: HYDROCARBON THERMODYNAMICS
Program & Sem: B.Tech (PET) & III

Date: 30.09.2019
Time: 2:30PM TO 3:30PM
Max Marks: 40
Weightage: 20%

Instructions:

(i) All questions are compulsory
(ii) Assume the missing value. Assumption should be reasonable.

Part A [Memory Recall Questions]

Answer both the Questions. Each Question carries five marks. (2Qx5M=10M)

1. Differentiate between closed system, open system and isolated system with example. (C.O.NO.1) [Knowledge]
2. What is the significance of critical temperature and critical pressure for pure substance? What is the value of critical temperature and pressure of water in SI system? (C.O.NO.1) [Knowledge]

Part B [Thought Provoking Questions]

Answer both the Questions. Each Question carries ten marks. (2Qx10M=20M)

3. Draw and explain the pressure temperature relation for single component water system? Find out the degree of freedom for sublimation, Fusion, Vapor pressure curve and triple point. (C.O.NO.1) [Comprehension]

4. 2 mole of an ideal gas was initially at 293 K and 15 atm. The expansion of gas takes place adiabatically when the external pressure is reduced to 5 atm. What will be the final temperature and volume? Also calculate the work done during the process, given that heat capacity ratio for the gas is 1.3. (C.O.NO.1) [Comprehension]

Part C [Problem Solving Questions]

Answer the Question. The Question carries ten marks. (1Qx10M=10M)

5. Derive the steady state equation for a system using first law of thermodynamics, where the incoming and outgoing flow rate of water is 100 lit/hour.

(C.O.NO:01) [Comprehension]

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GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

Date: 30.09.19

Time: 1 hour

Max Marks: 40

Weightage: 20%

Semester: 3rd

Course Code: PET 220

Course Name: Hydrocarbon Thermodynamics

Extract of question distribution [outcome wise & level wise]

Q.NO	C.O.NO	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels			Thought provoking type [Marks allotted] Bloom's Levels			Problem Solving type [Marks allotted]			Total Marks
			K			C/A			A			
1	1	1	5									5
2	2	2	5									5
3	1	1				10						10
4	1	1				10						10
5	2	2							10			10
	Total Marks		10			20			10			40

K =Knowledge Level C = Comprehension Level, A = Application Level

Note: While setting all types of questions the general guideline is that about 60%

Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

[I hereby certify that All the questions are set as per the above guide lines. Mr. Kalpajit]

Reviewers' Comments

SCHOOL OF Engineering

SOLUTION

Semester: 3rd

Course Code: PET 220

Course Name: Hydrocarbon Thermodynamics

Date: 30/09/19

Time: 1 hour

Max Marks: 40

Weightage: 20%

Part A (2Q x5 M = 10 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
1	**Closed system or control mass:** consists of a fixed amount of mass, and no mass can cross its boundary. But, energy in the form of heat or work, can cross the boundary, and the volume of a closed system does not have to be fixed. **Open system or control volume:** is a properly selected region in space. It usually Encloses a device that involves mass flow such as a compressor. Both mass and energy can cross the boundary of a control volume. **Isolated system:** A closed system that does not communicate with the surroundings by any means.	3+2	5
2	The **critical temperature** of a substance is the **temperature** at and above which vapor of the substance cannot be liquefied, no matter how much **pressure** is applied. The ***critical pressure*** of a substance is the pressure required to liquefy a gas at its critical temperature. The **critical temperature** of water is 647 K and pressure 218 atm.	2+2+1	5

Part B (2Q x10 M = 20 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
3		2+4+4	15

(a) Curves

The phase diagram of the water system consists of three stable curves and one metastable curve, which are explained as follows.

(i) Curve *OB*: The curve *OB* is known as *vapour pressure curve of water* and tells about the vapour pressure of water at different temperatures. Along this curve, the two phases *water* and *vapour* exist together in equilibrium.

At point *D* the vapour pressure of water become equal to the atmospheric pressure (100°C), which represents the boiling point of water. The curve *OB* finishes at point B (temp. 374°C and pressure 218 atm) where the liquid water and vapour are indistinguishable and the system has only one phase. This point is called the *critical point*.

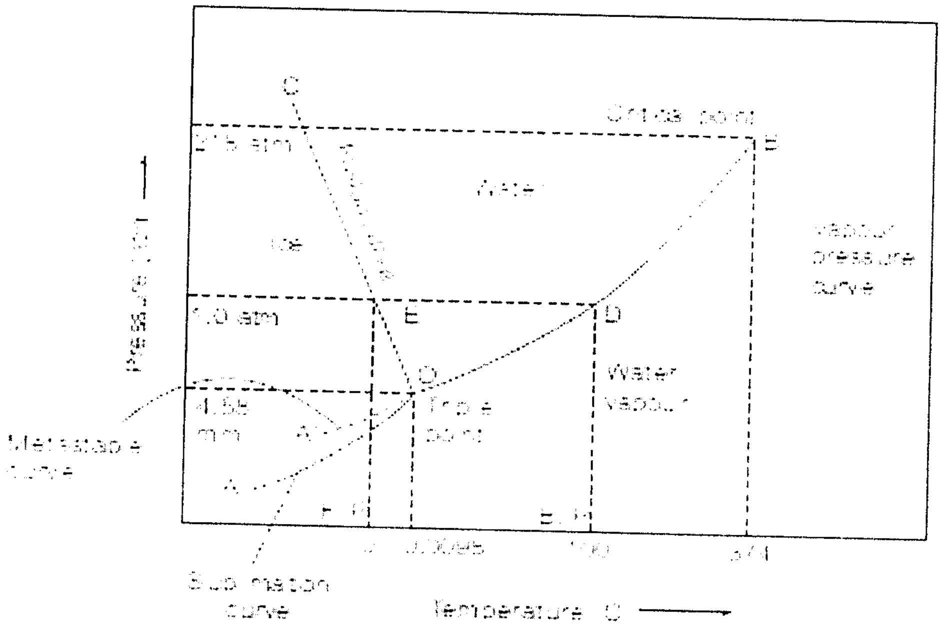
Applying the phase rule on this curve,

$$C = 1 \text{ and } P = 2$$

$$F = C - P + 2 = 1 - 2 + 2 = 1$$

Hence, the curve represents a *univariant system*. This explains that only one factor (either temperature or pressure) is sufficient to be fixed in order to define the system.

(ii) Curve *OA*: *It is known as sublimation curve of ice* and gives the vapour pressure of solid ice at different temperatures. Along sublimation curve, the two phases *ice* and *vapour* exist together in equilibrium. The lower end of the curve *OA* extends to absolute zero (−273°C) where no vapour exists.



4		3+3+4	20

[illegible]

$$n = 2$$

$$R = 0.082 \text{ L-atm/degree-K}$$

$$T = 293 \text{ K}$$

in the equation

$$PV = nRT$$

we get

$$V_1 = \frac{nRT}{P_1} = \text{[illegible]}$$

Hence, under adiabatic conditions

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

or

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

or

[illegible]

or

$$\left(\frac{V_2}{3.2}\right) = \text{[illegible]}$$

or

[illegible]

Hence, the final volume of the system [illegible]

Now, to determine the final [illegible]

[illegible]

or

[illegible]

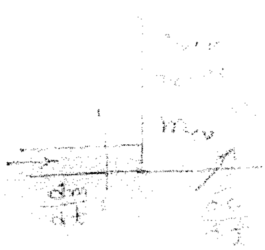
or

$$T_2 = 227 \text{ K} \text{ [illegible] } 46^{\circ}\text{C [illegible]}$$

Adiabatic work done can be calculated as

[illegible]

Part C (1Q x10 M =10 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
5	 Conservation of Energy [illegible]	7+3	15

[illegible] energy eqn.

$$\frac{d[illegible]}{dt} \quad \frac{d[illegible]}{dt}$$

$$\frac{dm}{dt}\left(u_1 + p_1 v_1 + [illegible]\right) [illegible]$$

$$u_1 + p_1 v_1 + \frac{V_1^2}{2} + g z_1 + \frac{\delta Q}{\delta m} [illegible]$$

$$\frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = \left(h_2 + \frac{V^2}{2} + g z\right) - [illegible]$$

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PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF Engineering

TEST –2

Semester: 3rd
Course Code: PET 220
Course Name: Hydrocarbon Thermodynamics
Program & Sem: B.Tech, 3rd SEM

Date: 18.11.19
Time: 1 Hour
Max Marks: 40
Weightage: 20%

Instructions:

(i) ***All questions are compulsory***
(ii) ***Assume the missing value. Assumption should be reasonable.***

Part A

Answer both the Questions. Each question carries 5 marks. **(2Qx5M=10)**

Q.NO.1. What is the significance of Helmholtz free energy? What are the different classification of thermodynamic properties? [5] (C.O. 3) [K]

Q.NO.2. Define 2nd law of thermodynamics? Write the Kelvin- Planck and Clausius statement for 2nd law of thermodynamics. [5] (C.O. 3) [K]

Part B

Answer both the Questions. Each question carries 10 marks. **(2x10=20)**

Q.NO.3. Differentiate between endothermic and exothermic reaction. On the basis of the data and the chemical reactions given in the following lines, find the heat of formation of $ZnSO_4$ from the constituent element. [10] (C.O. 2) [C]

$Zn + S = ZnS$ $\quad \Delta H = -44.0\ kcal/kmol$

$2ZnS + 3\,O_2 = 2ZnO + 2SO_2$ $\quad \Delta H = -221.88\ kcal/kmol$

$2SO_2 + O_2 = 2SO_3$ $\quad \Delta H = -46.88\ kcal/kmol$

$ZnO + SO_3 = ZnS \qquad \Delta H = -55.10 kcal/kmol$

The heat of formation of $ZnSO_4$ is

$Zn + S + O_2 = ZnSO_4$

Q.NO.4. What are the different thermodynamic process in Carnot cycle? Find out the equation of total work done by the Carnot cycle. [10] (C.O. 3) [C/A]

Part C

Answer the Question. Question carries 10 marks. (1Qx10M=10)

Q.NO.5. A Carnot engine absorb heat to the tune of 585 KJ/cycle from a hot reservoir at 650^0C and discard heat to a cold reservoir at 30^0 C. Then

(a) What is the thermal efficiency of the Carnot engine?

(b) What amount would be released to the cold reservoir? [10] (C.O. 3) [A]

SCHOOL OF Engineering

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

Semester: 3rd
Course Code: PET 220
Course Name: Hydrocarbon Thermodynamics

Date: 18.11.19
Time: 1 hour
Max Marks: 40
Weightage: 20%

Extract of question distribution [outcome wise & level wise]

Q.NO.	C.O.NO	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels			Thought provoking type [Marks allotted] Bloom's Levels			Problem Solving type [Marks allotted]			Total Marks
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K =Knowledge Level C = Comprehension Level, A = Application Level

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Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

SCHOOL OF Engineering

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

SOLUTION

Date: 18.11.19

Semester: 3rd

Time: 1 hour

Course Code: PET 220

Max Marks: 40

Course Name: **Hydrocarbon Thermodynamics**

Weightage: 20%

Part A (2Q x5 M = 10 Marks)

Q No	**Solution**	**Scheme of Marking**	**Max. Time required for each Question**
1	In thermodynamics, the Helmholtz free energy is a thermodynamic potential that measures the useful work obtainable from a closed thermodynamic system at a constant temperature and volume (isothermal, isochoric) ... the system to reach a definite state. ❖ **Reference or Primitive Properties** The properties which enable us to define the state of the system are known as reference properties. As the name implies, these properties have absolute values which are measured relative to some arbitrary reference state. For example, temperature, pressure, volume, entropy etc. are reference properties. ❖ **Energy Properties** These are defined as the properties in which the changes in the thermodynamic functions such as internal energy (U), enthalpy (H), etc. indicate some useful work under certain conditions. For example, Gibbs free energy (G), Helmholtz free energy (A), internal energy (U), enthalpy (H), etc. ❖ **Derived or Mathematically Derived Properties** These properties are mathematically derived on the basis of the aforementioned reference and energy properties. For instance, Joule–Thomson coefficient (μ), specific heat (C), isothermal compressibility (α), volume expansivity (β), etc.	**2.5+2.5**	**5**
2	The Kelvin–Planck statement (or the heat engine statement) of the second law of thermodynamics states that. It is impossible to devise a cyclically operating device, the sole effect of which is to absorb energy in the form of heat from a single thermal reservoir and to deliver an equivalent amount of work. Clausius statement states that it is impossible to construct a device whose sole effect is the transfer of heat from a cool reservoir to a hot reservoir. Equivalently, heat spontaneously flows from a hot body to a cooler one, not the other way around.	**1+2+2**	**5**

Part B (2Q x10 M = 20 Marks)

<table>
<tr><th>Q No</th><th>Solution</th><th>Scheme of Marking</th><th>Max. Time required for each Question</th></tr>
<tr><td>3</td><td>An exothermic reaction releases energy and feels warm while an endothermic reaction absorbs energy and feels cool

$Zn + S = ZnS$ $\Delta H = -44.0$ kcal/kmol
$2ZnS + 3O_2 = 2ZnO + 2SO_2$ $\Delta H = -221.88$ kcal/kmol
$2SO_2 + O_2 = 2SO_3$ $\Delta H = -46.88$ kcal/kmol
$ZnO + SO_3 = ZnSO_4$ $\Delta H = -55.10$ kcal/kmol

On multiplying (A) by 2 and adding Eq. (B), The rearrangement gives
$2Zn + 2S = 2ZnS$ $\Delta H_a = 2 \times (-44.0)$ kcal/kmol
$2ZnS + 3O_2 = 2ZnO + 2SO_2$ $\Delta H_b = -221.88$ kcal/kmol

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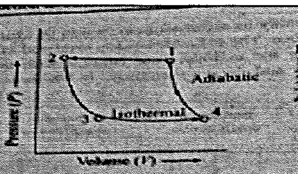
$2Zn + 2S + 3O_2 = 2ZnO + 2SO_2$ $\Delta H = -309.88$ kcal/kmol (E)
Similarly, on multiplying (C) by 2 and adding Eq. (D), the rearrangement gives
$2SO_2 + O_2 = 2SO_3$ $\Delta H_c = -46.88$ kcal/kmol
$2ZnO + 2SO_3 = 2ZnSO_4$ $\Delta H_d = 2 \times (-55.10)$ kcal/kmol

$2ZnO + 2SO_3 + O_2 = 2ZnSO_4$ $\Delta H = -157.08$ kcal/kmol (F)
Now on addition of Eqs. (E) and (F), we get
$2Zn + 2S + 3O_2 = 2ZnO + 2SO_2$ $\Delta H = -309.88$ kcal/kmol
$2ZnO + 2SO_3 + O_2 = 2ZnSO_4$ $\Delta H = -157.08$ kcal/kmol

$2Zn + 2S + 4O_2 = 2ZnSO_4$ (G)
or
$Zn + S + O_2 = ZnSO_4$ (H)
Then
$\Delta H_{f(ZnSO_4)} = 2\Delta H_a + \Delta H_b + \Delta H_c + 2\Delta H_d$
$= 2(-44) + (-221.88) + (-46.88) + 2(-55.10)$
$= (-309.88) + (-157.08)$
$= -466.96$ kcal/kmol for 2 kmols of $ZnSO_4$
Therefore, for 1 kmol of $ZnSO_4$, it is -233.48 kcal/kmol.</td><td>3+7</td><td>15</td></tr>
<tr><td>4</td><td>Step I: Reversible Isothermal Expansion (Process 1–2)
The heat source at temperature T_H is put in contact with the cylinder containing ideal gas. Now the gas is allowed to expand isothermally (as T_H = constant) from the state point 1 to 2 (volume change V_1 to V_2). As a result, the temperature of the gas decreases. Internal work is done by the system on the surroundings. Due to the drop in temperature, a certain amount of heat is transferred from the hot reservoir into the cylinder gas, to maintain the initial temperature T_H. The temperature constancy is maintained at T_H. Hence the gas expands isothermally and reversibly, and finally reaches position 2 along with the piston. This operation is represented diagrammatically by line 1–2 of the P–V diagram in Fig. 5.10.
Since the process is an isothermal expansion of an ideal gas, so the change in internal energy is zero, i.e., $\Delta U = 0$ or $dU = 0$.
The first law of thermodynamics then becomes
$dQ = dU + dW$
$= 0 + dW$
$dQ = dW$
It implies that all the heat added to the system is used to do work. The amount of heat absorbed by the gas is Q_H (corresponding to temperature T_H).</td><td>4+6</td><td>20</td></tr>
</table>



Legend
1–2: Reversible isothermal expansion
2–3: Reversible adiabatic expansion
3–4: Reversible isothermal compression
4–1: Reversible adiabatic compression

Fig. 5.10 *P–V* diagram of Carnot cycle.

The work done by the gas is $W_1 = \int_1^2 PdV$, which can be replaced by $P = nRT/V$ using the ideal gas law. The integral becomes

$$W_1 = nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

For 1 mole of an ideal gas, the expression becomes -

$$W_1 = Q_H = RT_H \ln \frac{V_2}{V_1} \quad (5.4)$$

This is the maximum work done by an ideal gas during reversible isothermal expansion.

Step II: Reversible Adiabatic Expansion (Process 2–3)

At step II the cylinder head, which was a perfect heat conductor and in contact with the heat source, is now insulated properly by replacing the heat source with the insulating stand. So there is no scope of heat transfer between the system and the surroundings. The expansion of gas goes on continuously until its temperature drops from T_H to T_L. So, the gas is allowed to expand adiabatically and reversibly from state point 2 to 3 (volume change V_2 to V_3). The pressure remains uniform throughout the system. This operation is represented diagrammatically by line 2–3 of the *P–V* diagram.

As the expansion is adiabatic, heat absorbed by the gas = 0, i.e., $Q = 0$.

Putting this in the first law of thermodynamics, we have

$$dQ = dU + dW$$
$$0 = dU + dW$$
$$dW = -dU = -C_V (T_L - T_H) = C_V (T_H - T_L)$$

So, the work done by the system for Step II

$$W_2 = C_V (T_H - T_L) \quad (5.5)$$

Step III: Reversible Isothermal Compression (Process 3–4)

The insulation is removed from the cylinder head, and it is brought into contact with the sink at T_L to make it perfect conductor. Now the piston is pushed inward by an external force, doing

work on the gas. The gas is now allowed to compress isothermally from state point 3 to 4, which in turn causes the temperature to rise. Due to the rise in temperature, heat is transferred from the cylinder to the sink (cold reservoir) to maintain at temperature T_L by dropping itself. Thus the gas temperature is kept constant at T_L. During this process, work is done on the system. The piston finally reaches state point 4. Pressure and volume change from P_3 and V_3 to P_4 and V_4.

The amount of heat released from the gas during this process is Q_L (corresponding to T_L). Therefore, the reversible work of compression (work done on the system) is given by

$$W_3 = Q_L = -\int_{V_3}^{V_4} PdV = -RT_L \ln \frac{V_4}{V_3} = RT_L \ln \frac{V_3}{V_4} \quad (5.6)$$

Step IV: Reversible Adiabatic Compression (Process 4–1)

The cylinder head which was in contact with cold reservoir is now insulated properly by replacing the cold reservoir with the insulating stand. The system becomes adiabatic. The gas is compressed reversibly and adiabatically from the state point 4 to 1. The gas returns to its initial state. The temperature rises from T_L to T_H during this reversible adiabatic compression process, which completes the cycle. In other words, the gas is allowed to compress adiabatically and reversibly along 4–1 to bring it back to its original pressure, volume and temperature.

Since the pressure is adiabatic, the amount of heat absorbed by the gas = 0, i.e., $Q = 0$.

Putting this in the first law of thermodynamics, we have

$$dQ = dU + dW$$
$$0 = dU + dW$$
$$dW = -dU = -C_V (T_H - T_L)$$

The work done on the system or work of compression is given by

$$W_4 = -[-C_V (T_H - T_L)]$$
$$= C_V (T_H - T_L) \quad (5.7)$$

The system returns to its original state and the Carnot cycle is completed.

The net work done by the gas in the complete cycle is given by

$$W_{cycle} = W_1 + W_2 - W_3 - W_4$$
$$= RT_H \ln \frac{V_2}{V_1} + C_V(T_H - T_L) - RT_L \ln \frac{V_3}{V_4} - C_V(T_H - T_L)$$
$$= RT_H \ln \frac{V_2}{V_1} - RT_L \ln \frac{V_3}{V_4}$$

But considering the adiabatic changes in operations 2 and 4, we have

(i) $T_L V_2^{\gamma-1} = T_H V_3^{\gamma-1}$

(ii) $T_H V_1^{\gamma-1} = T_L V_4^{\gamma-1}$

Dividing the above equations, we get

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

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Hence

$$W = Q_H - Q_L = RT_H \ln\frac{V_2}{V_1} - RT_L \ln\frac{V_3}{V_4}$$

$$= RT_H \ln\frac{V_2}{V_1} - RT_L \ln\frac{V_2}{V_1}$$

$$= R\ln\frac{V_2}{V_1}(T_H - T_L) \quad (5.8)$$

5.4.1 Efficiency of Carnot Cycle

Carnot efficiency is the maximum possible efficiency for an engine cycle operating between high and low temperature reservoirs at T_H and T_L respectively. The temperatures in Carnot efficiency expression must be expressed in terms of degrees Kelvin. Temperature in °C in the expression of efficiency causes erroneous results.

The efficiency of the Carnot cycle can be defined as

$$\eta = \frac{\text{Heat converted into work}}{\text{Heat absorbed from the source } (T_H)}$$

$$= \frac{\text{Net work output}}{\text{Total heat input}}$$

$$= \frac{W}{Q_H} = \frac{R\ln\frac{V_2}{V_1}(T_H - T_L)}{RT_H \ln\frac{V_2}{V_1}}$$

$$= \frac{(T_H - T_L)}{T_H} = 1 - \frac{T_L}{T_H} < 1 \quad (5.9)$$

This equation can be rearranged as

$$\frac{W}{Q_H} = \frac{(T_H - T_L)}{T_H}$$

$$W = Q_H\frac{(T_H - T_L)}{T_H} \quad (5.10)$$

This equation can be generalized as

$$W = Q\frac{\Delta T}{T} \quad (5.11)$$

This relation shows that maximum amount of work can be obtained from the engine operating between the temperatures T_H and T_L. This is the mathematical expression of the second law of thermodynamics.

Hence the efficiency of a Carnot cycle is given by

$$\frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = \frac{T_H - T_L}{T_H} \quad (5.12)$$

Part C (1Q x10 M =10 Marks)

<table>
<tr><th>Q No</th><th>Solution</th><th>Scheme of Marking</th><th>Max. Time required for each Question</th></tr>
<tr><td>5</td><td>

lution:

(a) We are given that $T_H = 650 + 273 = 923$ K and $T_L = 30 + 273 = 303$ K.
By applying Eq. (5.9), we have

$$\eta = \frac{T_H - T_L}{T_H} = \frac{923 - 303}{923} = 0.671$$

(b) From the knowledge of the ratio of heat and temperature between the two regions have

$$\frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

or

$$Q_L = \frac{T_L Q_H}{T_H} = \frac{303 \text{ K} \times 585 \text{ kJ}}{923 \text{ K}}$$

$$= 192 \text{ kJ}$$

</td><td>5+5</td><td>15</td></tr>
</table>

Roll No											

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

END TERM FINAL EXAMINATION

Semester: Odd Semester: 2019 - 20

Course Code: PET 220

Course Name: HYDROCARBON THERMODYNAMICS

Program & Sem: B.Tech (PET) & III Sem

Date: 26 December 2019

Time: 1:00 PM to 4:00 PM

Max Marks: 80

Weightage: 40%

Instructions:

(i) Read the all questions carefully and answer accordingly.
(ii) Scientific and nonscientific calculator are allowed

Part A [Memory Recall Questions]

Answer all the Questions. Each Question carries 4 marks. (5Qx4M=20M)

1. Define state function and path function with example. (C.O.No.1) [Knowledge]

2. Define Normality and mole fraction. 1 M of HCl solution is equal to ---- N of HCl solution. (Fill in the blank) (C.O.No.4) [Knowledge]

3. What is gas formation volume factor? What is its unit? What is API gravity of hydrocarbon? (C.O.No.5) [Knowledge]

4. What is sensible heat? Define latent heat of fusion and latent heat of vaporization. (C.O.No.2) [Knowledge]

5. What is the difference between Helmholtz free energy and Gibbs free energy function? The unit of entropy is ------ and the unit of Enthalpy is ------ (Fill in the blanks) (C.O.No.3) [Knowledge]

Part B [Thought Provoking Questions]

Answer all the Questions. Each Question carries 10 marks. (3Qx10M=30M)

6. Draw and explain the following for vapour- liquid equilibrium for binary mixture of benzene and toluene
   a. Temperature composition (T-x-y) diagram
   b. Pressure composition (P-x-y) diagram (C.O.No.4) [Comprehension]

7. Classify and explain the hydrocarbon reservoir according to the initial reservoir pressure. Draw the pressure temperature diagram for the following case and locate the following points
   a. Initial reservoir position
   b. Critical point
   c. Dew point line
   d. Bubble point line

Case 1: The bubble point pressure of the reservoir is 2000 psi at 100^0 C temperature.
Case 2: The initial reservoir pressure is 2500 psi and temperature is 100^0 C.
Case 3: The critical reservoir pressure and temperature are 2200 psi and 120° C

(C.O.No.5) [Comprehension]

8. Classify the oil reservoir based on the composition, gas-oil ratio, appearance, and pressure-temperature phase diagrams. Write short notes on
   a. Volatile oil reservoir
   b. Near critical oil reservoir (C.O.No.5) [Comprehension]

Part C [Problem Solving Questions]

Answer all the Questions. Each Question carries 10 marks. (3Qx10M=30M)

9. A solution of Hydrochloric acid (HCl) is prepared by the careful addition of 16.5 $\times 10^{-3}$ kg of the acid to 51.5 $\times 10^{-3}$ kg of water. The density of the solution is 1.1 $\times 10^{-3}$ kg. m^{-3}. Calculate
   i. The concentration in weight percent
   ii. The molality
   iii. The molarity
   iv. The normality
   v. The mole fraction of HCl (C.O.No.4) [Application]

10. A gas well is producing a natural gas with the following composition. Assuming an ideal gas behavior, calculate the following
   i. Apparent molecular weight
   ii. Specific gravity
   iii. Gas density at 3000 psia and 170°F
   iv. Specific volume at 3000 psia and 170°F

Sl.No	Component	Composition (y_i)
1	CO_2	0.05
2	CH_4	0.85
3	C_2H_6	0.05
4	C_3H_8	0.05

(C.O.No.5) [Application

11. A gas reservoir has the following gas composition: the initial reservoir pressure and temperature are 2500 psia and 150°F, respectively. Calculate the pseudo reduced pressure and pseudo reduced temperature of the system. What is compressibility factor of gas?

Sl.No	Component	Composition (y_i)	Critical Temperature (T_{ci} in °R)	Critical Pressure (p_{ci} in psi)
1	CO_2	0.02	547.91	1071
2	N_2	0.01	227.49	493.1
3	CH_4	0.85	343.33	666.4
4	C_2H_6	0.04	549.92	706.5
5	C_3H_8	0.03	666.06	616.4
6	iC_4H_{10}	0.03	734.46	527.9
7	nC_4H_{10}	0.02	765.62	550.6

(C.O.No.5) [Application]

SCHOOL OF ENGINEERING

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

END TERM FINAL EXAMINATION

Extract of question distribution [outcome wise & level wise]

Q.NO.	C.O.NO (% age of CO)	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels	Thought provoking type [Marks allotted] Bloom's Levels	Problem Solving type [Marks allotted]	Total Marks
			K	C	A	
Q. NO1	C.O.1	Unit-I	4	-	-	4
Q. NO2	C.O.4	Unit-IV	4	-	-	4
Q. NO3	C.O.5	Unit-V	4	-	-	4
Q. NO4	C.O.2	Unit-II	4	-	-	4
Q. NO5	C.O.3	Unit-III	4	-	-	4
Q.NO.6	C.O. 4	Unit-IV	-	10	-	10
Q.NO.7	C.O. 5	Unit-V	-	10	-	10
Q.NO.8	C.O. 5	Unit-V	-	10	-	10
Q.NO.9	C.O. 4	Unit-V	-	-	10	10
Q.NO.10	C.O. 5	Unit-V	-	-	10	10
Q.NO.11	C.O.5	Unit-V	-	-	10	10
	Total Marks		20	30	30	80

K =Knowledge Level C = Comprehension Level, A = Application Level

Note: While setting all types of questions the general guideline is that about 60%

Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

last page

I hereby certify that all the questions are set as per the above guidelines.

Faculty Signature:

Reviewer Commend:

Format of Answer Scheme

SCHOOL OF ENGINEERING

SOLUTION

Semester: Odd Sem. 2019-20
Course Code: PET 220
Course Name: HYDROCARBON THERMODYNAMICS
Program & Sem: B.Tech (PET) & 3

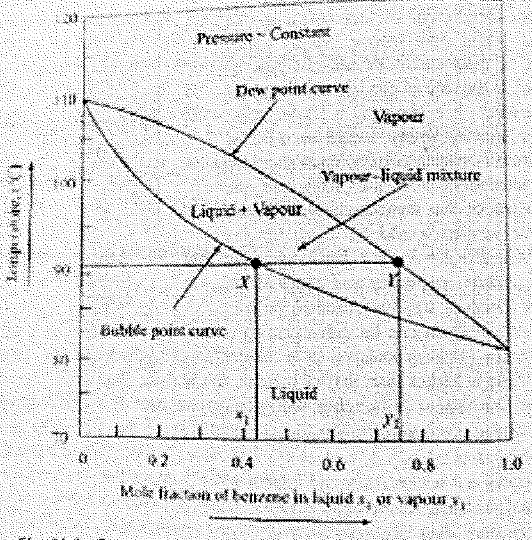
Date: 26.12.2019
Time: 1:00 PM to 4:00 PM
Max Marks: 80
Weightage: 40%

Part A (5Q x 4M = 20Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
1	A state function is a property whose value does not depend on the path taken to reach that specific value ex Entropy. In contrast, functions that depend on the path from two values are call path functions ex Work, heat. Both path and state functions are often encountered in thermodynamics.	**2+2**	**4**
2	Normality (N) is defined as the number of mole equivalents per liter of solution: normality = number of mole equivalents/1 L of solution. Like molarity, normality relates the amount of solute to the total volume of solution; however, normality is specifically used for acids and bases. 1M HCl solution is equal to 1 N of HCl	**1.5+1.5+1**	**4**
3	The gas formation volume factor is used to relate the volume of gas, as measured at reservoir conditions, to the volume of the gas as measured at standard conditions, i.e., 60°F and 14.7 psia. This gas property is then defined as the actual volume occupied by a certain amount of gas at a specified pressure and temperature, divided by the volume occupied by the same amount of gas at standard conditions. Unit ft^3/scf $\text{API gravity} = \frac{141.5}{SG} - 131.5$	**2+1+1**	**4**
4	**sensible heat** is energy transferred that is evident in change of the temperature of the atmosphere or ocean, or ice, without those phase changes. **Latent heat of fusion** is the amount of **heat** required to change phase from solid to liquid at constant temperature.	**1+1.5+1.5**	**4**

	Latent heat of vaporization is a physical property of a substance. It is defined as the **heat** required to change one mole of liquid at its boiling point under standard atmospheric pressure. It is expressed as kg/mol or kJ/kg		
5	The Gibbs' free energy is the energy available to do non-PV work in a thermodynamically-closed system at constant pressure and temperature. The Helmholtz free energy is the maximum amount of "useful" (non-PV) work that can be extracted from a thermodynamically-closed system at constant volume and temperature. The unit of entropy is J K^{-1} mol^{-1} and the unit of Enthalpy is kJ mol^{-1}	**2+1+1**	**4**

Part B (3Q x 10M = 30 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
6	**10.6.1 Temperature–Composition (T–x–y) Diagram** The vapour–liquid equilibrium of a binary mixture at constant pressure can be represented [illegible] T–x–y diagram in which temperature (along the ordinate) is plotted against composition of liquid and vapour (along the abscissa). This diagram is known as the *boiling point diagram* and is shown in Fig. 10.4. It is used to understand how the equilibrium values change with temperature. The boiling point diagram for a benzene–toluene system at a total pressure of 101.32 kPa is depicted in the figure. It can be seen from the plot that benzene, which boils at 80.1°C, is more volatile than toluene, which boils at 110.6°C. The upper curve is the saturated vapour curve, which is called the dew point curve, and the lower curve is the saturated liquid curve, known as the bubble point curve. These two curves meet where the mixture becomes purely one component, when $x_1 = 0$ (and $y_1 = 0$, pure component 2) or $x_1 = 1$ (and $y_1 = 1$, pure component 1). The temperatures at these two points correspond to the boiling points of the two pure components.  Fig. 10.4 Temperature–composition diagram of binary VLE mixture. The region bounded by these two curves is called the *two-phase region*, where the mixture is partly liquid and partly vapour. The region below the bubble point curve is known as *sub-cooled region* (sub-cooled liquid) and the region above the dew point curve is *superheated region* (superheated vapour). Any point above the upper curve represents a mixture which consists entirely of vapour and any point below the lower curve represents a completely liquid mixture. Point X on the lower curve, represents a completely liquid mixture of composition $x_1 = 0.42$ wh[illegible]	**5+5**	**10**

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will start to boil at 90°C, and the composition of the vapour in equilibrium is represented by point y' that is, $y_1 > x_1$. So the points x and y, which lie on the same horizontal line, represent equilibrium compositions at a temperature of 95°C. For systems which follow Raoult's law, the boiling point diagram can be drawn from the pure component vapour pressure data. These two curves meet where the mixture becomes purely one component, where $x_1 = 0$ (and $x_2 = 1$, pure component 2) or $x_1 = 1$ (and $x_2 = 0$, pure component 1). The temperatures at these two points correspond to the boiling points of the two pure components.

10.6.2 Pressure–Composition (P–x–y) Diagram

At constant temperature the vapour–liquid equilibrium of a binary mixture can be illustrated on a P-x-y diagram (see Fig. 10.5) with pressure along the ordinate and the composition of liquid and vapour along the abscissa. Considering again the benzene–toluene system, benzene (species 1) is the lighter or more volatile of the two, so at saturated condition the vapour pressure of benzene is higher than that of toluene (species 2), i.e., $P_1^{Sat} > P_2^{Sat}$.

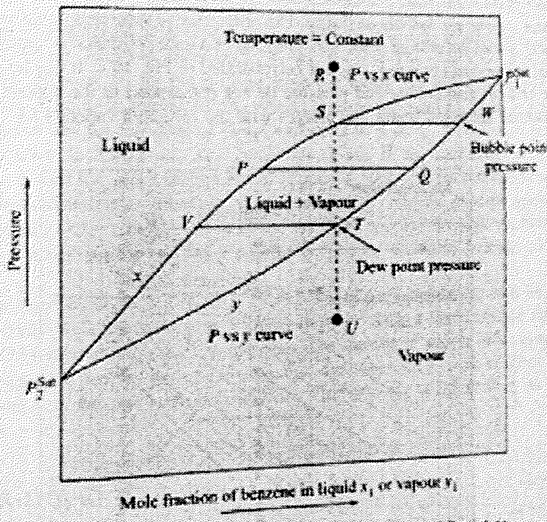

Fig. 10.5 Pressure–composition diagram of binary VLE mixture

The upper curve is the saturated liquid curve, which is called the P versus x curve, and the lower curve is the saturated vapour curve and is known as the P versus y curve. The space between the two curves is the region of coexistence of both liquid and vapour phases is called the two-phase region. Here the mixture is partly saturated liquid and partly saturated vapour. The vapour is richer in the more volatile component, i.e., benzene. Consequently, at any pressure, $y_1 > x_1$. In Fig. 10.5, the horizontal lines such as PQ, VT and SW are called tie lines. They connect the vapour and liquid phases in equilibrium. Now, on lowering the pressure at constant temperature, the liquid mixture starts forming the vapour bubble and therefore the pressure at which the bubble formation takes place is known as the bubble point pressure. The point S in the line RSTU represents the bubble point pressure. The condition of the binary vapour–liquid equilibrium mixture is represented by the line RSTU. On further reduction in pressure, the entire liquid is gradually transformed into vapour and a drop of liquid is left. This pressure is called the dew point pressure, represented by the point T. The pressure is reduced further and at the point U, the vapour is converted into superheated vapour.
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<tr><td>7</td><td>
Undersaturated oil reservoir. If the initial reservoir pressure p_i is greater than the bubble-point pressure p_b of the reservoir fluid, the reservoir is labeled an undersaturated oil reservoir.
2. Saturated oil reservoir. When the initial reservoir pressure is equal to the bubble-point pressure of the reservoir fluid the reservoir is called a saturated oil reservoir.
3. Gas-cap reservoir. If the initial reservoir pressure is below the bubble point pressure of the reservoir fluid, the reservoir is termed a gas-cap or two-phase reservoir, in which the gas or vapor phase is underlain by an oil phase. The appropriate quality line gives the ratio of the gas-cap volume to reservoir oil volume.
</td><td>6+4</td><td>10</td></tr>
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	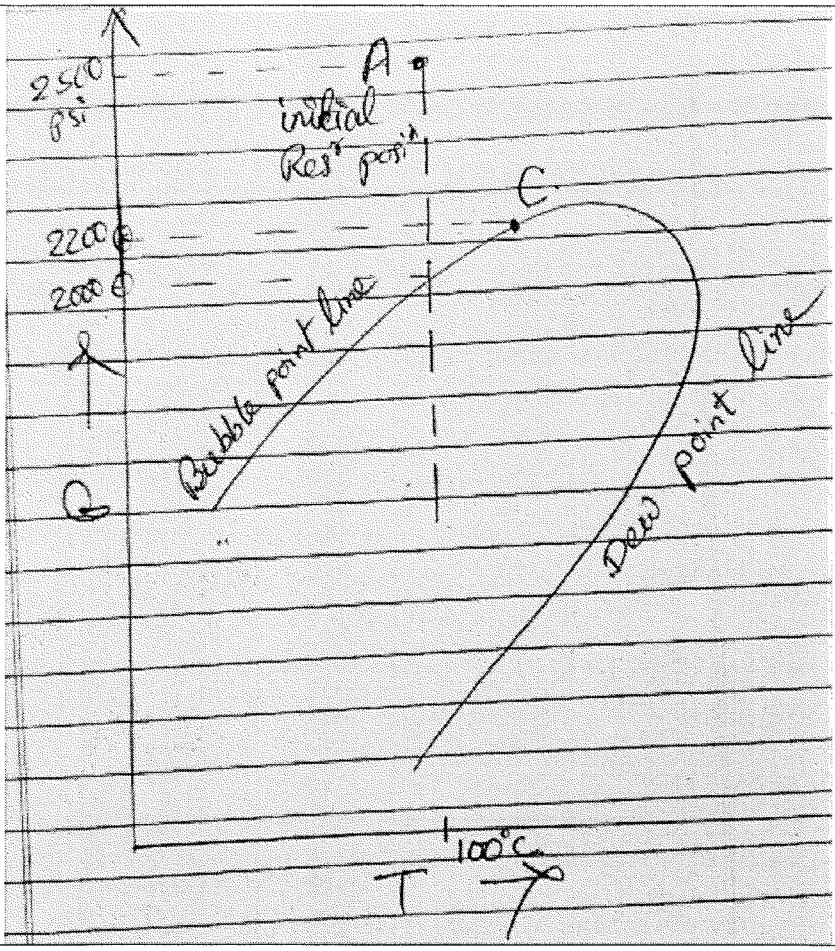		
8	• Ordinary black oil • Low-shrinkage crude oil • High-shrinkage (volatile) crude oil • Near-critical crude oil	2+4+4	10

3. **Volatile crude oil.** The phase diagram for a volatile (high-shrinkage) crude oil is given in Figure 1-6. Note that the quality lines are close together near the bubble-point and are more widely spaced at lower pressures. This type of crude oil is commonly characterized by a high liquid shrinkage immediately below the bubble-point as shown in Figure 1-7. The other characteristic properties of this oil include:

- Oil formation volume factor less than 2 bbl/STB
- Gas-oil ratios between 2,000–3,200 scf/STB
- Oil gravities between 45–55° API

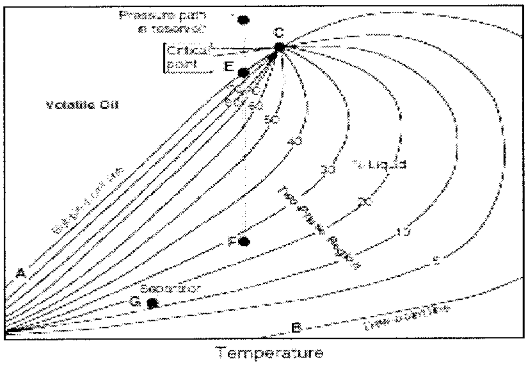

Figure 1-6. A typical p-T diagram for a volatile crude oil.

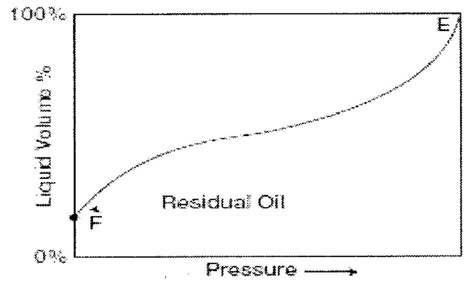

Figure 1-7. A typical liquid-shrinkage curve for a volatile crude oil.

4. **Near-critical crude oil.** If the reservoir temperature T is near the critical temperature T_c of the hydrocarbon system, as shown in Figure 1-8, the hydrocarbon mixture is identified as a near-critical crude oil. Because all the quality lines converge at the critical point, an isothermal pressure drop (as shown by the vertical line EF in Figure 1-8) may shrink the crude oil from 100% of the hydrocarbon pore volume at the bubble-point to 55% or less at a pressure 10 to 50 psi below the bubble-point. The shrinkage characteristic behavior of the near-critical crude oil is shown in Figure 1-9. The near-critical crude oil is characterized by a high GOR in excess of 3,000 scf/STB with an oil formation volume factor of 2.0 bbl/STB or higher. The compositions of near-critical oils are usually characterized by 12.5 to 20 mol% heptanes-plus, 35% or more of ethane through hexanes, and the remainder methane.

Figure 1-10 compares the characteristic shape of the liquid-shrinkage curve for each crude oil type.

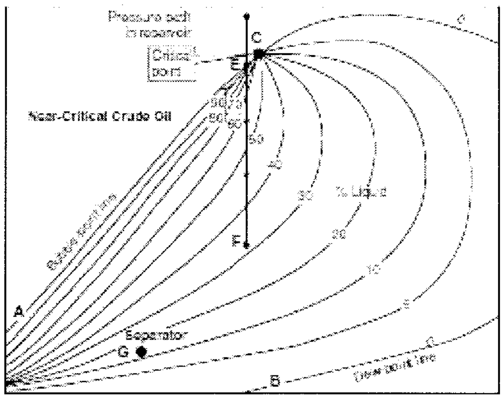

Figure 1-8. A schematic phase diagram for the near-critical crude oil.

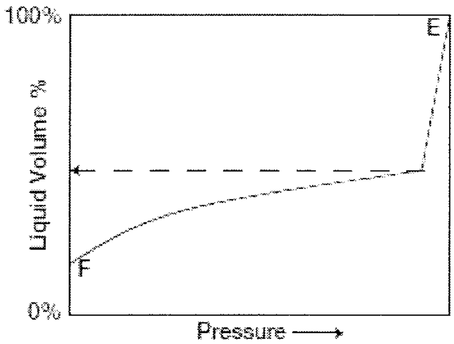

Figure 1-9. A typical liquid-shrinkage curve for the near-critical crude oil

Part C

(3Q x 10M = 30Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question

9	(i) HCl % = $[16.5\times10^{-3}/(51.5+16.5)\times10^{-3}]\,100$ (ii) no. of moles of HCl = $\frac{16.5\times10^{-3}}{36.5\times10^{-3}}$ molarity = $\frac{\text{no. of moles of ~~solvent~~ HCl}}{\text{~~51.5×10}^{-3}\text{~~ Vol}^m\text{ of sol}^n}$ (iii) Vol^n of sol^n = $\frac{(16.5+51.5)\times10^{-3}}{1.1\times10^{-3}}$ m^3 (iv) molality = $\frac{\text{no. of moles of HCl}}{\text{kg of solvent}}$ (v) no. of equivalence of HCl = $\frac{16.5\times10^{-3}}{36.5\times10^{-3}}$ Normality = no of equivalence / lit. (vi) mole fraction of HCl = $\frac{\text{no of moles of HCl}}{\text{moles of }(H_2O+HCl)}$	2*5	10
10	see below	2.5*4	10
11	The gas compressibility factor z is a dimensionless quantity and is defined as the ratio of the actual volume of n-moles of gas at T and p to the ideal volume of the same number of moles at the same T and p	2+4+4	10

Question 10:

Component	y_i	M_i	$y_i \cdot M_i$
CO_2	0.05	44.01	2.200
C_1	0.90	16.04	14.436
C_2	0.03	30.07	0.902
C_3	0.02	44.11	0.882
			$M_a = 18.42$

a. Apply Equation 2-5 to calculate the apparent molecular weight:

$M_a = 18.42$

b. Calculate the specific gravity by using Equation 2-10:

$\gamma_g = 18.42 / 28.96 = 0.636$

c. Solve for the density by applying Equation 2-7:

$$\rho_g = \frac{(2000)(18.42)}{(10.73)(610)} = 5.628 \text{ lb/ft}^3$$

d. Determine the specific volume from Equation 2-8:

$$v = \frac{1}{5.628} = 0.178 \text{ ft}^3\text{/lb}$$

Component	y_i	T_{ci}, °R	$y_i T_{ci}$	p_{ci}	$y_i\, p_{ci}$
CO_2	0.02	547.91	10.96	1071	21.42
N_2	0.01	227.49	2.27	493.1	4.93
C_1	0.85	343.33	291.83	666.4	566.44
C_2	0.04	549.92	22.00	706.5	28.26
C_3	0.03	666.06	19.98	616.4	18.48
$i - C_4$	0.03	734.46	22.03	527.9	15.84
$n - C_4$	0.02	765.62	15.31	550.6	11.01
			$T_{pc} = 383.38$		$p_{pc} = 666.38$

Step 1. Determine the pseudo-critical pressure from Equation 2-14:

$$p_{pc} = 666.18$$

Step 2. Calculate the pseudo-critical temperature from Equation 2-15:

$$T_{pc} = 383.38$$

Step 3. Calculate the pseudo-reduced pressure and temperature by applying Equations 2-12 and 2-13, respectively:

$$p_{pr} = \frac{p}{p_{pc}} \qquad (2\text{-}12)$$

$$T_{pr} = \frac{T}{T_{pc}} \qquad (2\text{-}13)$$