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Chapter 5 ⇝ Single - Phase System.

1- Solid & Liquid densities :-

- independent of P ⟶ in compressible
- Slightly dependent on T (can be neglected)

+ Mixtures of liquids.

$\bar{\rho}$ = average density ; $\frac{1}{\bar{\rho}} = \sum_{i=1}^{N} \frac{x_i}{\rho_i}$

OR $\bar{\rho} = \sum_{i=1}^{N} x_i \rho_i$

x_i ⇝ mass Fraction.

2- Ideal Gas :-

$$\hat{V} = \frac{V}{n} = \frac{RT}{P}$$

Density of gas is highly dependent on T & P

We need an equation of state (EOS)

$P \propto \frac{nT}{V}$ ⇝ base of (EOS)

For ideal gases : $P = \frac{nRT}{V}$

R = gas constant ⇝ $PV = nRT$ ⇝ $R = \frac{PV}{nT}$ (P: absolute pressure, T: absolute temp)

R = 8.314 $m^3 \cdot Pa / (mole \cdot K)$

= 0.08206 $L \cdot atm / (mol \cdot K)$

= 0.7302 $ft^3 \cdot atm / (lb\text{-}mol \cdot {}^\circ R)$

= 10.73 $ft^3 \cdot Psia / (lb\text{-}mol \cdot {}^\circ R)$

+ Standard temp & pressure, STP

$T_S = 0^\circ C$ $P_S = 1 atm$

$$\frac{RT_S}{P_S} = \hat{V}_S = 22.4 \frac{m^3 (STP)}{kmol} = \frac{22.4\ L(STP)}{mol}$$

$$= 359 \frac{ft^3\ (STP)}{lb\text{-}mol}$$

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* When is it safe to use ideal gas law ?

1) $T \geq 0°C$ $P \leq 1 atm$

2) When $|\epsilon| < 1\%$ $|\epsilon| = \frac{x_{ideal} - x_{true}}{x_{true}}$

$|\epsilon| < 1\%$ when $\frac{RT}{P} < 5$ L/mol (diatomic gas: e.g. $O_2, N_2 \rightarrow H, \dots$)

$\frac{RT}{P} > 20$ L/mol (other gas)

$\hat{V} = \frac{V}{n}$ = specific molar volume $\Rightarrow \hat{V}_{ideal} = \frac{RT}{P}$

$\rho = \frac{m}{V} = \frac{nM}{V} = \frac{M}{\hat{V}} \Rightarrow \boxed{\rho = \frac{MP}{RT}}$

* Ideal Gas mixtures : n_A, n_B, n_C, at

partial pressure (of A) = P_A = pressure could be exerted by n_A moles alone in same V at same T

* pure compononent volume V_A = volume occupied by n_A moles alone at ~~T~~ T of the mix, pressure found

$PV = nRT$

tot tot tot

$P_A V = n_A RT$

$P = nRT$

$\Rightarrow \frac{P_A}{P} = y_A \Leftarrow$ ~~Dalton~~ always true

$\sum_{i=1}^{NN} P_i = P$

$V_A = y_A V \longrightarrow$ ideal gas only

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Ty - Pg 197 :

Q2 → ideal gas mixture , $P = 10$ bar / $T = 200°C$ / $V = 100\ m^3$

$y_{H_2} = 0.5$ / $y_{N_2} = 0.5$

$P_H = (0.5)(10) = 5$ bar

$V_{H_2} = (0.5)(100) = 50\ m^3$

} if T↑ , P_{H_2}? V_{H_2}?

$P_{H_2} V = n_2 RT$

$P V_{H_2} = n_{H_2} RT$

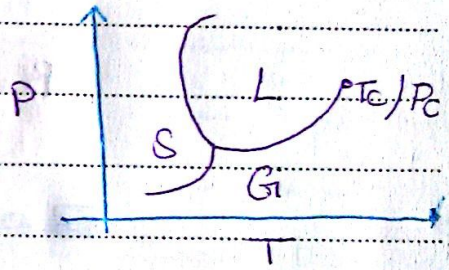
P_{H_2}↑ , V_{H_2}↑

* if we don't have ideal gas →

EOS for No ideal Gas

at sufficienty T & High P → $\hat{V}$ ideal is way off

Critical T & P : T_c & T_p



T_c : The highest T at which aspecies can existin 2 phase (L, G)

P_c : cortes ponding pressure

For water, $T_c = 374.15°C$

$P_c = 218.3$ atm

at $T > T_c$ No condensation can occure no matter what pis

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Vapor VS gas :-

Vapor :- gaseous species below it's T_c

gas :- species above it's T_c

* Super critical fluid :- substance at temprature above T_c & P_c , pressure above

I. virial EOS :-

$$\frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}} + \frac{C}{\hat{V}} + \frac{D}{\hat{V}} \dots$$

if $B = C = D = \dots$ ideal gas Law.

Simple approximation →

$$\frac{P\hat{V}}{RT} = 1 + \frac{BP}{RT}$$

$$B = \frac{PT_c}{P_c}(B_0 + \omega B_2)$$

~~$B_0 = 0.139 - 0.172$~~ $B_0 = 0.083 + \frac{0.422}{T_r^{1.6}}$ $\left(T_r = \frac{T}{T_c}\right)$

$B_0 = 0.139 + \frac{0.172}{T_r^{1.6}}$ } $T_r = \frac{T}{T_c}$ → reduced T

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

ω = pitzer acentric factor (Table 5.3)

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Example ⇝ (Conversion From Standard Conditions)

Butane C_4H_{10} at 360°C and 3.00 atm abs. Flows into a reactor at rate of 1100 Kg/h. Calculate the Volumetric Flow rate of this stream using conversion From Standard conditions.

$$\dot{n} = \frac{1100\ Kg/h}{58.1\ Kg/Kmol} = 19.0\ Kmol/h$$

$T = 273 + 360 = 633°K$ | $P = 3.00\ atm$

$$\frac{P\dot{V}}{P_S V_S} = \frac{\dot{n} T}{T_S} \Rightarrow \dot{V} = \dot{n} \hat{V}_S \frac{T}{T_S} \frac{P_S}{P}$$

$$\dot{V} = \frac{19.0\ Kmol}{h} \left| \frac{22.4\ m^3(STP)}{Kmol} \right| \frac{633\ K}{273\ K} \left| \frac{1.00\ atm}{3.00\ atm} \right.$$

$$= 329\ m^3/h$$

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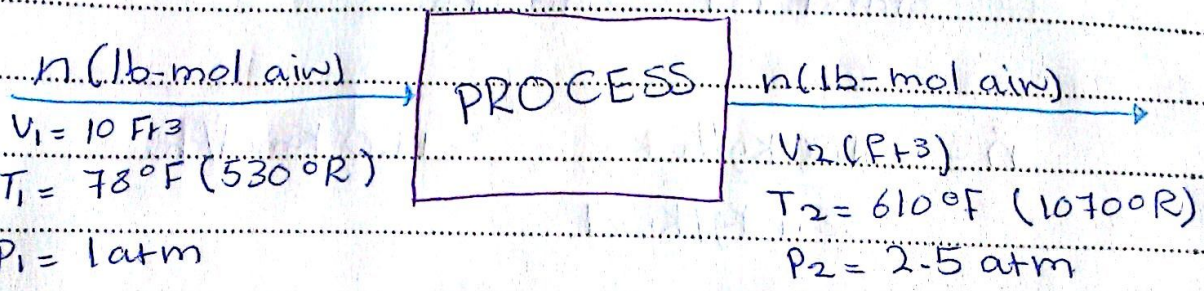
Example2 → " Effects of T and P on Volumetric FlowRates"

Ten Cubic feet of air at 70°F and 1.00 atm is heated to 610°F and compressed to 2.50 atm. What volume ~~does~~ does the gas occupy in it's ~~Final~~ Final State?



$$P_2 V_2 = nRT_2 \Rightarrow \frac{P_2 V_2}{P_1 V_1} = \frac{T_2}{T_1}$$

$$P_1 V_1 = nRT_1 \Rightarrow V_2 = V_1 \left(\frac{P_1}{P_2}\right)\left(\frac{T_2}{T_1}\right)$$

$$= \frac{10.0\ ft^3 \mid 1.00\ atm \mid 1070°R}{2.5\ atm \mid 530°R} = 8.08\ ft^3$$

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Example 3 ⟶ "Standard and True Volumetric Flow Rates"

The Flow rate of methane stream at 285°F and 1.30 atm is measured with an orifice meter. The Calibration chart for the meter indicates that the Flow rate is $3.95 * 10^5$ SGFH. Calculate the molar flow rate and the true volumetric flow rate of the stream.

SGFH = ft³ (STP) / h

$$\dot{n} = \frac{3.95 * 10^5 \text{ ft}^3}{\text{h}} \left| \frac{\text{lb-mol}}{359 \text{ ft}^3 \text{ (STP)}} \right. = 1.10 * 10^3 \text{ lb-moles/h}$$

$$\dot{V}_2 = \dot{V}_1 \left(\frac{T_2}{T_1}\right)\left(\frac{P_1}{P_2}\right) = (3.95 * 10^5 \text{ ft}^3/\text{h}) (745°\text{R} / 492°\text{R}) (1.00 \text{ atm} / 1.30 \text{ atm})$$

$$= 4.60 * 10^5 \text{ ft}^3/\text{h}$$

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III. Compressibility Factor EOS

Compressibility Factor = $Z = \frac{P\hat{V}}{RT}$

For ideal gas, $Z = 1$

Z can be found from tables (Perry's Hand book) or charts.

It's a function of T_r & P_r & $\hat{V}_r$ ideal

$T_r = \frac{T}{T_c}$, $P_r = \frac{P}{P_c}$

↳ table B.1

$$\hat{V}_r^{ideal} = \frac{\hat{V}}{\hat{V}_c\ ideal} = \frac{\hat{V}\,P_c}{RT_c}$$

* Non-ideal gas mixtures:

$T'_c = \sum y_i T_{ci}$

$P'_c = \sum y_i P_{ci}$

y_i = mole fraction

$$T'_r = \frac{T}{T'_c} \qquad P'_r = \frac{P}{P'_c}$$

P5-66 ~~>

$m = 100$ lbm CO_2

$V = 10.0$ Ft^3

$P_{safety\ limit} = 1600$ psig

$T_{max} = ??$

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$PV = ZnRT$

$T = \frac{PV}{ZnR} = \frac{1614.7\ psia \mid 10}{0.84 \mid 2.3\ lb\text{-}mol \mid 10.73} = 772\ °R$

$P = 1600 + 14.7 = 1614.7\ psia$ abso

$V = 10\ Ft^3$

$n = \frac{100}{44} = 2.3\ lb\text{-}mol$

CO_2 : $T_c = 304.2\ K$

$P_c = 72.9\ atm$

Appendix B.1 $M = 44$

$R = 10.73\ Ft^3 \cdot psia / (lb\text{-}mol \cdot °R)$

$T_r =$

$\frac{P}{P_c} = P_r = \frac{1614.7\ psia \mid 1\ atm}{72.9\ atm \mid 14.7\ psia} = 1.51$

$\hat{V}_r^{ideal} = \frac{\hat{V} P_c}{RT_c} = \frac{10\ Ft^3 \mid 72.9\ atm \mid lb\text{-}mol \cdot °R \mid 1.8\ °R}{2.3\ lb\text{-}mol \mid 304.2\ K \mid 0.7302\ Ft^3 \cdot atm}$

$\hat{V} = \frac{V}{n}$

$= 0.80$

dimensionless $Z = 0.84$

P5.74

$m = 10\ kg\ mix$

$T = 90°C$

$P = 200\ bar$

$V = ?$

	y_i	M_i	Tc_i	Pc_i
CH_4	0.20	16	190.7	45.8
C_2H_6	0.30	30	305.4	48.2
C_2H_4	0.50	28	283.1	50.5

$\bar{M} = \sum y_i M_i = 26.2$

$n = \frac{m}{\bar{M}} = \frac{10}{26.2} = 0.382\ Kmol = 382\ mol$

$Tc' = \sum y_i Tc_i = 271.3\ K \Rightarrow T_r = \frac{90° + 273.15}{271.3\ K} = 1.34$

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$P'_c = \sum y_i P_{ci} = 48.9 \text{ atm} \Rightarrow P'_r = \frac{200 \text{ bar}}{48.9 \text{ atm}} \left| \frac{1 \text{ atm}}{1.0 \text{ bar}} \right. =$

$Z = 0.7$

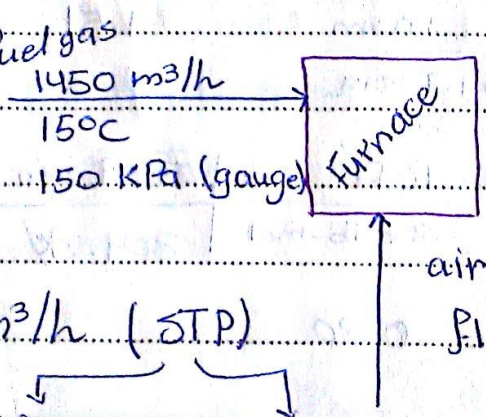
$V = \frac{Zn.RT}{P}$

$V = \frac{0.7 * 382 \text{ mol}}{200 \text{ bar}} \left| \frac{(90+273)K}{} \right| \frac{0.08314 \text{ bar.L}}{\text{mol.K}} = 40.8 \text{ L}$

P5.30 → $y_{CH_4} = 0.86$ ← % by volume for ideal gas ⇕ mol fraction

[by volume] $y_{C_2H_6} = 0.08$

$y_{C_3H_8} = 0.06$



SCMH = m^3/h (STP)

0°C, 1atm

bar: 22.4 m^3/mol STP

$P = 150 + 101.325 = 251.325 \text{ KPa}$

assuming ideal gas

$PV = nRT$

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

$C_2H_6 + \frac{7}{2} O_2 \longrightarrow 2CO_2 + 3H_2O$

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

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$$n = \frac{PV}{RT} = \frac{251.325\ kPa \mid 1450\ m^3 \mid mol \cdot K \mid 10^3\ Pa}{h \mid (15+273.15)K \mid 1\ kPa}$$

$$= 152\ Kmol/h$$

$$\text{Theo } O_2 = 152\left[\underbrace{0.86}_{CH_4} * 2 + \underbrace{0.08}_{C_2H_6} * \frac{7}{2} + \underbrace{0.06}_{C_3H_8} * 5\right]$$

$$= 349.6\ kmol/hr$$

$$\text{Theo air} = \frac{349.6}{0.21} = 1664\ Kmol/h$$

$$\text{total} = 1664 * (1 + 0.08)$$

$$= 1798\ Kmol/h$$

$$\hookrightarrow \frac{1798\ Kmol \mid 22.4\ m^3\ (STP)}{h \mid Kmol}$$

$$= 4 * 10^4\ m^3\ (STP)/h$$

SCMH