Tutorial

- Consider a rectification column for $\mathbf{N_2}$ and $\mathbf{O_2}$ separation operating at 1 atm. Determine the number of theoretical plates required to yield **97%** $\mathbf{N_2}$ at top and **95%** $\mathbf{O_2}$ at bottom. Feed stream is **50%** $\mathbf{N_2}$ and **50%** $\mathbf{O_2}$. Molar fraction of liquid in feed stream is **0.7** mole liquid/mole mixture. The desired flow rate at the bottom product is **20** mole/sec and the heat removed in the condenser at top of the column is **500** kW.

Tutorial

Given
Working Pressure : 1 atm
Mixture : N_2 + O_2
Feed stream : 50% N_2 + 50% O_2
Bottom flow rate : 20 mole/sec = **B**
Feed liq. : 0.7 = **q**

For above mixture
Reqt. of N_2 (top) : 97% = $\mathbf{x_D}$
Reqt. of O_2 (bottom) : 95% = $\mathbf{x_B = 0.05}$
Total number of theoretical plates

Tutorial

$$F = B + D$$

- Mole balance

$$x_F F = x_B B + x_D D$$

- Mole balance for **N_2**

Data	
x_F	0.5
x_B	0.05
x_D	0.97
B	20

$$F = 20 + D$$

$$0.5F = (0.05)(20) + (0.97)D$$

- Solving, we have
- F=39.14 mole/sec, D=19.14 mole/sec.

Tutorial

- Enthalpy balance

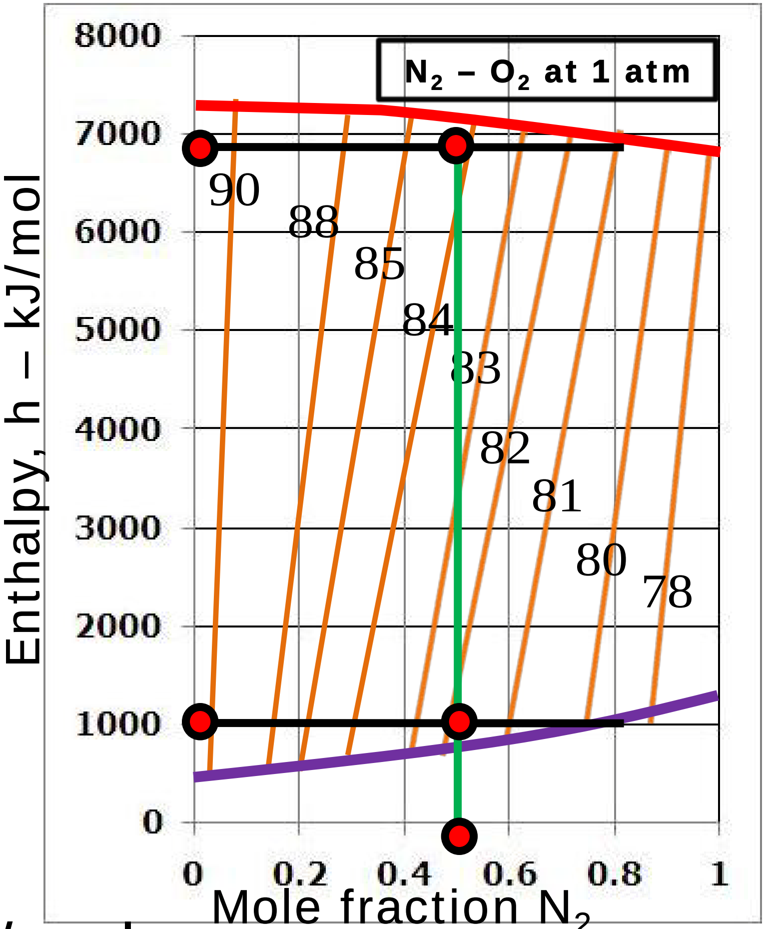
$$\dot{Q}_B = \dot{Q}_D + h_D D + h_B B - h_F F$$

- Fraction of stream in feed

$$q = \frac{H - h_F}{H - h}$$

- Rearranging, we have

$$h_F = qh + (1 - q)H$$



- For 50% $\mathbf{N_2}$ + 50% $\mathbf{O_2}$
- h=1084 J/mol, H=6992 J/mol

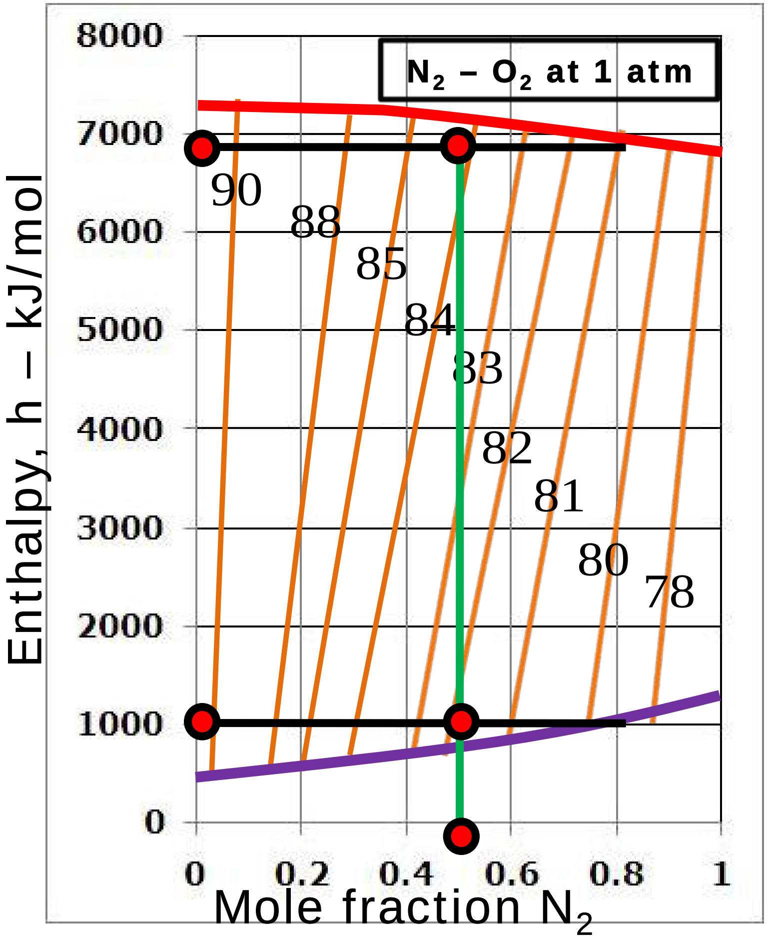
Tutorial

$$h_F = qh + (1-q)H$$

Data	
h	1084 J/m
H	6992 J/m
q	0.7

$$h_F = (0.7)1084 + (1-0.7)6992$$

$$h_F = 2856.4\ J/mol$$

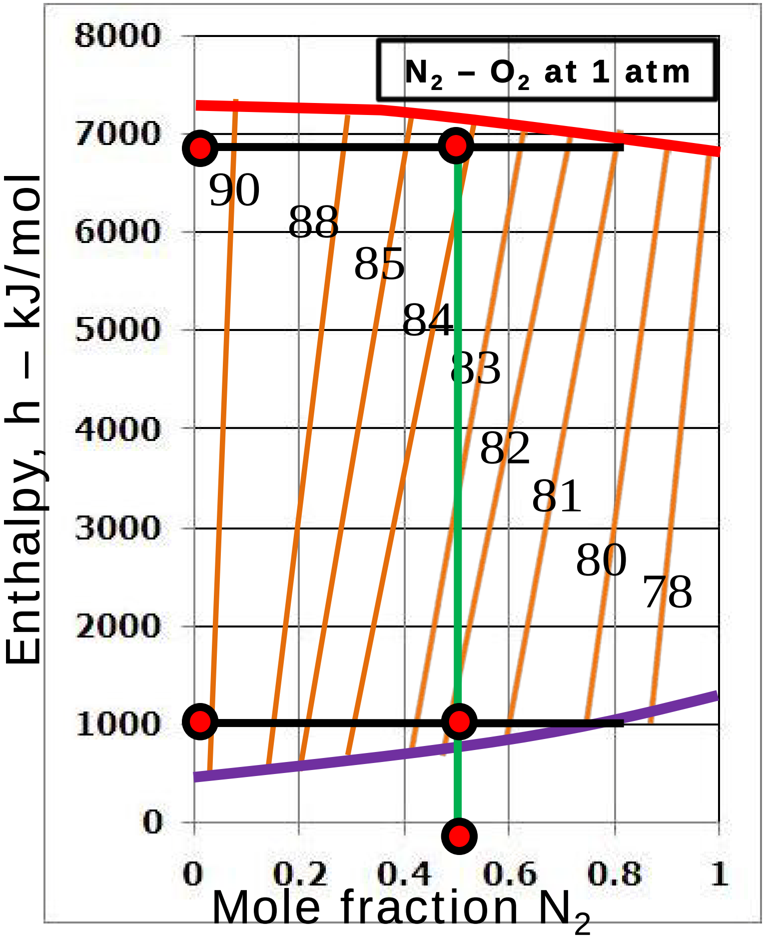


Tutorial

$$\dot{Q}_B = \dot{Q}_D + h_D D + h_B B - h_F F$$

Data	
Q_D	500 kW
h_D	1084 J/m
h_B	1084 J/m
h_F	2856.4 J/m

Data	
F	39.14
B	20
D	19.14



$$\dot{Q}_B = (500)10^3 + (1084)(19.14) + (1084)(20) - (2856.4)(39.14)$$

$$\dot{Q}_B = 430.6kW$$

Tutorial

- Operating line for **Enriching Section**

$$\frac{D}{V_n}=\frac{H_n-h_{n+1}}{\frac{\dot{Q}_D}{D}+h_D-h_{n+1}}$$

Data	
Q_D	500kW
H_n	6992 J/m
h_{n+1}	1084 J/m
h_D	1084 J/m
D	19.14 mol/s

$$\frac{D}{V_n}=\frac{6992-1084}{\frac{500000}{19.14}+1084-1084}$$

$$\frac{D}{V_n}=0.226$$

$$\frac{L_{n+1}}{V_n}=1-\frac{D}{V_n}$$

$$\frac{L_{n+1}}{V_n}=1-0.226$$

$$\frac{L_{n+1}}{V_n}=0.773$$

Tutorial

- Operating line for **Enriching Section**

$$y_n = \left(\frac{L_{n+1}}{V_n}\right) x_{n+1} + \left(\frac{D}{V_n}\right) x_D$$

$$\frac{D}{V_n} = 0.226$$

$$\frac{L_{n+1}}{V_n} = 0.773$$

$$y_n = (0.773)\, x_{n+1} + (0.226)(0.97)$$

Data	
x_D	0.97

$$y_n = 0.773 x_{n+1} + 0.22$$

Tutorial

- Operating line for **Stripping Section**

$$\frac{B}{V_m} = \frac{H_m - h_{m+1}}{\frac{\dot{Q}_B}{B} - h_B + h_{m+1}}$$

Data	
Q_B	430.6 kW
H_m	6992 J/m
h_{m+1}	1084 J/m
h_B	1084 J/m
B	20 mol/s

$$\frac{B}{V_m} = \frac{6992 - 1084}{\frac{(430.6)10^3}{20} - 1084 + 1084}$$

$$\frac{B}{V_m} = 0.274$$

$$\frac{L_{m+1}}{V_m} = 1 + \frac{B}{V_m}$$

$$\frac{L_{m+1}}{V_m} = 1 + 0.274$$

$$\frac{L_{m+1}}{V_m} = 1.274$$

Tutorial

- Operating line for **Stripping Section**

$$y_m = \left(\frac{L_{m+1}}{V_m}\right) x_{m+1} - \left(\frac{B}{V_m}\right) x_B$$

$$\frac{B}{V_m} = 0.274$$

$$\frac{L_{m+1}}{V_m} = 1.274$$

$$y_m = (1.274)\, x_{m+1} - (0.274)(0.05)$$

Data	
x_B	0.05

$$y_m = 1.274 x_{m+1} - 0.013$$

Tutorial

- Equation of **Feed Line**

$$q = \frac{H - h_f}{H - h}$$

$$y = \frac{q}{q-1}x + \frac{x_F}{1-q}$$

$$y = \frac{0.7}{0.7-1}x + \frac{0.5}{1-0.7}$$

$$y = -2.34x + 1.67$$

Data	
H	6992 J/m
h_f	2856.4 J/m
h	1084 J/m
x_F	0.5

Tutorial

- Summarizing, we have the following.
- OP line for enriching section : $y_n = 0.773x_{n+1} + 0.22$
- OP line for stripping section : $y_m = 1.274x_{m+1} - 0.013$
- q line : $y = -2.34x + 1.67$
- The stair casing procedure is shown on an excel sheet to have a better understanding of the method.

Tutorial

- From the excel sheet, it is clear that the total number of vertical lines are **9**.

- Therefore, the total number of theoretical plates for this column can be tabulated as shown below.

McCabe – Thiele Method	
Enriching Section	3 + 1 (Condenser)
Stripping Section	6 + 1 (Boiler)