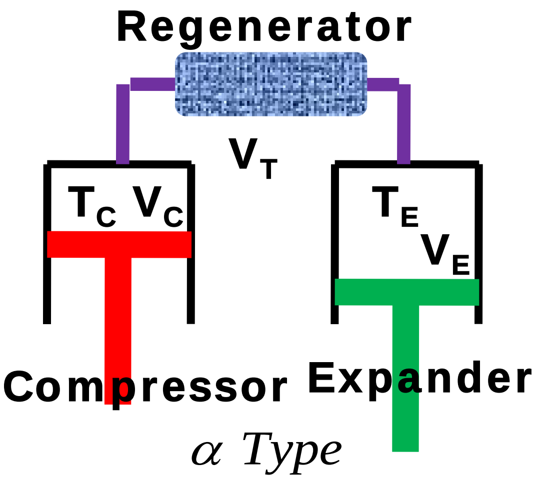
Tutorial

- Design an **α** – type Stirling Nitrogen liquefier using the Schmidt's analysis. The working gas is Helium and the capacity of the plant is 10 liter per hour of $\mathbf{LN_2}$. The maximum allowable pressure in the system is 40 bar. The speed of the prime mover is 1440 rpm.

- Use the standard T – s diagrams for entropy and enthalpy values.

Tutorial

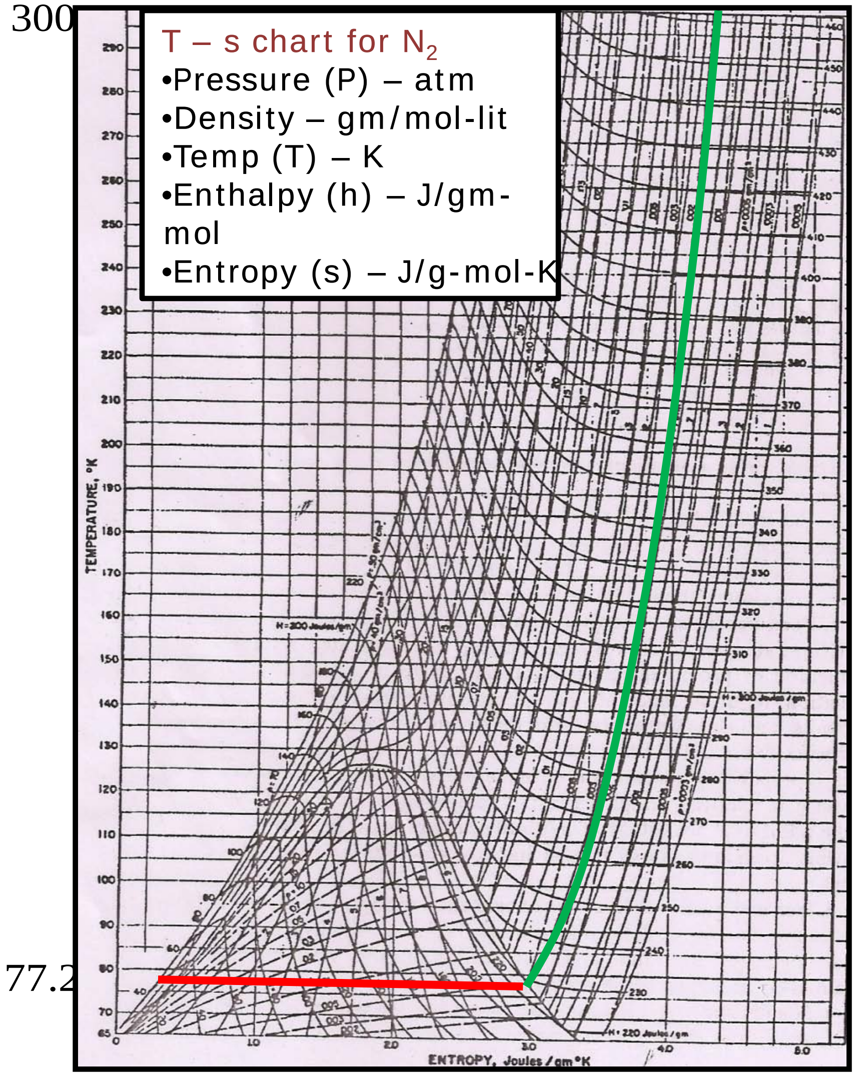
- The schematic of an **α** – type Stirling cryocooler is as shown.



- Given parameters are
  - Evap. Temp. **(T_E)**: 77.2 K.
  - Cond. Temp. **(T_C)**: 300 K.
  - Max. Pressure **(P_{max})**: 40 bar.
  - N = 1440 rpm.

- Parameters to be calculated are
  - Volumes: **(V_C)**, **(V_E)**, **(V_T)**.
  - Phase angle **(α)**

Tutorial



- Consider the T – s diagram for Nitrogen as shown in the figure.
- It is important to note that, the energy required to condense Nitrogen involves
  - Sensible heat from 300 K to 77 .2 K.
  - Latent heat of vaporization at 77.2 K.

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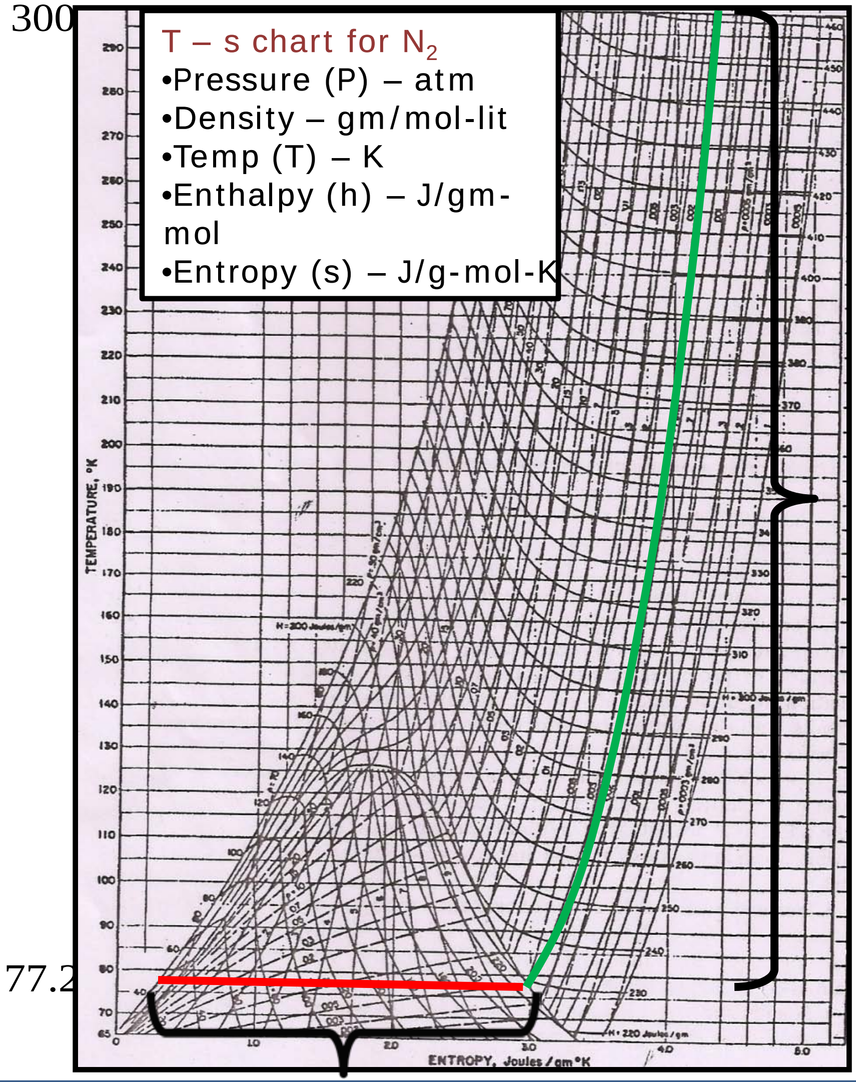


- From the standard T – s diagram for Nitrogen, the change in enthalpy for these processes are as shown below.
- Sensible heat (KJ/Kg-K) $\Delta h_s = 231.7$
- Latent heat (KJ/Kg-K) $\Delta h_l = 199.1$
- The net change in enthalpy is $\Delta h_{net} = 430.8$

Tutorial

- The required capacity of the given liquefier is **10** liter per hour.

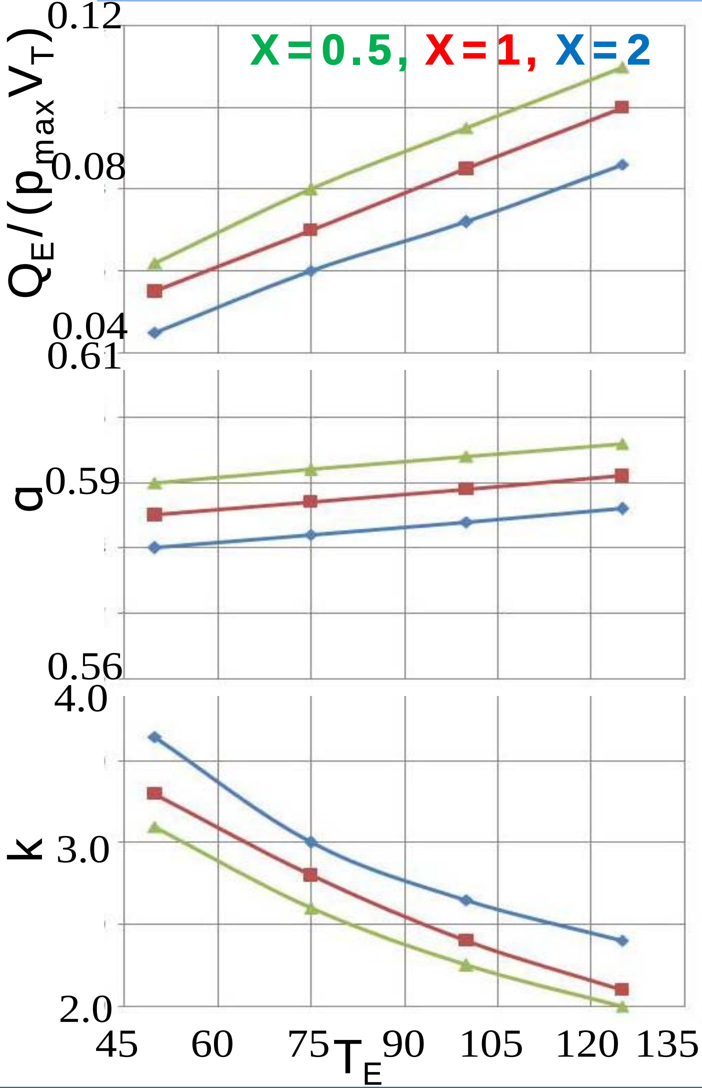
- The density of liquid nitrogen is 808 kg/m^3. Hence, the required mass flow rate across the liquefier corresponding to 10 liter per hour is calculated as shown below.

$$\dot{m} = \frac{n(m^3/hr)\rho}{3600} = \frac{(10)(10^{-3})(808)}{3600} = 0.00224\,Kg/s$$

- The net cooling power required to produce **10** liter per hour **LN$_2$** is

$$Q_{E,reqd} = \Delta h_{net}\dot{m} = (430.8)(0.00224) = 965W$$

Tutorial



- Therefore, $\mathbf{Q_{E,\ Design}}$ at $\mathbf{T_E}$ = **77.2 K** is given by

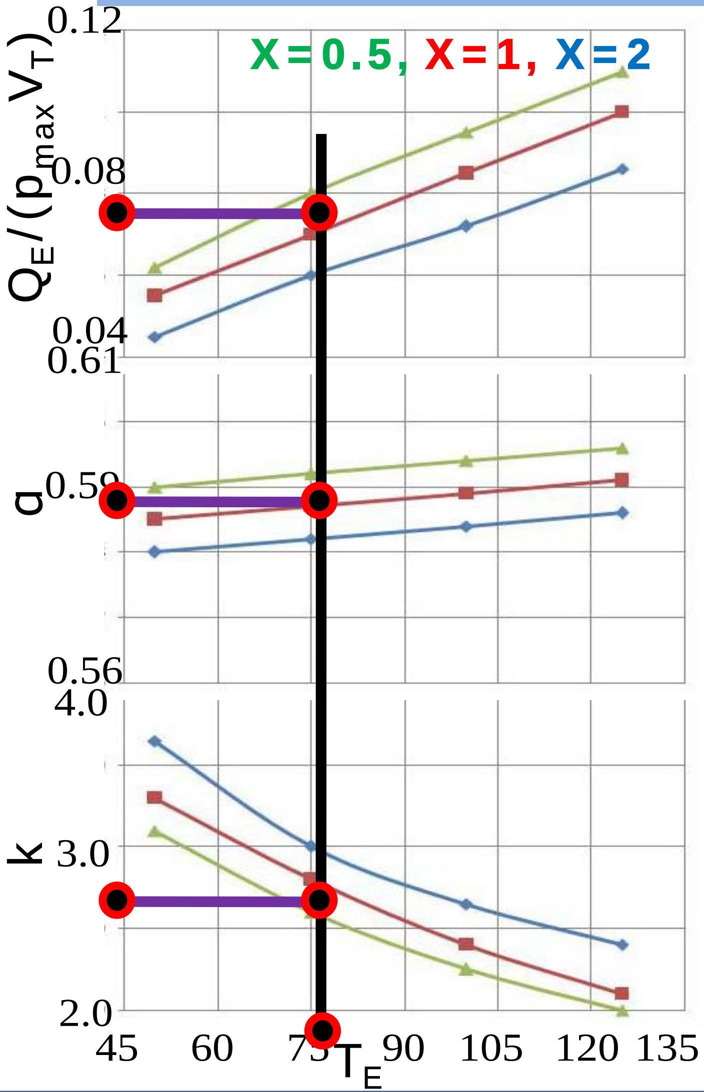
$$Q_{E,Design} = 3(965) \qquad = 2895W$$

- The RPM of the prime mover is given as 1440. Therefore, the **N(rps)** is **24**.

- The $\mathbf{Q_{E,\ Design}}$ per unit cycle is calculated as shown below.

$$Q_{E,Design} = \frac{2895}{24} \qquad = 120.6$$

Tutorial



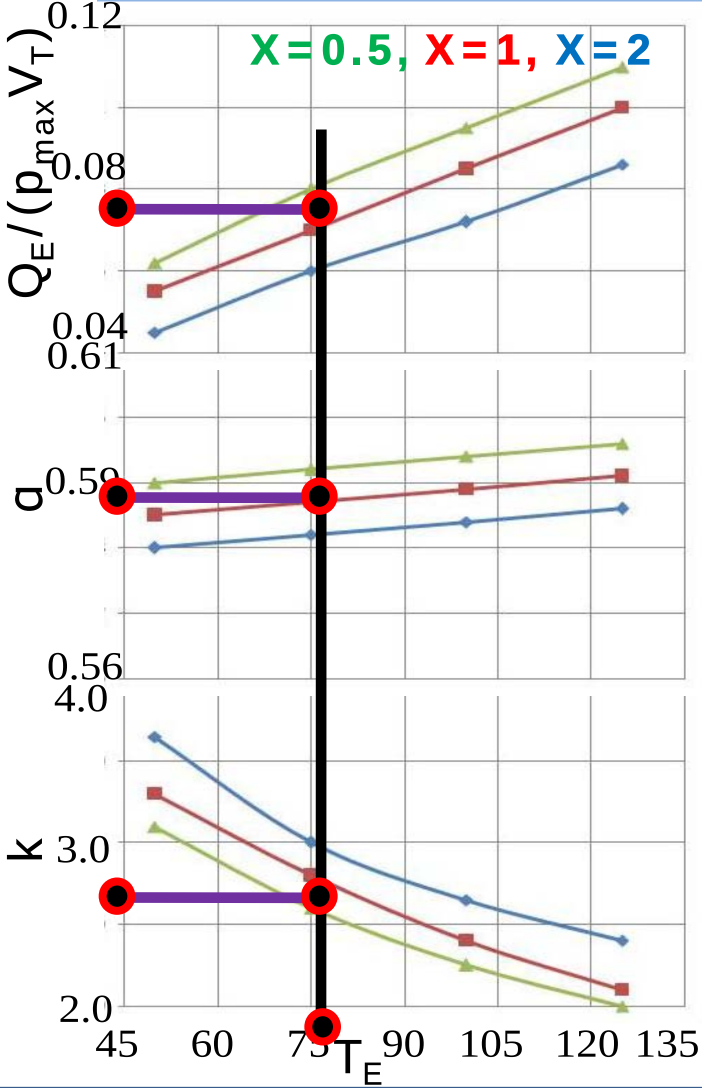
- Choosing **X = 1** on **Walker's Optimization Chart**, we have the following values.

$$k = 2.85$$

$$\alpha = 0.575^c \qquad = 32.9^o$$

$$Q_{max} = 0.07$$

Tutorial



- From the definition of $\mathbf{Q_{max}}$, we have the following.

$$Q_{max} = \frac{Q_{E,Design}}{P_{max} V_T}$$

$$p_{max} = 40\,bar$$

$$V_T = \frac{120.6}{(0.07)(40)(10^5)}$$

$$= 4.3\left(10^{-4}\right) m^3$$

$$= 430cc$$

$$k = \frac{V_C}{V_E} = 2.85$$

$$V_T = V_C + V_E$$

$$V_E = 1.12\left(10^{-4}\right) m^3$$

$$V_C = 3.18\left(10^{-4}\right) m^3$$

Tutorial

- Assuming a stroke to bore ratio of **0.75**, for both compressor and expander – displacer pistons, we have the following dimensions.

$$V_C = \frac{\pi}{4} D_C^2 S_C = 3.18\left(10^{-4}\right)$$

$$\frac{S_C}{D_C} = 0.75$$

$$D_C = 81.4mm$$

$$S_C = 60.8mm$$

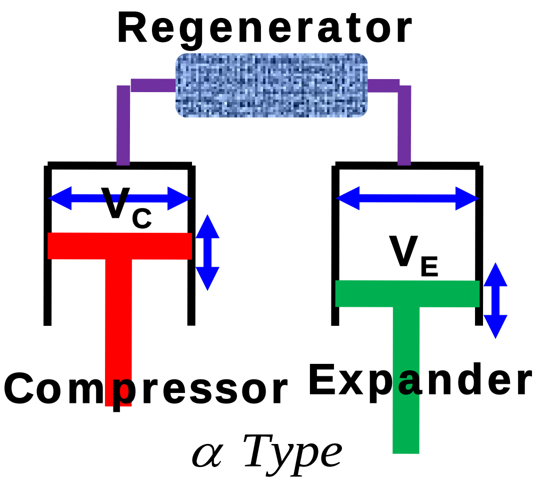
$$V_E = \frac{\pi}{4} D_E^2 S_E = 1.12\left(10^{-4}\right)$$

$$\frac{S_E}{D_E} = 0.75$$

$$D_E = 57.5mm$$

$$S_E = 43.1mm$$

Tutorial



$D_C = 81.4mm$

$D_E = 57.5mm$

$S_C = 60.8mm$

$S_E = 43.1mm$

Operating Parameters

- T_E: 77.2 K
- T_C: 300 K
- P_{max}: 40 bar
- N: 1440

Design Parameters

$V_C = 3.18\left(10^{-4}\right)m^3$

$V_E = 1.12\left(10^{-4}\right)m^3$

$\alpha = 0.575^c$

$= 32.9^o$

Tutorial

- For a given $\mathbf{Q_{E,\ Design}}$, if the dimensions of the piston and expander – displacer are very large, say more than 150mm, the system may be designed for two cylinders or more.

- This is an iterative process until the feasible dimensions are decided.