Tutorial

- Determine **W/m$_f$** & **FOM** for a Linde Dual – Pressure System with Argon as working fluid for the following intermediate pressures. The system operates between 1.013 bar (1 atm) and 121.5 bar (120 atm). The intermediate mass ratio **i** is **0.6**.

Ar	Int. Pr. 2
I	4.05 bar
II	20.3 bar
III	75.9 bar
IV	101.3 bar

- Repeat the above problem for **i** = 0.7. Plot the data graphically and comment on the nature of **y**, **W/m$_f$**, **FOM** versus **i**.

Tutorial

Given
Cycle : Linde Dual – Pressure System
Working Pressure : 1 atm → P_i → 120 atm
Working Fluid : Argon
Temperature : 300 K
Intermediate mass ratio : i = 0.6 & 0.7

For above System, Calculate	
1	Work/unit mass of gas liquefied and FOM

Ar	Int. Pr. 2
I	4.05 bar
II	20.3 bar
III	75.9 bar
IV	101.3 bar

Methodology

- The two mass ratio **(i)** conditions under study are 0.6 and 0.7.

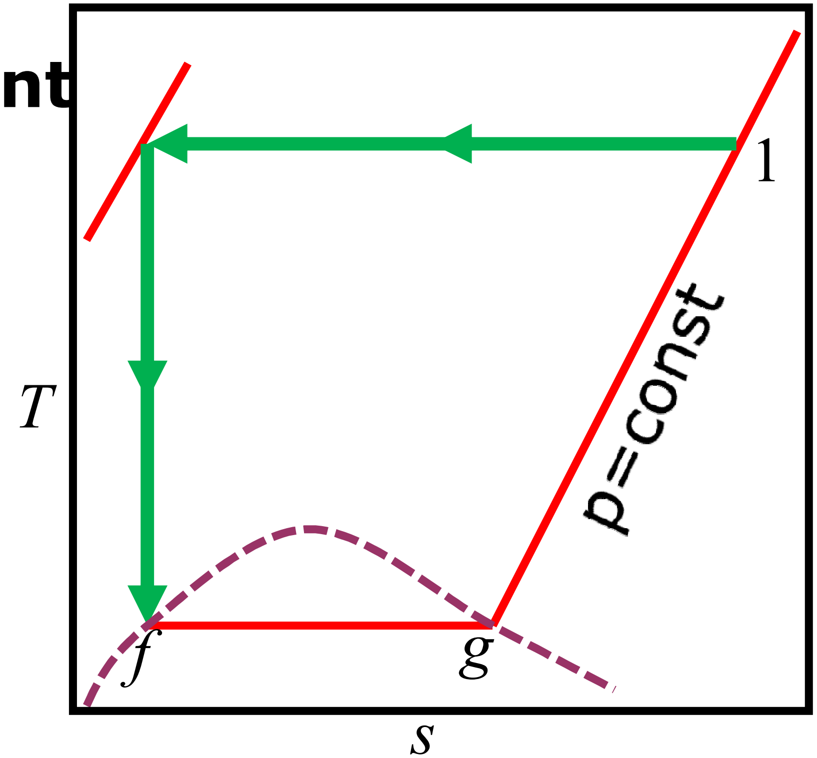
- In this tutorial, the liquid yield and work/unit mass of gas liquefied are calculated only for **i = 0.6** and **4.05 bar** as intermediate pressure condition.

- All other calculations pertaining to **i = 0.6 & 0.7** and for all other intermediate pressure conditions are left as an exercise to students.

Tutorial

- **Ideal Work Requirement**

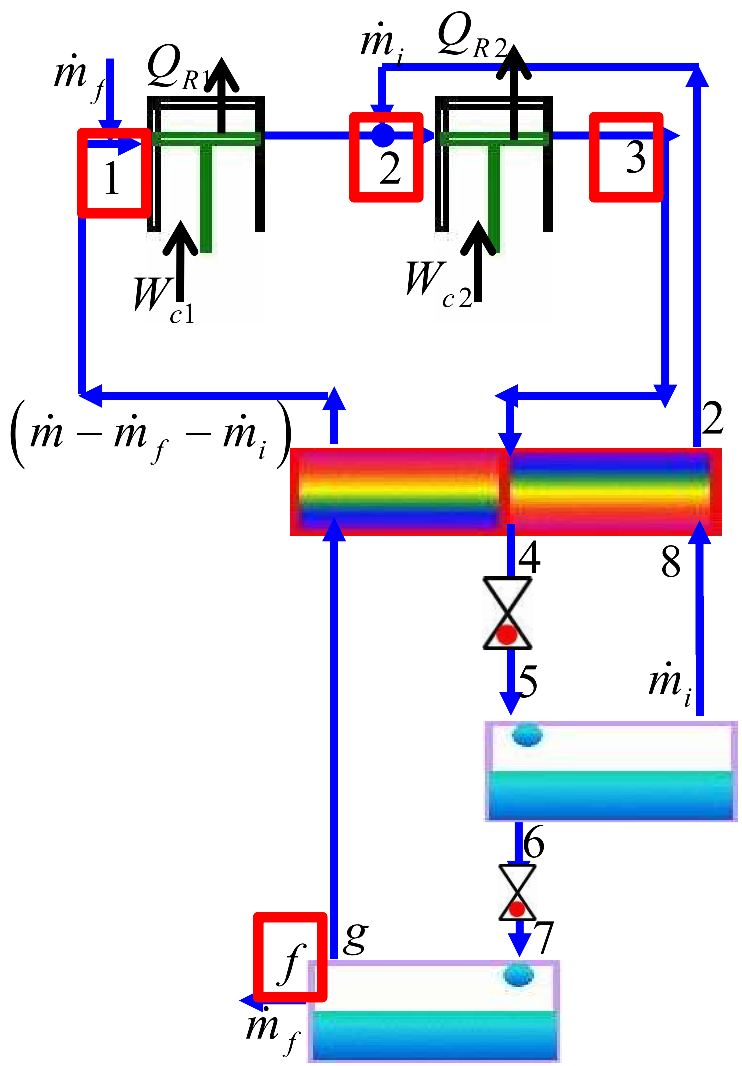
$$-\frac{\dot{W}_i}{\dot{m}} = T_1\left(s_1 - s_f\right) - \left(h_1 - h_f\right)$$



	1	f
p (bar)	1.013	1.013
T (K)	300	87.3
h (J/g)	349	75
s (J/gK)	3.85	1.4

$$-\frac{W_c}{\dot{m}} = 300\left(3.85 - 1.4\right) - \left(349 - 75\right) \quad = 461\ J/g$$

Tutorial



- The enthalpies and entropies are as given below.

	1	2
p (bar)	1.013	4.05
T (K)	300	300
h (J/g)	349	348
s (J/gK)	3.85	3.6

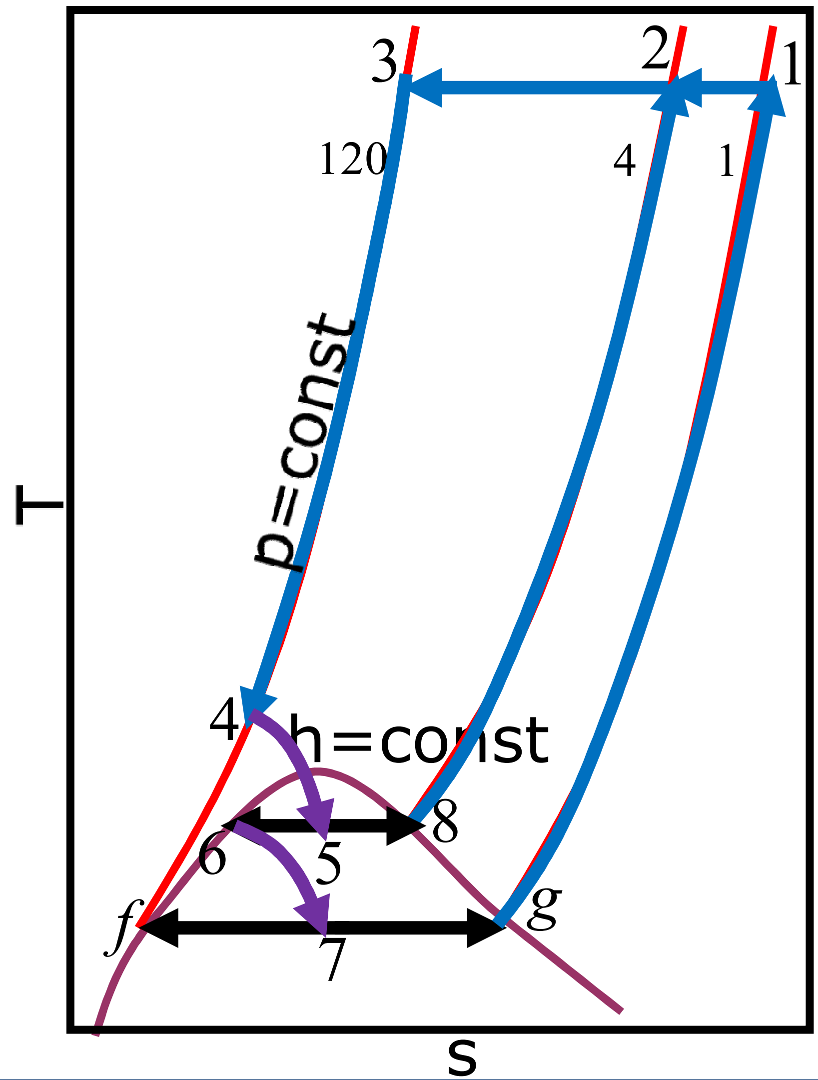
	3	f
p (bar)	121.5	1.013
T (K)	300	87.3
h (J/g)	326	75
s (J/gK)	2.84	1.4

Tutorial

Ar	i	Int. Pr. 2
I	0.6	4.05 bar

- The T – s diagram for a Linde Dual – Pressure system is as shown.

- The compression process is from **1 atm → 4 atm → 120 atm**, As shown in the figure.



Tutorial

- **Liquid yield**

$$y = \frac{\dot{m}_f}{\dot{m}} = \frac{h_1 - h_3}{h_1 - h_f} - i\left(\frac{h_1 - h_2}{h_1 - h_f}\right)$$

Ar	i	Int. Pr. 2
I	0.6	4.05 bar

	1	2	3	f
p (bar)	1.013	4.05	121.5	1.013
T (K)	300	300	300	87.3
h (J/g)	349	348	326	75
s (J/gK)	3.85	3.6	2.84	1.4

$$y = \frac{(349-326)}{(349-75)} - 0.6\frac{(349-348)}{(349-75)} = \frac{(23)}{(274)} - 0.6\frac{(1)}{(274)} = 0.0817$$

Tutorial

- **Work/unit mass of Ar compressed**

$$i = 0.6$$

$$-\frac{W_c}{\dot{m}} = T_1\left(s_1 - s_3\right) - \left(h_1 - h_3\right) - i\left(T_1\left(s_1 - s_2\right) - \left(h_1 - h_2\right)\right)$$

	1	2	3	f
p (bar)	1.013	4.05	121.5	1.013
T (K)	300	300	300	87.3
h (J/g)	349	348	326	75
s (J/gK)	3.85	3.6	2.84	1.4

$$-\frac{W_c}{\dot{m}} = \begin{matrix} 300\left(3.85 - 2.84\right) - \left(349 - 326\right) \\ -0.6\left(300\left(3.85 - 3.6\right) - \left(349 - 348\right)\right) \end{matrix} = 235.6\, J/g$$

Tutorial

- **Work/unit mass of Ar liquefied**

$$-\frac{W_c}{\dot{m}} = 235.6$$

$$y = 0.0817$$

$$-\frac{W_c}{\dot{m}_f} = -\frac{W_c}{y\dot{m}} = \frac{235.6}{0.0817} = 2883.7 \; J/g$$

- **FOM**

$$-\frac{W_i}{\dot{m}_f} = 461$$

$$FOM = \frac{W_i}{\dot{m}_f} \Big/ \frac{W_c}{\dot{m}_f} = \frac{461}{2883.7} = 0.1598$$

Tutorial

- Tabulating the results for i = 0.6, we have the following comparison for the various values of
  - Intermediate pressure.

	Int. Pressure	y	$-\frac{W}{\dot{m}}$	$-\frac{W}{\dot{m}_f}$	FOM
I	4.05 bar	0.0817	235.6	2883.7	0.1598
II	20.3 bar	0.0752	172.6	2295.2	0.2008
III	75.9 bar	0.0512	118.0	2304.6	0.2000
IV	101.3 bar	0.0424	111.4	2627.4	0.1754

Tutorial

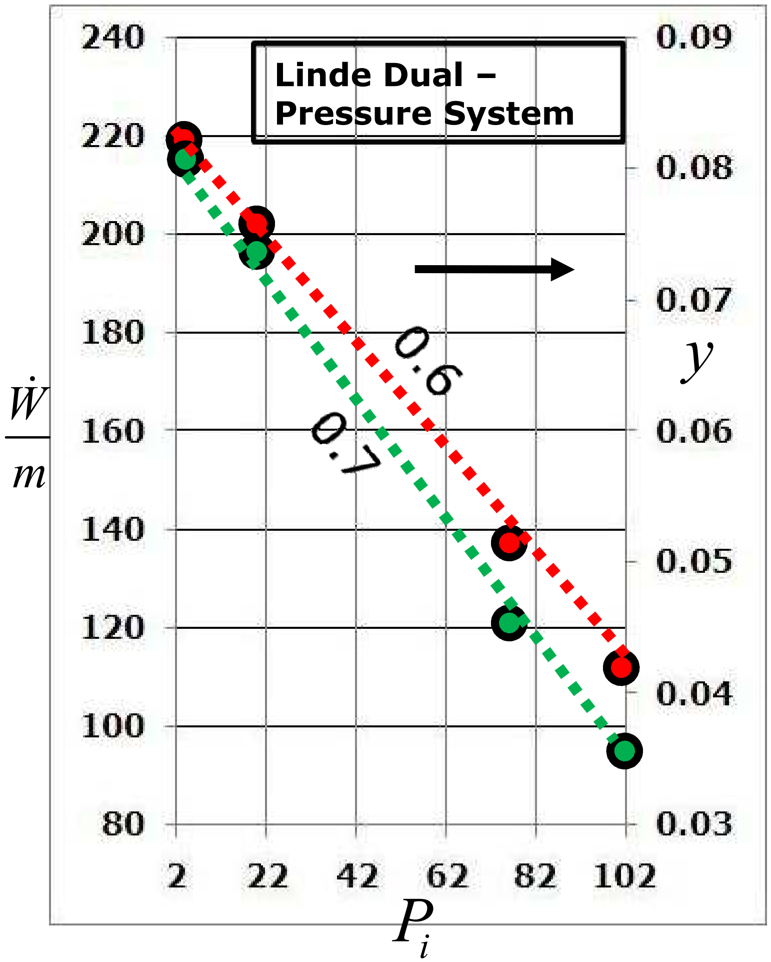
- Similarly, calculating the results for i = 0.7, we have the following comparison for the various values of

  - Intermediate pressure.

	Int. Pressure	y	$-\frac{W}{\dot{m}}$	$-\frac{W}{\dot{m}_f}$	FOM
I	4.05 bar	0.0814	228.2	2803.4	0.1644
II	20.3 bar	0.0738	154.7	2096.2	0.2199
III	75.9 bar	0.0457	91.0	1991.2	0.2315
IV	101.3 bar	0.0355	83.3	2346.5	0.1964

Tutorial

- **Liquid yield v/s. i**



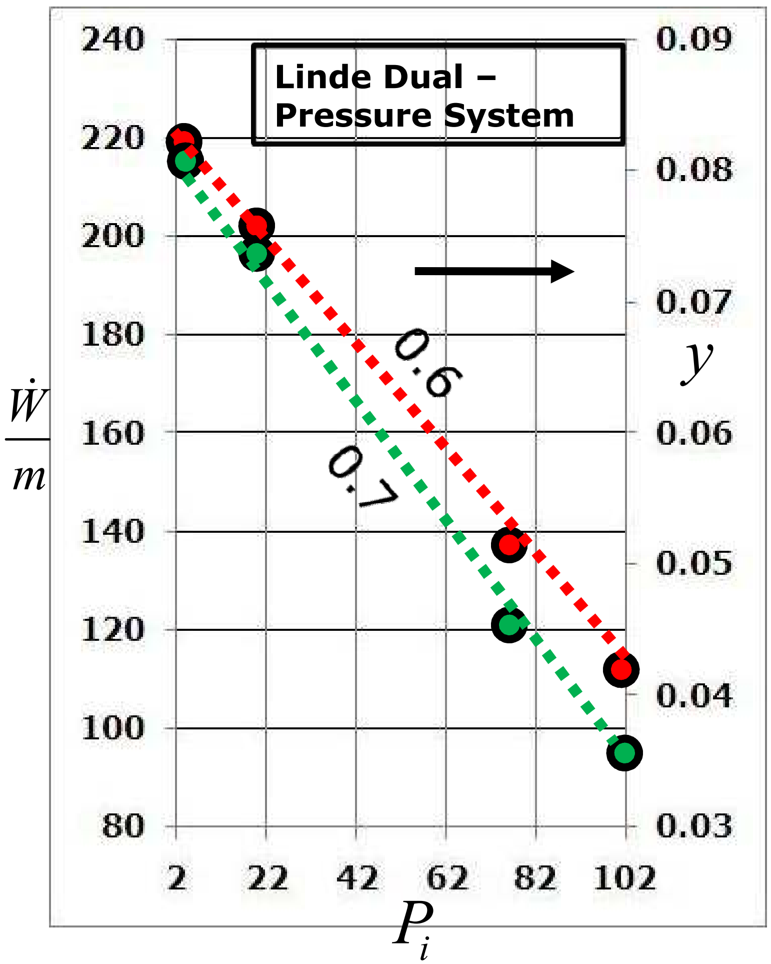
- The Plot for **y** versus **i** for different pressures is as shown.

i=0.6	P_i	y
I	4.05 bar	0.0817
II	20.3 bar	0.0752
III	75.9 bar	0.0512
IV	101.3 bar	0.0424

i=0.7	P_i	y
I	4.05 bar	0.0814
II	20.3 bar	0.0738
III	75.9 bar	0.0457
IV	101.3 bar	0.0355

Tutorial

- **Liquid yield v/s. i**

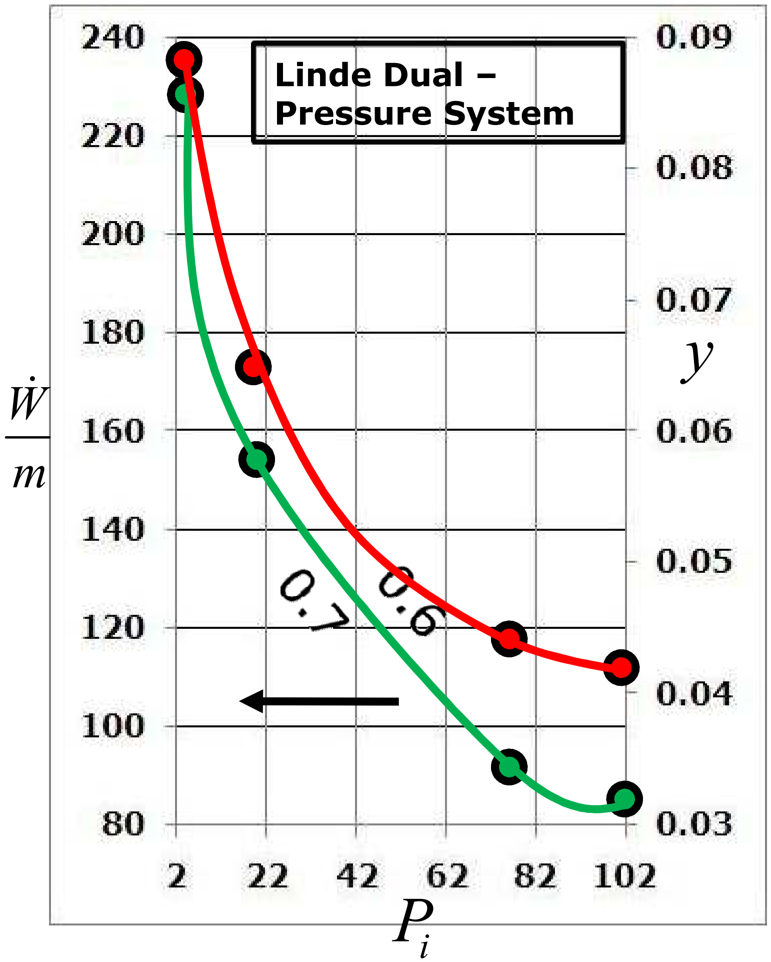


- For a given value of mass ratio **i**, the yield (dotted line) of the system decreases with the increase in the intermediate pressure.

- As the mass ratio **i** increases, the yield of the system decreases because, the mass of gas actually expanded in J – T device decreases.

Tutorial

- **W/m v/s. i**



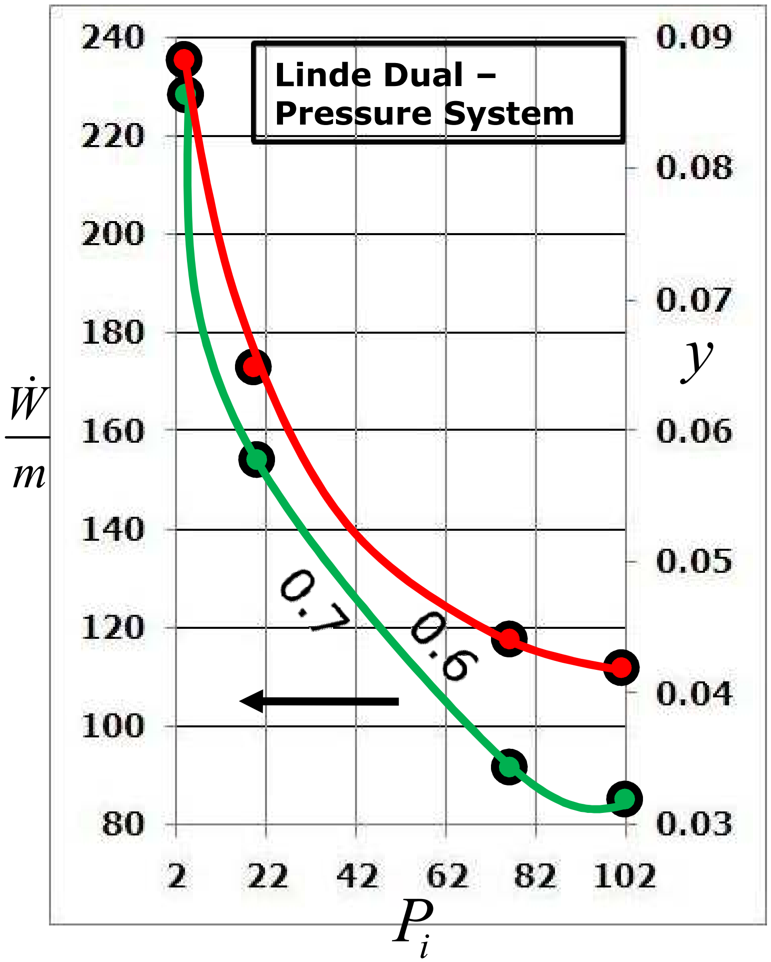
- The Plot for **W/m** versus **i** for different pressures is as shown.

i=0.6	P_i	$-W/\dot{m}$
I	4.05 bar	235.6
II	20.3 bar	172.6
III	75.9 bar	118.0
IV	101.3 bar	111.4

i=0.7	P_i	$-W/\dot{m}$
I	4.05 bar	228.2
II	20.3 bar	154.7
III	75.9 bar	91.0
IV	101.3 bar	83.3

Tutorial

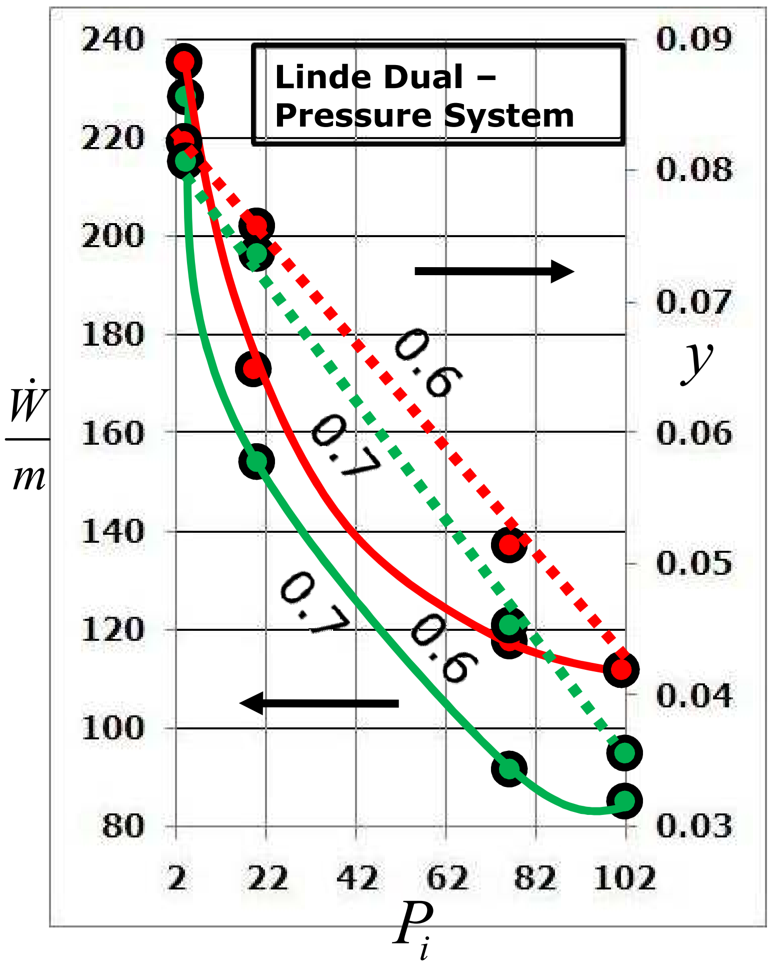
- **W/m v/s. i**



- For a given value of mass ratio **i**, the **W/m** (solid line) of the system decreases with the increase in the intermediate pressure.

- As the mass ratio **i** increases, the **W/m** decreases because, the more of the mass flow rate is bypassed from compressor – **1**.

Tutorial

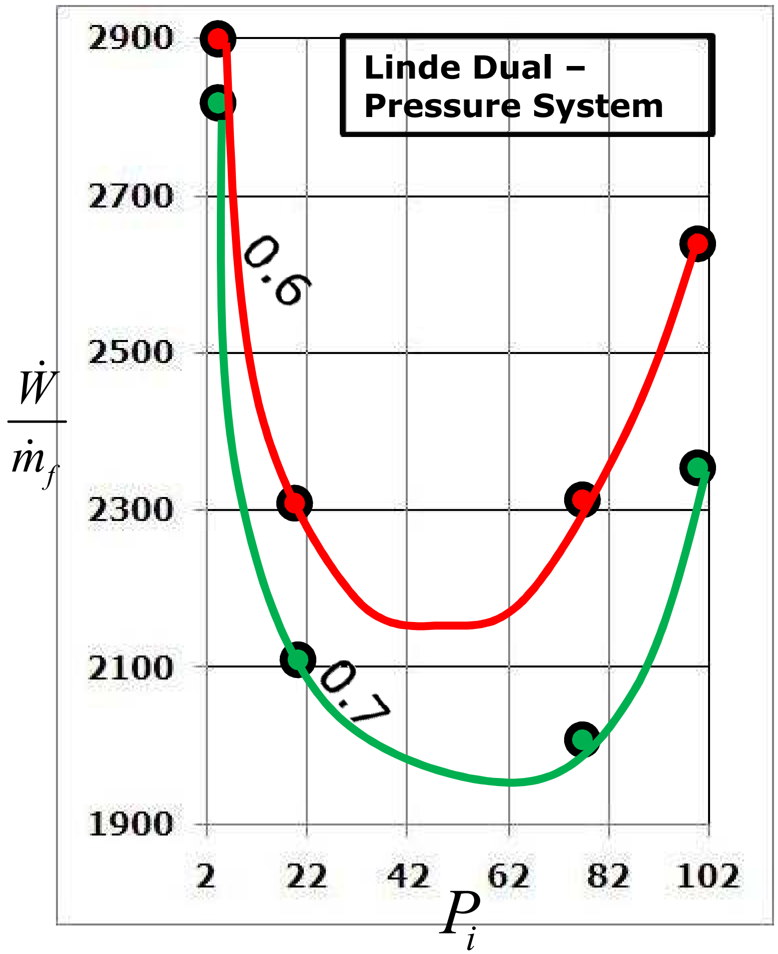


- It is important to note that, initially the slope of **W/m** (solid lines) is much steeper than that of **y** (dotted lines).

- Later on, as the intermediate pressure increases, the slope of **y** (dotted lines) is steeper while the slope **W/m** (solid lines) decreases.

Tutorial

- **W/m$_f$ v/s. i**



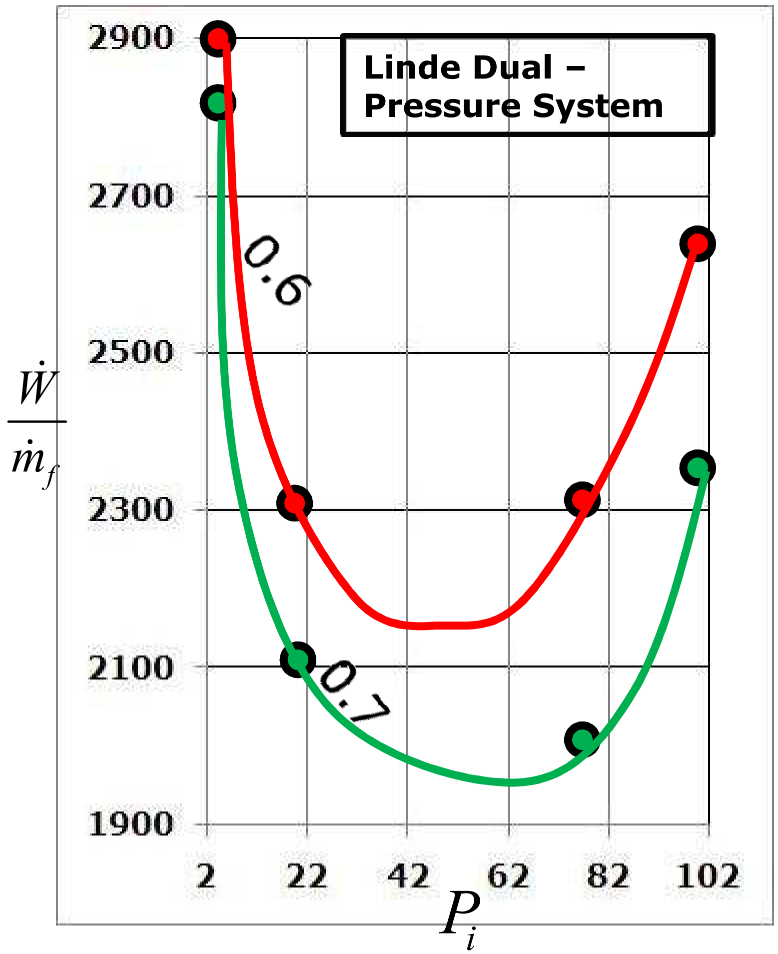
- The Plot for **W/m$_f$** versus **i** for different pressures is as shown.

i=0.6	P_i	$-W/\dot{m}_f$
I	4.05 bar	2883.7
II	20.3 bar	2295.2
III	75.9 bar	2304.6
IV	101.3 bar	2627.4

i=0.7	P_i	$-W/\dot{m}_f$
I	4.05 bar	2803.4
II	20.3 bar	2096.2
III	75.9 bar	1991.2
IV	101.3 bar	2346.5

Tutorial

- **W/m_f v/s. i**



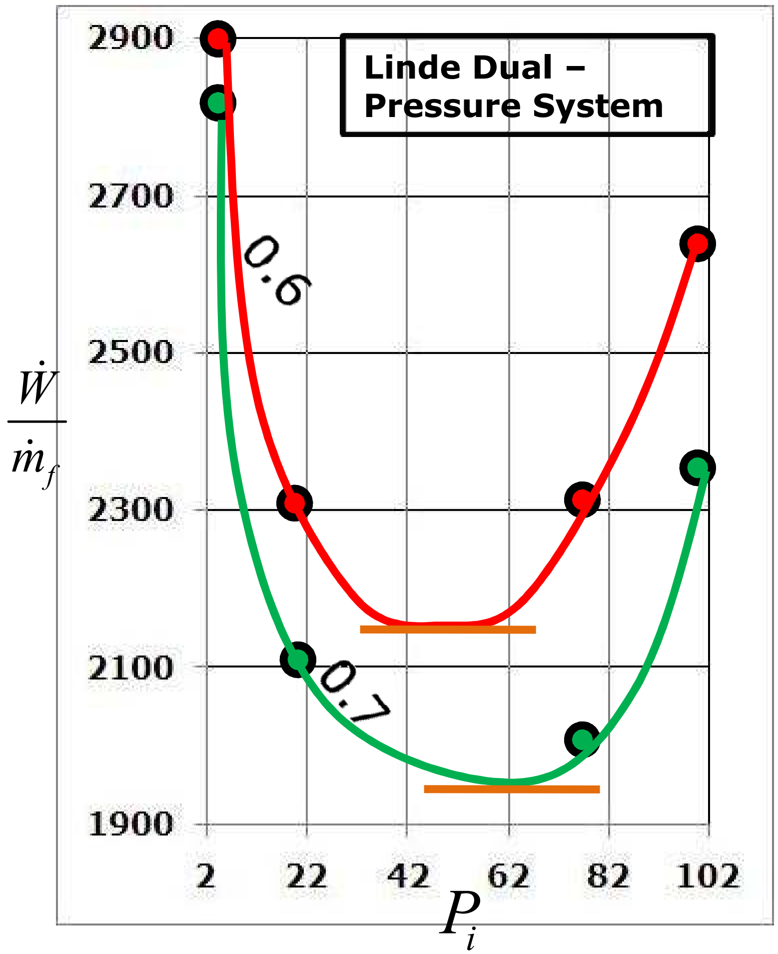
- Mathematically,

$$-\frac{W}{\dot{m}_f} = \frac{-\frac{W}{\dot{m}}}{y}$$

- **W/m_f** being a ratio of **W/m** and liquid **y**, the relative decrease in the numerator and denominator determines the slope of the curve of **W/m_f.**

Tutorial

- **W/m$_f$ v/s. i**



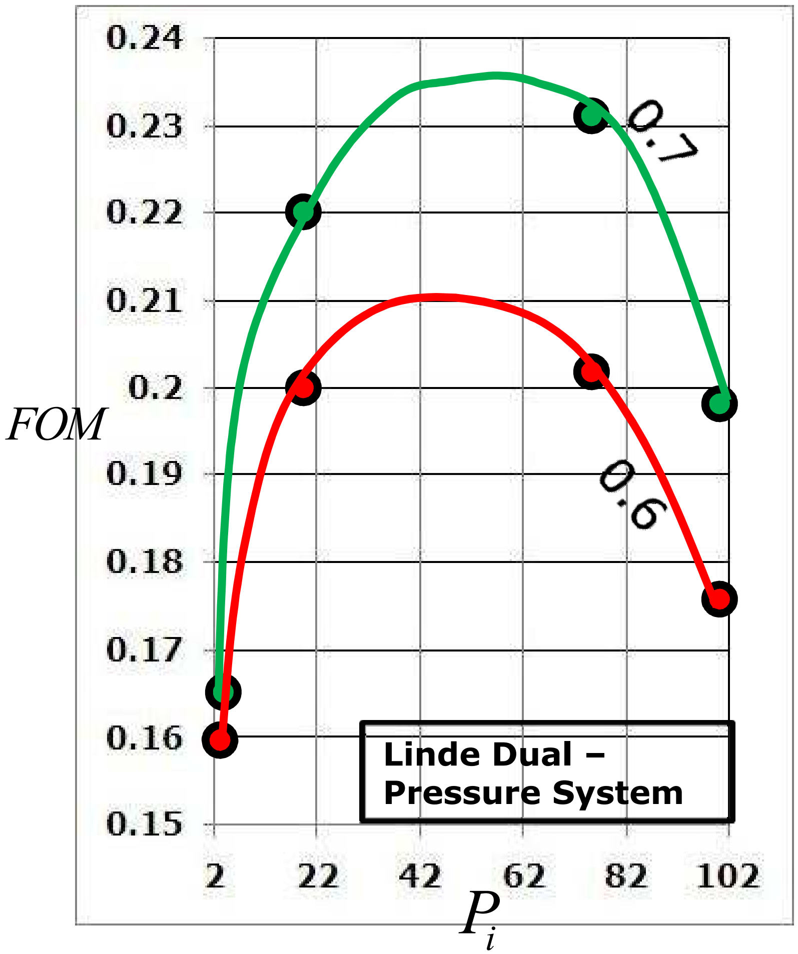
- For a mass ratio **i**, the **W/m$_f$** decreases with the increase in the intermediate pressure.

- This work falls to a minima and then increases with the increase in the intermediate pressure.

- The working point is a compromised value between **y** and **(W/m$_f$)$_{min}$.**

Tutorial

- **FOM v/s. i**



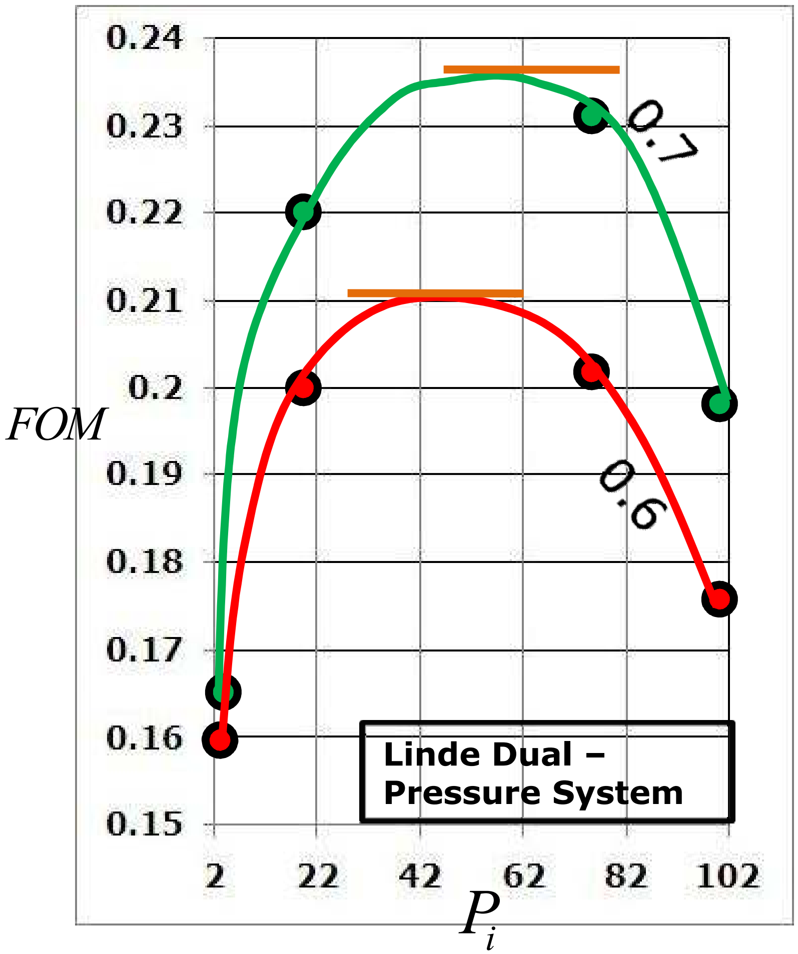
- The Plot for **FOM** versus **i** for different pressures is as shown.

i=0.6	P_i	FOM
I	4.05 bar	0.1598
II	20.3 bar	0.2008
III	75.9 bar	0.2000
IV	101.3 bar	0.1754

i=0.7	P_i	FOM
I	4.05 bar	0.1644
II	20.3 bar	0.2199
III	75.9 bar	0.2315
IV	101.3 bar	0.1964

Tutorial

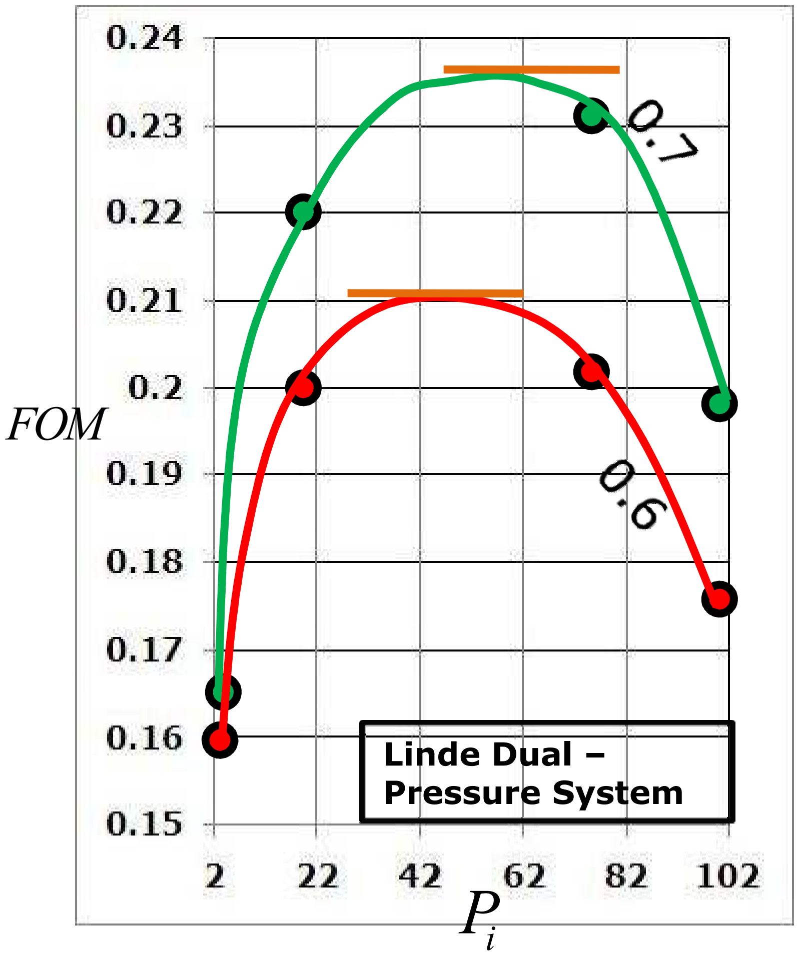
- **FOM v/s. i**



- For a mass ratio **i**, the **FOM** increases with the increase in the intermediate pressure.
- With the further increase in the intermediate pressure, the FOM reaches a maxima value and thereby it decreases.

Tutorial

- **FOM v/s. i**



- It is important to note that the **FOM** reaches a maxima value at the same intermediate pressure at which the **W/m$_f$** reaches a minima, for a given value of mass ratio **i**.