Tutorial

A. Determine $\mathbf{W/m_f}$ for a Claude Cycle with N_2 as working fluid. The system operates between 1.013 bar (1 atm) and 40.52 bar (40 atm). The expander inlet $\mathbf{T_3}$ is at 225 K. The expander flow ratio is varied between 0.1 and 0.9.

B. Repeat the above problem for $\mathbf{T_3}$ = 300 K, 275 K, 250 K and 225 K. Plot the data **y**, $\mathbf{W/m_f}$ versus **x** graphically and comment on the results.

Tutorial

Given
Cycle : Claude System
Working Pressure : 1 atm → 40 atm
Working Fluid : Nitrogen
T_3 : 300 K, 275 K, 250 K, 225 K
Mass flow ratio : x = 0.1 → 0.9

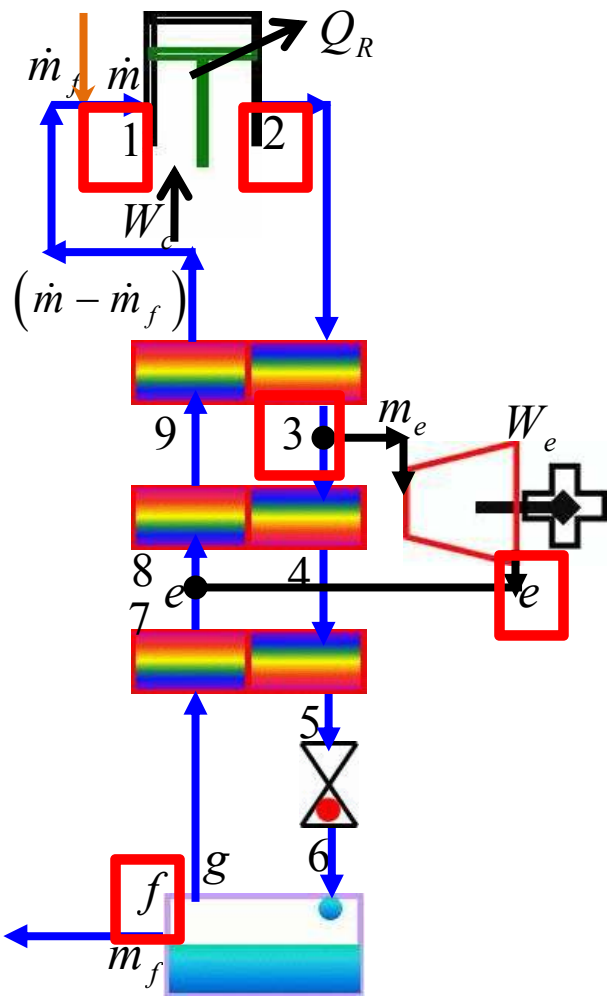
For above System, Calculate	
1	Work/unit mass of gas liquefied

N_2	Point 3
I	300 K
II	275 K
III	250 K
IV	225 K

Methodology

- In the part **A**, the expander inlet condition under study is 225 K at 40.52 bar.
- The expander mass flow ratio varies between 0.1 and 0.9.
- In this tutorial, the **y**, $\mathbf{W/m_f}$ is calculated only for **x = 0.2** and **225 K** as inlet condition.

Tutorial



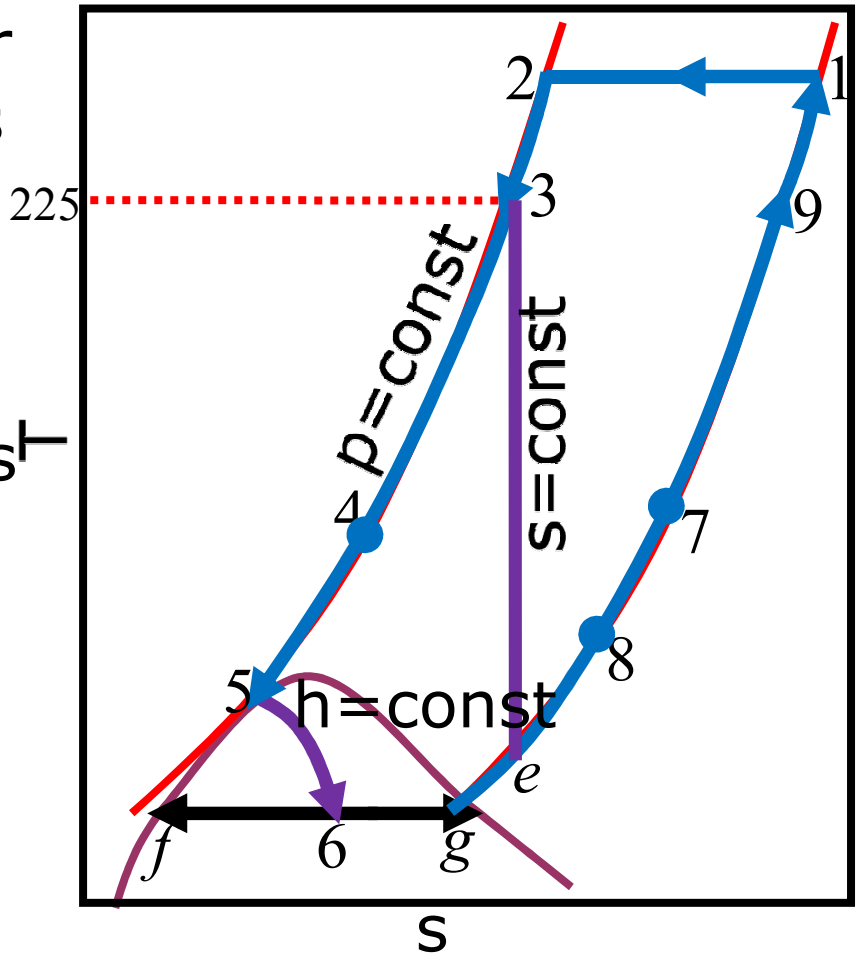
	1	2	3
p (bar)	1.013	40.52	40.52
T (K)	300	300	225
h (J/g)	462	453	369
s (J/gK)	4.42	3.3	3.0

	e	f
p (bar)	1.013	1.013
T (K)	80*	77
h (J/g)	228	29
s (J/gK)	3.0	.25

* The point **e** is located on p=1bar isobar by drawing a vertical line from point **3**.

Tutorial

- The T – s diagram for a Claude System is as shown.
- The expander inlet condition and its mass flow ratio are **225 K** and **0.2** respectively.



Tutorial

- **Liquid yield**

$$y = \frac{h_1 - h_2}{h_1 - h_f} + x\left(\frac{h_3 - h_e}{h_1 - h_f}\right)$$

x	Point 3
0.2	225 K, 40 atm

	1	2	3	e	f
p (bar)	1.013	40.52	40.52	1.013	1.013
T (K)	300	300	225	80	77
h (J/g)	462	453	369	228	29
s (J/gK)	4.42	3.3	3.1	3.1	3.0

$$y = \frac{(462-453)}{(462-29)} + 0.2\frac{(369-228)}{(462-29)} = 0.021 + 0.065 = 0.086$$

Tutorial

- **Work/unit mass of N_2 compressed**

$$-\frac{W_c}{\dot{m}} = T_1(s_1 - s_2) - (h_1 - h_2) - x(h_3 - h_e)$$

	1	2	3	e	f
p (bar)	1.013	40.52	40.52	1.013	1.013
T (K)	300	300	225	80	77
h (J/g)	462	453	369	228	29
s (J/gK)	4.42	3.3	3.1	3.1	3.0

$$-\frac{W_c}{\dot{m}} = 300(4.42 - 3.3) - (462 - 453) - 0.2(369 - 228)$$

$$= 299\ J/g$$

Tutorial

- **Work/unit mass of N_2 liquefied**

$$-\frac{W_c}{\dot{m}} = 299$$

$$y = 0.086$$

$$-\frac{W_c}{\dot{m}_f} = -\frac{W_c}{y\dot{m}} = \frac{299}{0.086} = 3476.7\ J/g$$

Tutorial

- Extending the calculations for all other values of **x** and tabulating the results, we have

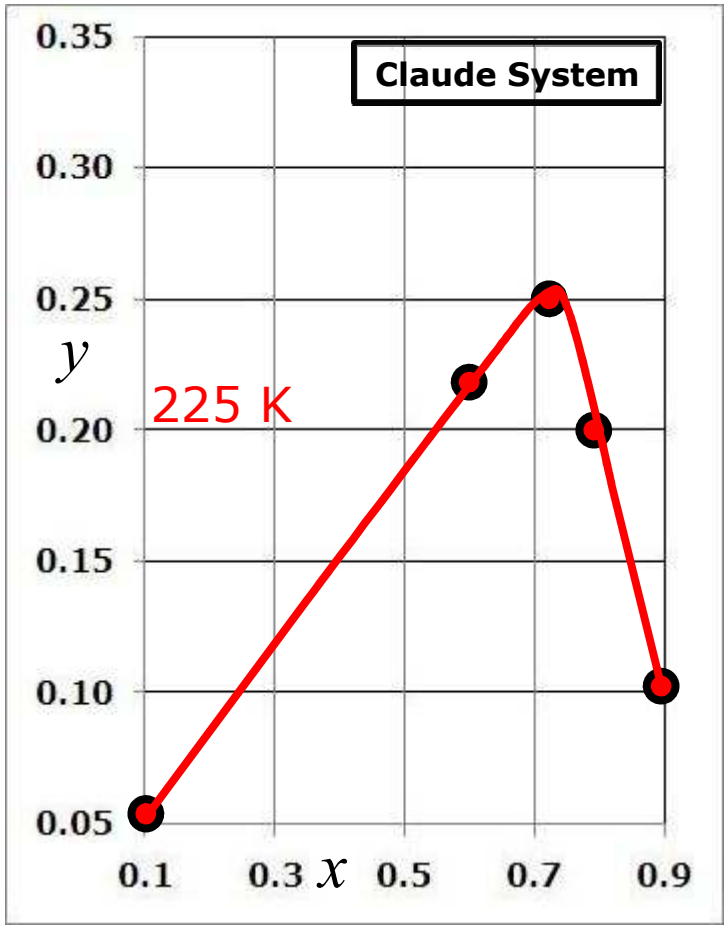
- In the adjacent table, the equation for **y** is used from **x=0.1** to **0.73**. Thereafter, **y=0.99-x** is used.

- Actual **y** may be less than this value.

225		
x	**y**	**W/m_f**
0.10	0.05	5865.2
0.20	0.09	3478.0
0.30	0.12	2403.0
0.40	0.15	1791.6
0.50	0.18	1397.0
0.60	0.22	1121.4
0.70	0.25	917.9
0.73	**0.26**	**866.8**
0.80	0.19	1127.4
0.90	0.09	2223.3

Tutorial

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

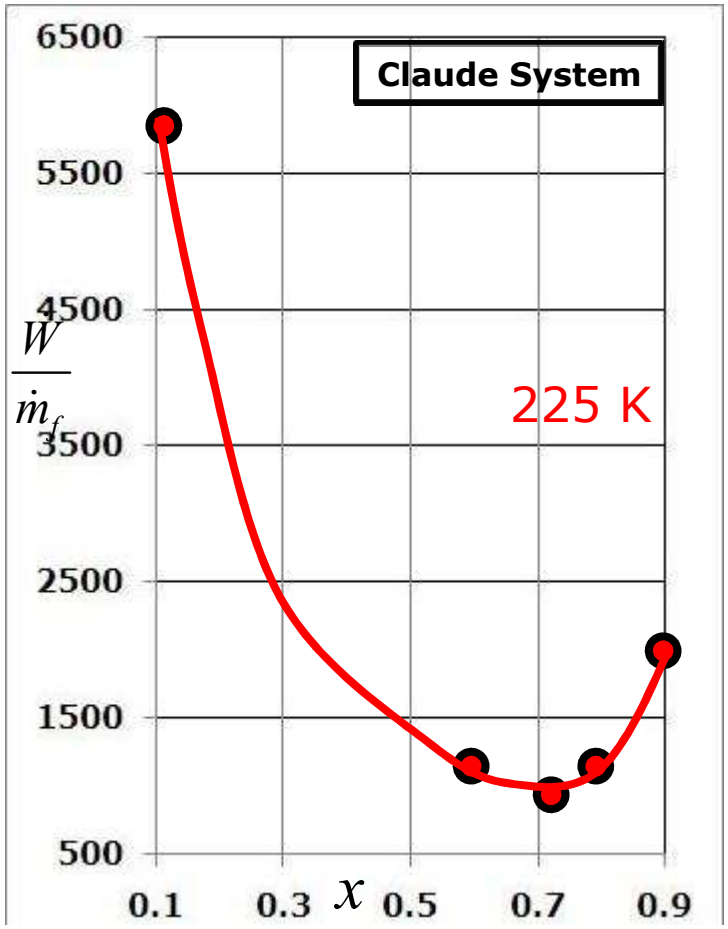


225 K	x	y
I	0.1	0.05
II	0.6	0.22
III	**0.73**	**0.26**
IV	0.8	0.19
V	0.9	0.09

- From the plot, it is clear that **y** crosses a maxima with the increasing **x**.
- Beyond this maxima, the **y** is estimated as limiting value of **y=0.99-x**.

Tutorial

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



225 K	x	$-\dot{W}/\dot{m}_f$
I	0.1	5865.2
II	0.6	1121.4
III	**0.73**	**866.8**
IV	0.8	1127.4
V	0.9	2223.3

- The trend shows that the **W/m_f** crosses a minima with the increasing **x**.
- Beyond this minima, the **W/m_f** is estimated based on limiting value of **y**.

Tutorial

- All the calculations pertaining to part **B** are left as an exercise.

- The results for these calculations are as shown.

300		275		250	
x	**y**	**x**	**y**	**x**	**y**
0.10	0.07	0.10	0.06	0.10	0.06
0.20	0.11	0.20	0.10	0.20	0.09
0.30	0.16	0.30	0.15	0.30	0.13
0.40	0.20	0.40	0.19	0.40	0.16
0.50	0.25	0.50	0.23	0.50	0.20
0.60	0.29	0.60	0.27	0.60	0.24
0.67	**0.32**	**0.69**	**0.30**	0.70	0.27
0.70	0.29	0.70	0.29	**0.72**	**0.27**
0.80	0.19	0.80	0.19	0.80	0.19
0.90	0.09	0.90	0.09	0.90	0.09

Tutorial

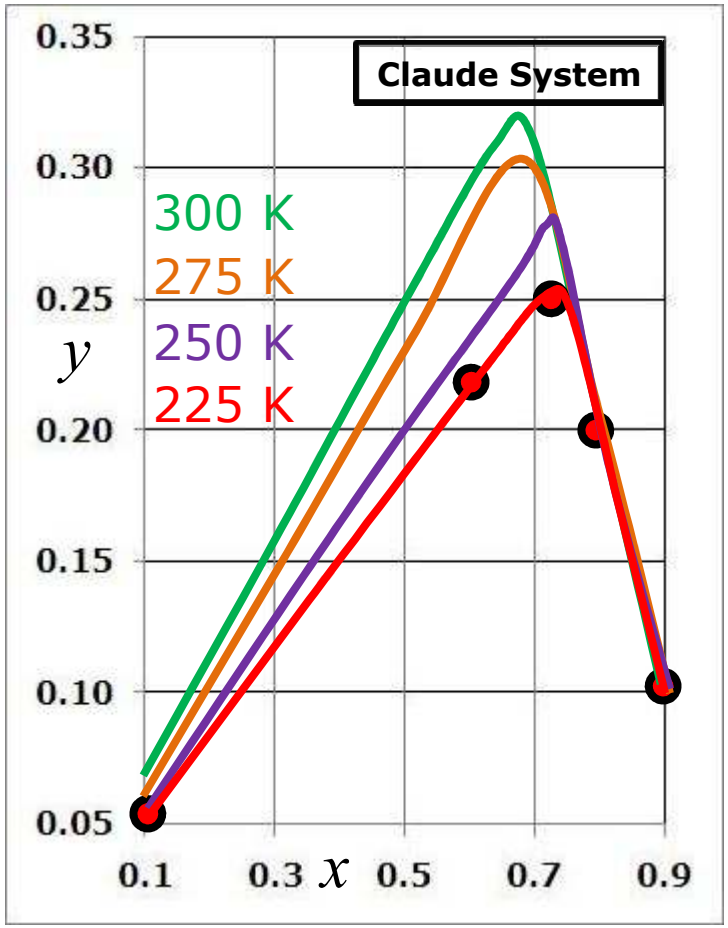
- All the calculations pertaining to part **B** are left as an exercise.

- The results for these calculations are as shown.

300		275		250	
x	W/m$_f$	x	W/m$_f$	x	W/m$_f$
0.10	4671.8	0.10	4955.4	0.10	5505.3
0.20	2598.0	0.20	2800.1	0.20	3204.2
0.30	1722.4	0.30	1876.3	0.30	2188.4
0.40	1239.3	0.40	1363.1	0.40	1616.1
0.50	933.1	0.50	1036.6	0.50	1248.9
0.60	721.7	0.60	810.5	0.60	993.4
0.67	**608.8**	**0.69**	**659.3**	0.70	805.2
0.70	656.9	0.70	693.1	**0.72**	**773.4**
0.80	900.0	0.80	963.2	0.80	1068.4
0.90	1683.3	0.90	1833.3	0.90	2083.3

Tutorial

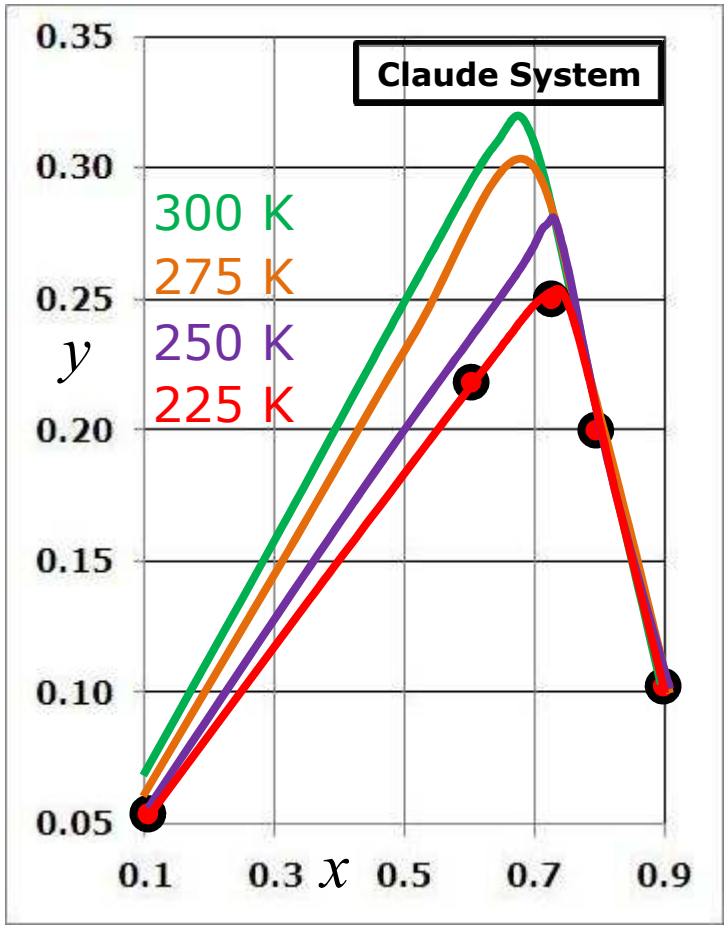
- **Liquid yield v/s. x**



- The plot for **y** versus **x** for all other values of T_3 is as shown.
- As mentioned earlier, **y** crosses a maxima with the increase in the value of **x** for each of the T_3.
- Also, the position of this maxima shifts to the right with the decrease in the value of T_3.

Tutorial

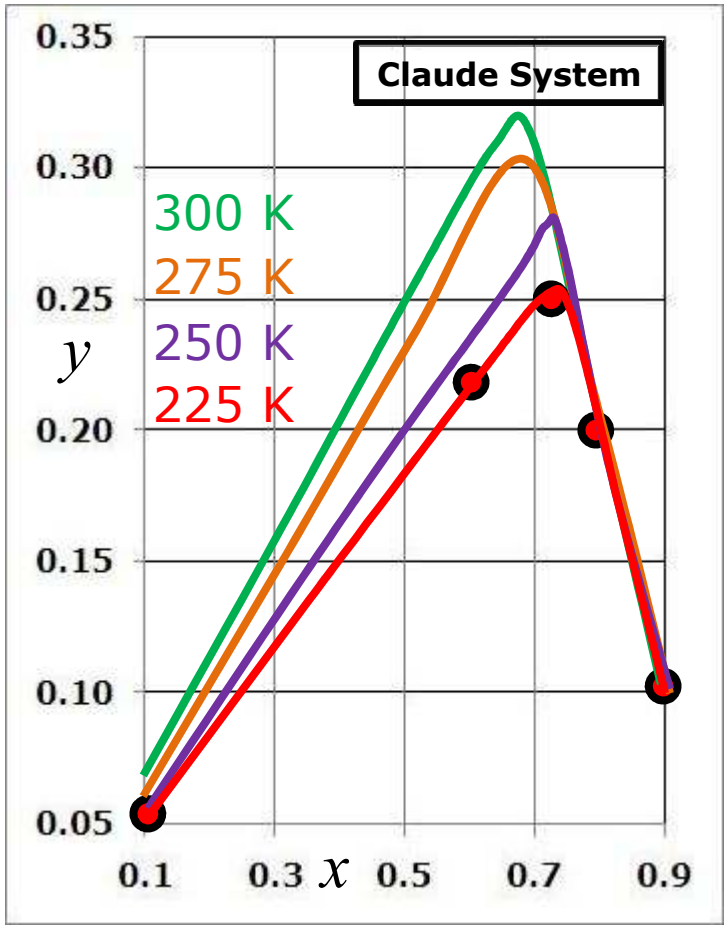
- **Liquid yield v/s. x**



- This occurs because the expander work ($\mathbf{h_3-h_e}$) decreases with the decrease in $\mathbf{T_3}$.
- Also at the lower values of $\mathbf{T_3}$, more amount of the gas can be diverted to the expander engine.
- This is because the product $\mathbf{x(h_3-h_e)}$ is maximized.

Tutorial

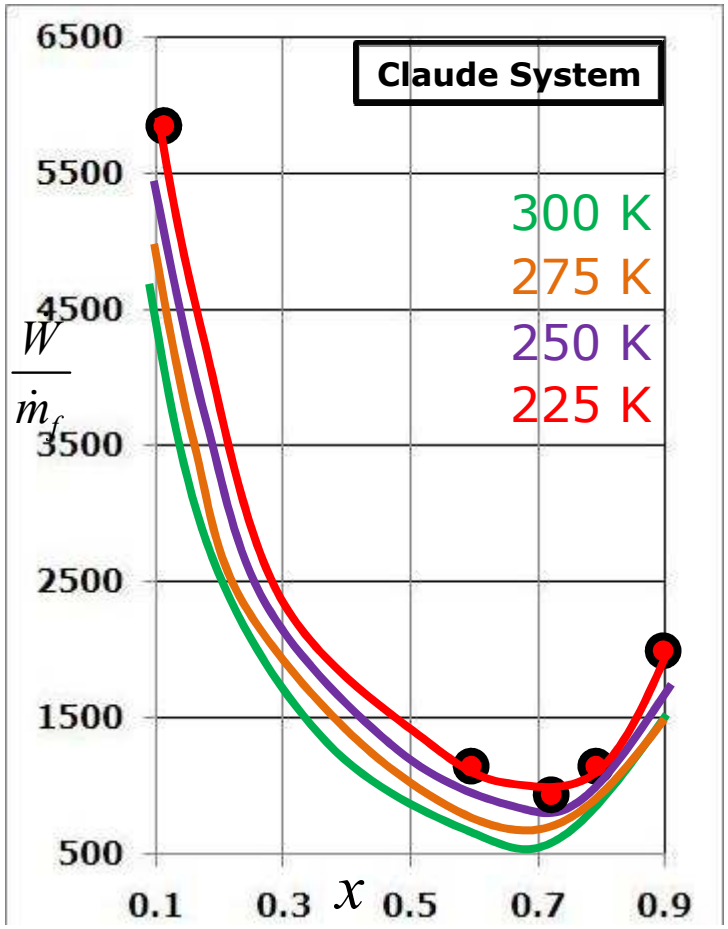
- **Liquid yield v/s. x**



- However, T_3 is limited by the position of the point **e** on the T – s diagram.

Tutorial

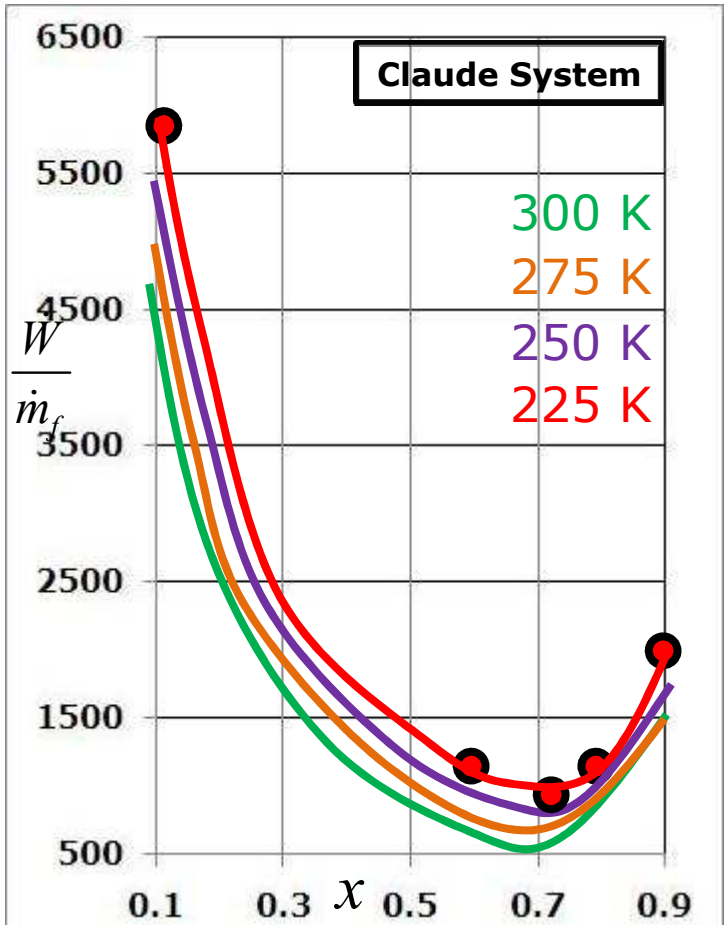
- **W/m_f v/s. x**



- The plot for **W/m_f** versus **x** for all other values of **T_3** is as shown.
- As stated earlier, the **W/m_f** crosses a minima with the increase in the **x**, for each of the **T_3**.
- Also, the position of this minima shifts to the right with the decrease in the value of **T_3**.

Tutorial

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



- The minima shifts to the right because the expander work (h_3-h_e) decreases with the decrease in T_3.
- Also, at the lower values of T_3, more amount of the gas can be diverted so that the product $x(h_3-h_e)$ is maximized.