Lebanese university

Faculty of engineering

Branch I

Project Industrial chemistry:

Separate two component and design of heat exchanger

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I. Given:

Group	Student	Binary mixture	Working pressure (bar)	Temperature (°C)	Light component molar concentration (%)	flow rate (kmol/s)	Distillate light component molar concentration(%)	Residue light component molar concentration(%)	Reflux ratio R/Rmin
5	Maria-Rita Abboud	Ethane/Ethene	16	18	32	1	92	10	1.4
	Safaa Moubayed		19	32	35	1	96	5	1.5

II. Part A: Vapor-Liquid Equilibrium diagram:

The normal boiling point of ethane is -88.598 °C and -103.771 °C for the ethene. So, ethene is the light component because its boiling temperature is smaller than the other component.

Working pressure: 19 bar

$$Feed: \begin{cases} T_F = 32°C \\ light\ comp.molar\ concentration: ethene: 35\% \\ molar\ concentration\ for\ ethane: 65\% \\ flow\ rate: 1Kmol/s \end{cases}$$

$$Distillate: \begin{cases} light\ comp.molar\ concentration: ethene: 96\% \\ molar\ concentration\ for\ ethane: 4\% \end{cases}$$

$$Residue: \begin{cases} light\ comp.molar\ concentration: ethene: 5\% \\ molar\ concentration\ for\ ethane: 95\% \end{cases}$$

$$Reflux\ ratio: \frac{R}{R_{min}} = 1.5$$

To draw the vapor-liquid equilibrium diagram we need first to find the equation of curves and to know the saturation temperature of ethane and ethene.

At P=19 bar (working pressure)

$$\begin{cases} T_{sat,ethane} = -9.1653\ °C \\ T_{sat,ethene} = -30.687\ °C \end{cases}$$

By using Raoult and Dalton laws:

$$\frac{y}{x} = \frac{P_A^{\circ}}{P}$$

and

$$\frac{1-y}{1-x} = \frac{P_B^\circ}{P}$$

So, we obtain the equation of x and y:

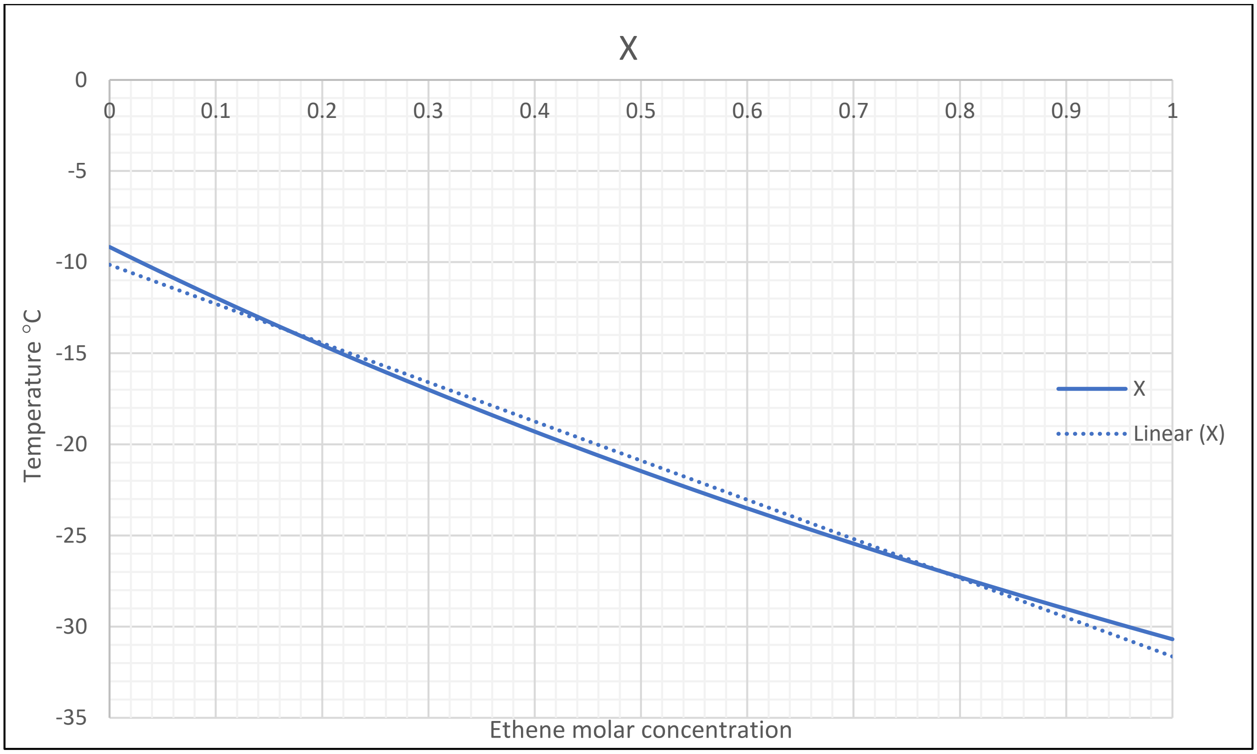
$$x = \frac{1 - \frac{P_B^\circ}{P}}{\frac{P_A^\circ}{P} - \frac{P_B^\circ}{P}}$$

$$y = \frac{\frac{P_B^\circ}{P} - 1}{\frac{P_A^\circ}{P_B^\circ} - 1}$$

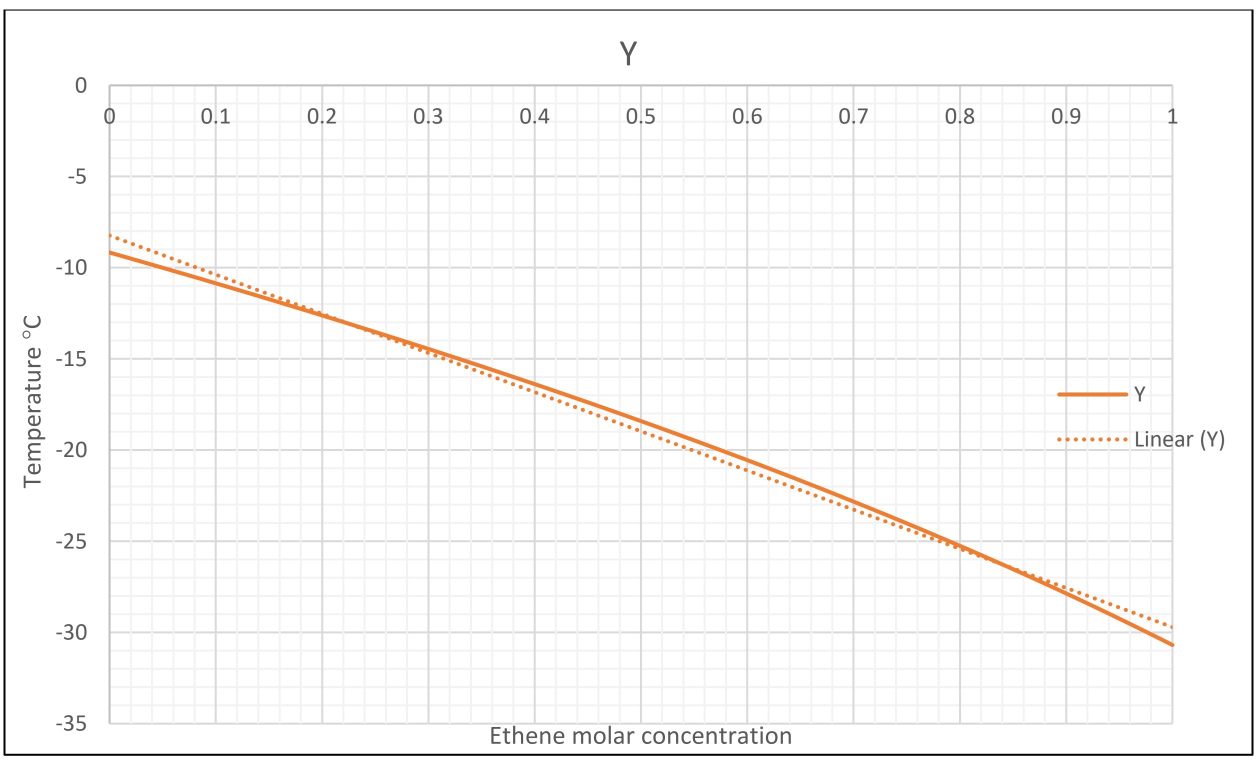
We obtain:

Temperature °C	P° ethane bar	P° ethene bar	P° ethane/P	P° ethene/P	P° ethane/P° ethene	X_ethene	Y_ethene
-30.687	10.4312	19	0.549010526	1	0.549010526	1	1
-30	10.649	19.366	0.560473684	1.019263158	0.549881235	0.958013078	0.976467435
-29	10.973	19.907	0.577526316	1.047736842	0.551213141	0.898477726	0.941368215
-28	11.304	20.459	0.594947368	1.076789474	0.552519673	0.840633534	0.90518534
-27	11.643	21.022	0.612789474	1.106421053	0.553848349	0.784411984	0.867889933
-26	11.988	21.596	0.630947368	1.136631579	0.555102797	0.729808493	0.82952338
-25	12.341	22.182	0.649526316	1.167473684	0.556351997	0.676658876	0.789981431
-24	12.702	22.779	0.668526316	1.198894737	0.557618859	0.624987596	0.749294339
-23	13.07	23.388	0.687894737	1.230947368	0.55883359	0.574723784	0.707454729
-22	13.446	24.008	0.707684211	1.263578947	0.560063312	0.525847377	0.664449676
-21	13.83	24.64	0.727894737	1.296842105	0.561282468	0.47826087	0.620228833
-20	14.222	25.284	0.748526316	1.330736842	0.562490112	0.431929127	0.574784002
-19	14.622	25.941	0.769578947	1.365315789	0.563663698	0.386783285	0.528081326
-18	15.029	26.61	0.791	1.400526316	0.564787674	0.342889215	0.480225369
-17	15.445	27.291	0.812894737	1.436368421	0.565937489	0.3001013	0.43105603
-16	15.87	27.985	0.835263158	1.472894737	0.567089512	0.258357408	0.380533267
-15	16.302	28.692	0.858	1.510105263	0.568172313	0.217756255	0.328834867
-14	16.744	29.412	0.881263158	1.548	0.569291446	0.178086517	0.275677929
-13	17.193	30.146	0.904894737	1.586631579	0.570324421	0.139504362	0.221342026
-12	17.652	30.893	0.929052632	1.625947368	0.571391577	0.101805	0.165529571
-11	18.119	31.653	0.953631579	1.665947368	0.572425994	0.065095316	0.10844537
-10	18.596	32.428	0.978736842	1.706736842	0.573455039	0.029207634	0.049849746
-9.1653	19	33.086	1	1.741368421	0.574261017	0	0

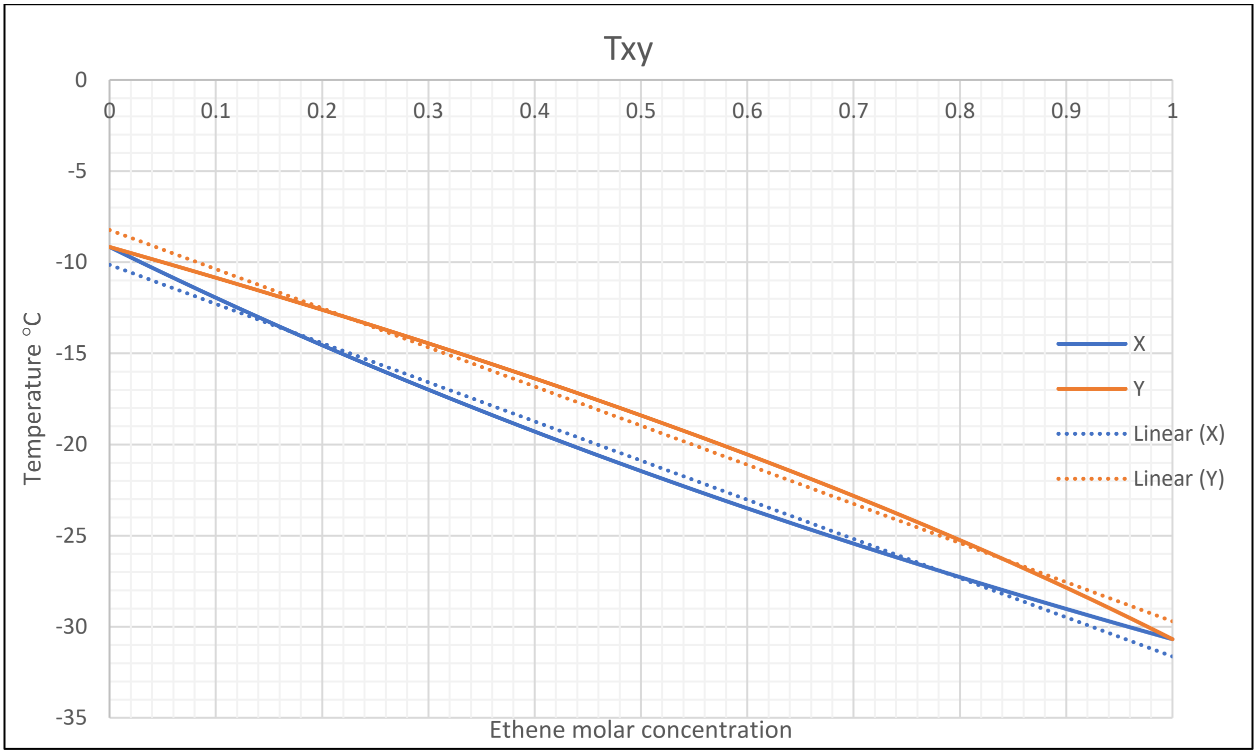
1. <u>Diagram for X alone: (19 bar)</u>



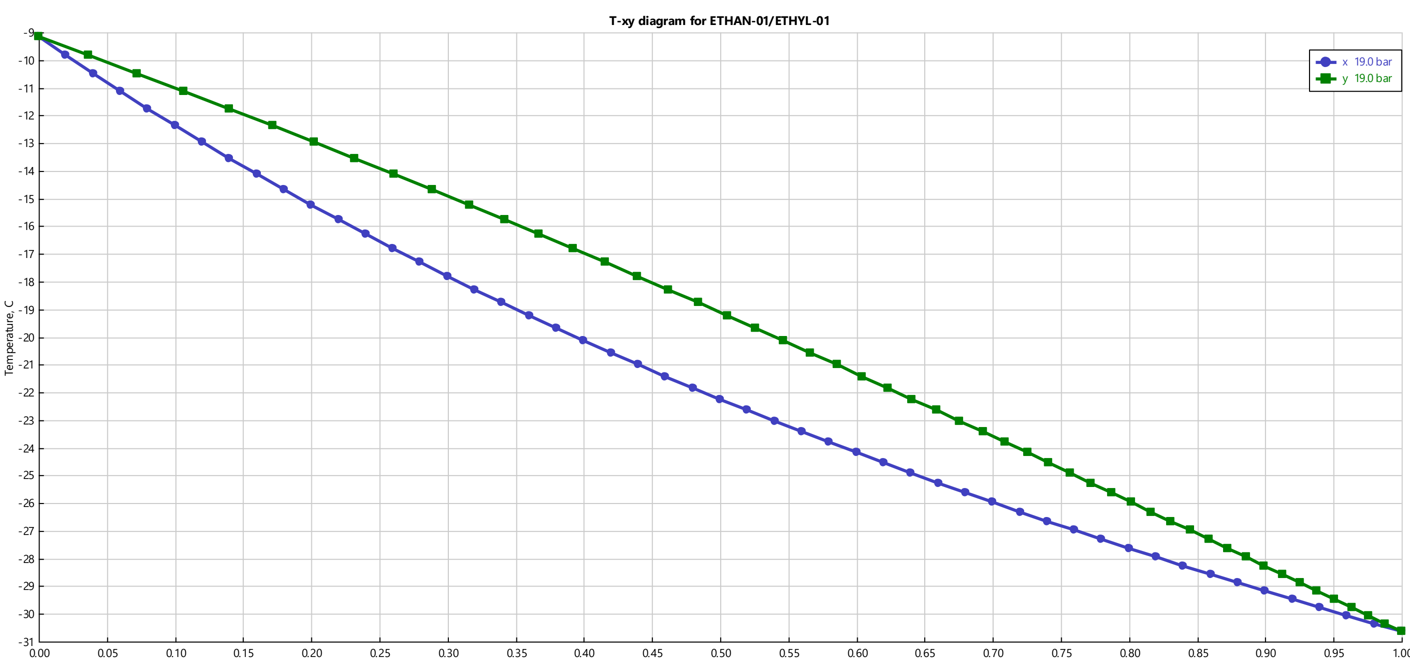
2. <u>Diagram for Y alone: (19 bar)</u>



3. Equilibrium diagram at P=19 bar:



4. Txy diagram on aspen: (19 bar)



III. Part B: Distillation column:

1. The distillate and residue flow rates: (19 bar)

Mass conservation: $D + W = F$

So; $Dx_D + Wx_W = Fz_F$

For the Ethane:

$$D * 0.04 + W0.95 = 0.65 \quad (1)$$

For the Ethene:

$$D * 0.96 + W0.05 = 0.35 \quad (2)$$

So; D= 0.329 W= 0.67

	Z_F	$F.\ Z_F$	X_D	$D.\ X_D$	X_W	$W.\ X_W$
Ethane	0.65	0.65	0.04	0.0132	0.95	0.6365
Ethene	0.35	0.35	0.96	0.3158	0.05	0.0335
	1	1	1	0.329	1	0.67

2. Temperature of the top of the distillation column: (19 bar)

For T_{top}=-25 °C

K_{ethane}=0.71 K_{ethene}=1.1

$$\sum \frac{y_i}{k_i} = 1$$

$$\frac{0.04}{0.71} + \frac{0.96}{1.1} = 0.929 < 1$$

For T_{top}=-26 °C

K_{ethane}=0.7 K_{ethene}=1.05

$$\sum \frac{y_i}{k_i} = 1$$

$$\frac{0.04}{0.7} + \frac{0.96}{1.05} = 0.97 < 1$$

For T_{top}=-27 °C

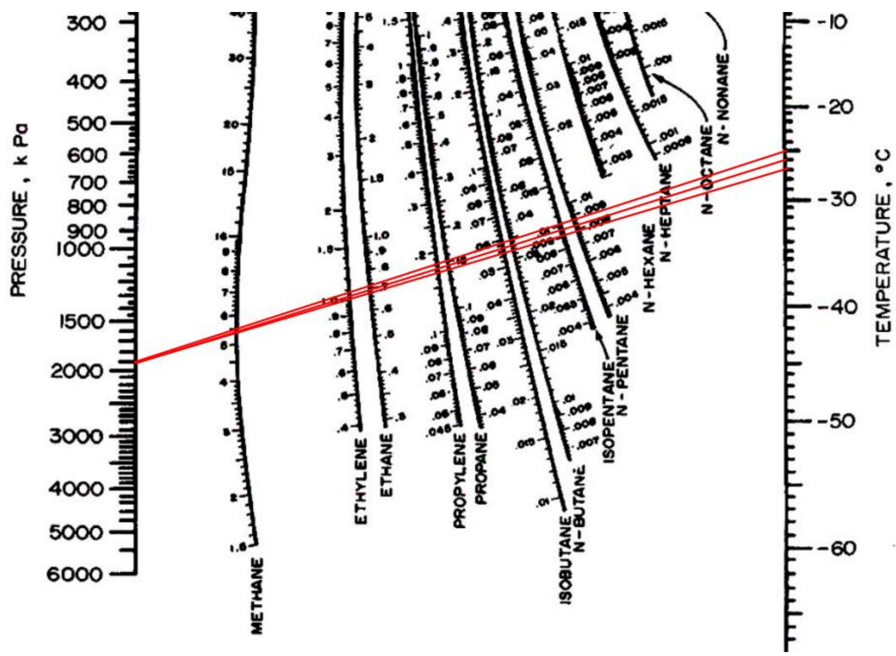
K_{ethane}=0.69 K_{ethene}=1

$$\sum \frac{y_i}{k_i} = 1$$

$$\frac{0.04}{0.69} + \frac{0.96}{1} = 1.018 > 1$$

So the temperature at the top is between -26°C and -27°C :

By interpolation: $\frac{T_{top}+26}{1-0.97} = \frac{-27+26}{1.018-0.97} \Rightarrow T_{top} = -26.625°C$



3. Temperature of the bottom of the distillation column: (19 bar)

For T_{bott}=-8 °C

K_{ethane}=1 K_{ethene}=1.5

$$\sum K_i x_i = 1$$

$$1 * 0.95 + 1.5 * 0.05 = 1.025$$

For T_{bott}=-10 °C

K_{ethane}=0.99 K_{ethene}=1.45

$$\sum K_i x_i = 1$$

$$0.99 * 0.95 + 1.45 * 0.05 = 1.013$$

<u>For T_{bott}=-12 °C</u>

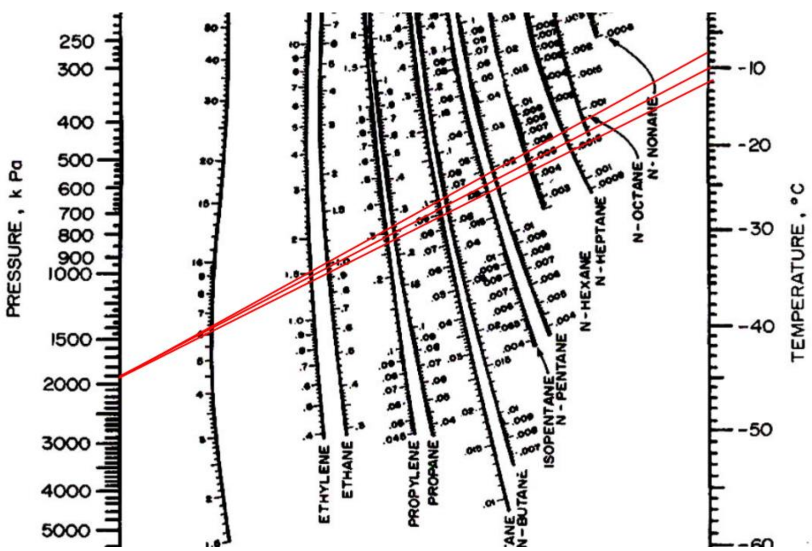
K_{ethane}=0.947 K_{ethene}=1.4

$$\sum K_i x_i = 1$$

$$0.947 * 0.95 + 1.4 * 0.05 = 0.96965$$

So the temperature at the bottom is between -10°C and -12°C :

By interpolation: $\frac{T_{bott}+12}{1-0.96965} = \frac{-10+12}{1.013-0.96965} \Rightarrow T_{bott} = -10.6°\text{C}$



4. <u>The equilibrium curve equation Y = f(x): (19 bar)</u>

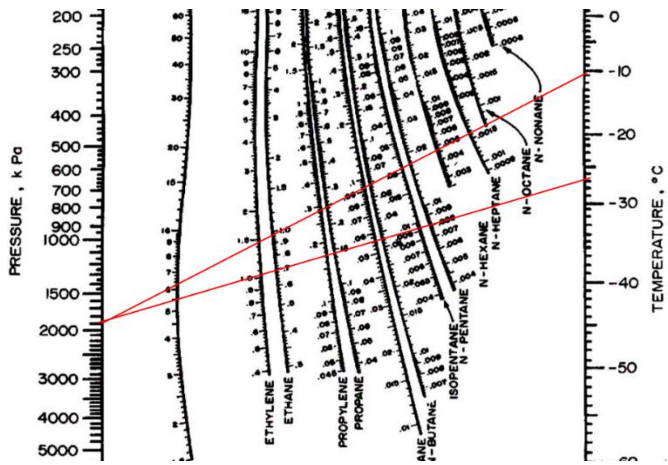
$$y = \frac{\alpha x}{1 + (\alpha - 1)x}$$

Where $\alpha = \frac{K_{ethene}}{Kethane}$

It is better to determine an average value of α between T_{top} and T_{bott}. For our case T_{top}= -26.625°C and T_{bott}= -10.6 °C .

$$\alpha_{top} = \frac{1.47}{0.99} = 1.4848$$

$$\alpha_{bott} = \frac{1.05}{0.6995} = 1.511$$

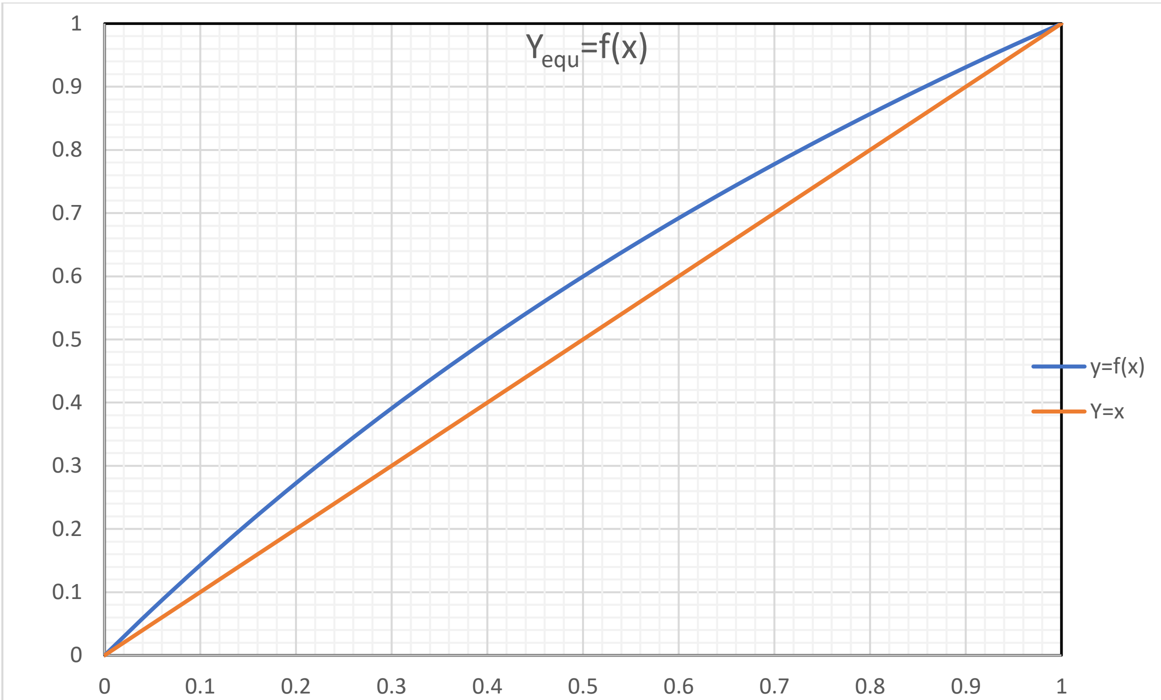


$$\alpha = \frac{\alpha_{top} + \alpha_{bott}}{2} = \frac{1.4848 + 1.511}{2} = 1.4979$$

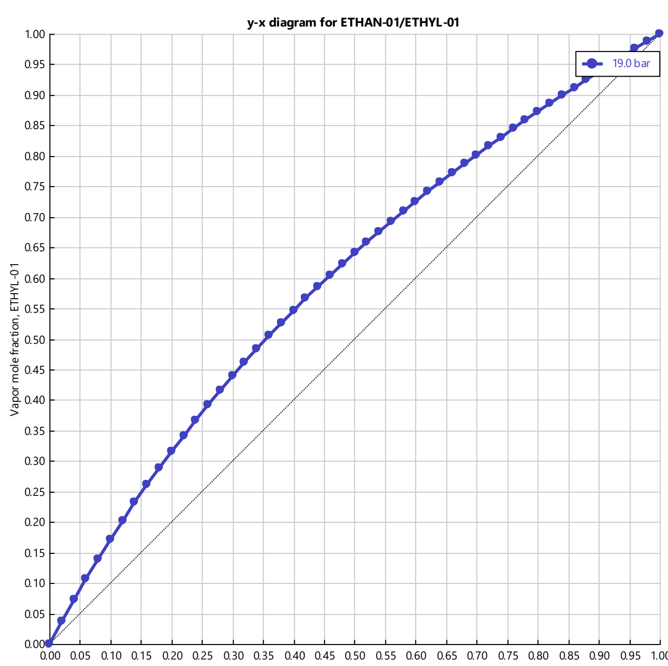
$$y = \frac{1.4979x}{1 + 0.4979x}$$

We plot y=f(x) on Excel:

x	y_equ
0	0
0.05	0.073076
0.1	0.142686
0.15	0.209071
0.2	0.272449
0.25	0.333022
0.3	0.390971
0.35	0.446462
0.4	0.49965
0.45	0.550674
0.5	0.599664
0.55	0.646739
0.6	0.692009
0.65	0.735577
0.7	0.777536
0.75	0.817973
0.8	0.856971
0.85	0.894605
0.9	0.930944
0.95	0.966056
1	1



By using Aspen:



5. The rectifying, stripping and feed sections operation lines equations: (19 bar)

a) The operating line for the rectifying section:

$$y_{rect} = \left(\frac{R}{R+1}\right)x + \left(\frac{1}{R+1}\right)x_D$$

To determine R, we need first to determine R_{min}:

$$R_{min} = \frac{1}{Z_f(\alpha - 1)}$$

We assume, the feed pressure, P_F=20 bar ($P_{distillate}$<P_F due to the friction in pipes)

At T_F=32°C and P_F=20 bar, we have:

K_{ethane} = 2 K_{ethene}=2.99

$$\alpha = \frac{2.99}{2} = 1.495$$

$$R_{min} = \frac{1}{0.35 * (1.495 - 1)} = 5.772$$

$$\frac{R}{R_{min}} = 1.5 \Rightarrow R = R_{min} * 1.5 = 5.772 * 1.5 \Rightarrow R = 8.658$$

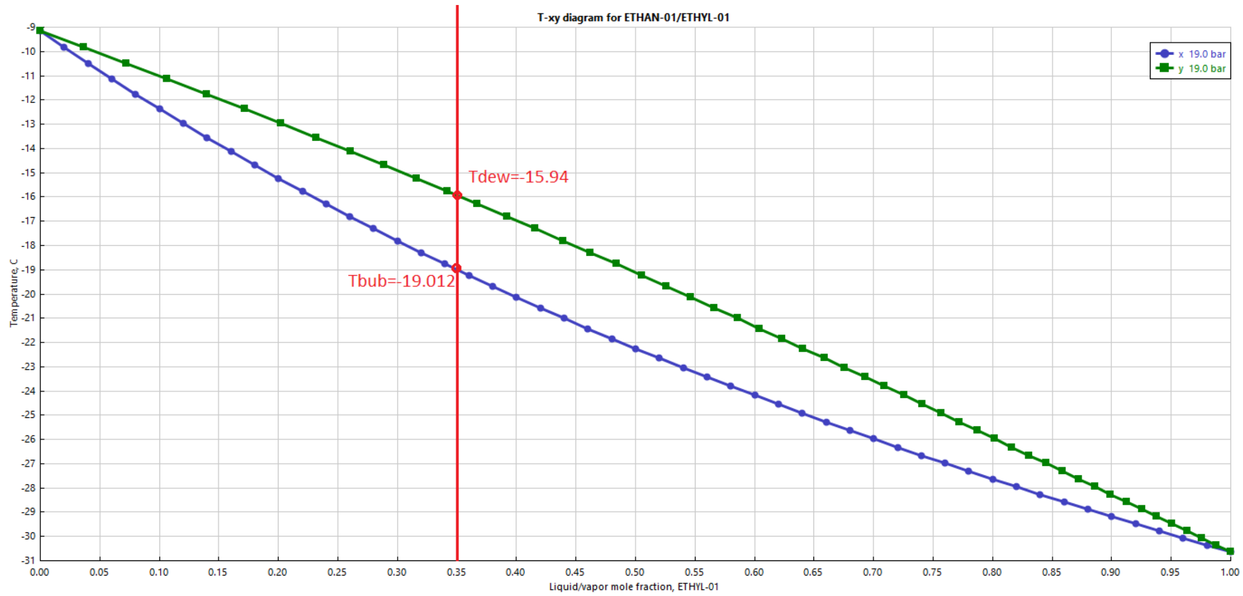
$$y_{rect} = \left(\frac{8.658}{8.658+1}\right)x + \left(\frac{1}{8.658+1}\right)0.96$$

$$y_{rect} = 0.896x + 0.0994$$

b) The feed section line equation:

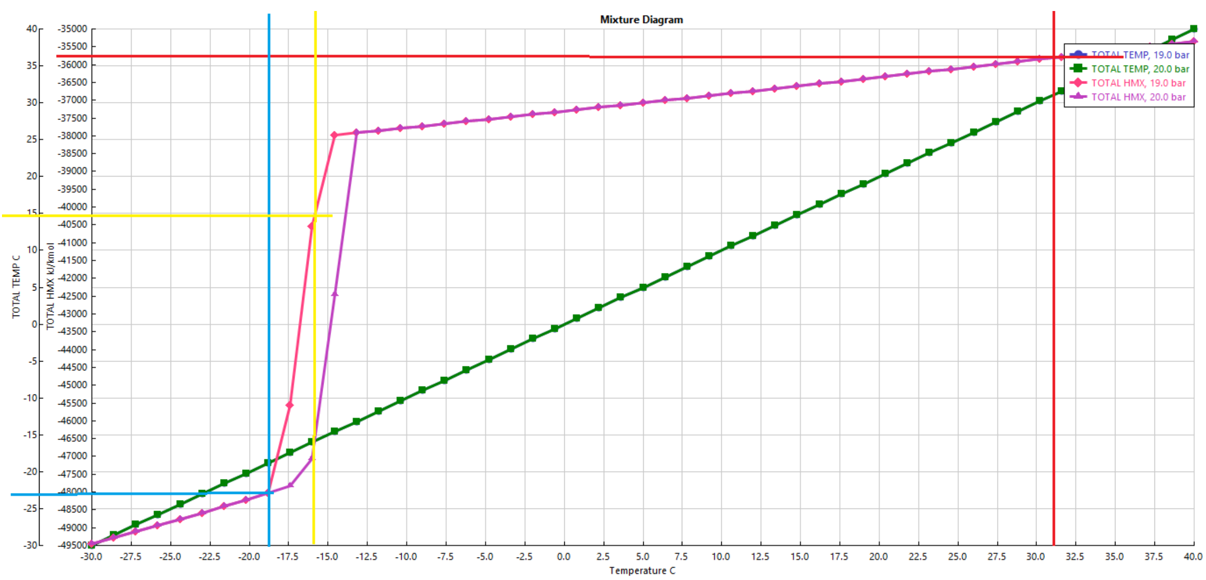
$$y_{feed} = \left(\frac{q}{q-1}\right)x - \left(\frac{Z_F}{q-1}\right)$$

q is obtained based on the feed conditions. (Feed → superheated vapor)



T_{bubb}=-19.012°C T_{dew}=-15.94°C

$$q = \frac{(h_F)_{S.V.} - h_F}{(h_F)_{S.V.} - (h_F)_{S.L.}}$$



$$T_F = 32°\text{C} \quad \Rightarrow \; h_f = -35763.2 \; KJ/Kmol$$

$$T_{bubb} = -19.012°\text{C} \quad \Rightarrow \; h_{SL} = -48047.5 \; KJ/Kmol$$

$$T_{dew} = -15.94°\text{C} \quad \Rightarrow \; h_{SV} = -40440.6 \; KJ/Kmol$$

$$q = \frac{-40440.6 + 35763.2}{-40440.6 + 48047.5} = -0.6149$$

$$y_{feed} = \left(\frac{-0.6149}{-0.6149 - 1}\right)x - \left(\frac{0.35}{-0.6149 - 1}\right)$$

$$y_{feed} = 0.3807x + 0.2167$$

c) The stripping section operating line equation:

$$y_{str} = \left(\frac{V_B + 1}{V_B}\right)x - \left(\frac{1}{V_B}\right)x_B$$

$$R = \frac{L}{D} \Rightarrow \frac{L}{0.329} = 8.658 \Rightarrow L = 2.848$$

$\frac{1}{V_B} = \frac{B}{\bar{V}}$ we have $\frac{L}{V} = \frac{R}{R+1} = 0.896 \Rightarrow V = 3.1785$

$$q = \frac{\bar{L} - L}{F} \Rightarrow \bar{L} = L + q = 2.848 - 0.6149 \Rightarrow \bar{L} = 2.2331$$

A total material balance around the feed stage gives:

$$F + \bar{V} + L = V + \bar{L} \Rightarrow 1 + \bar{V} + 2.848 = 3.1785 + 2.2331 \Rightarrow \bar{V} = 1.5636$$

$$\bar{L} = \bar{V} + B \Rightarrow B = 0.7$$

$$V_B = \frac{1.5636}{0.7} = 2.234$$

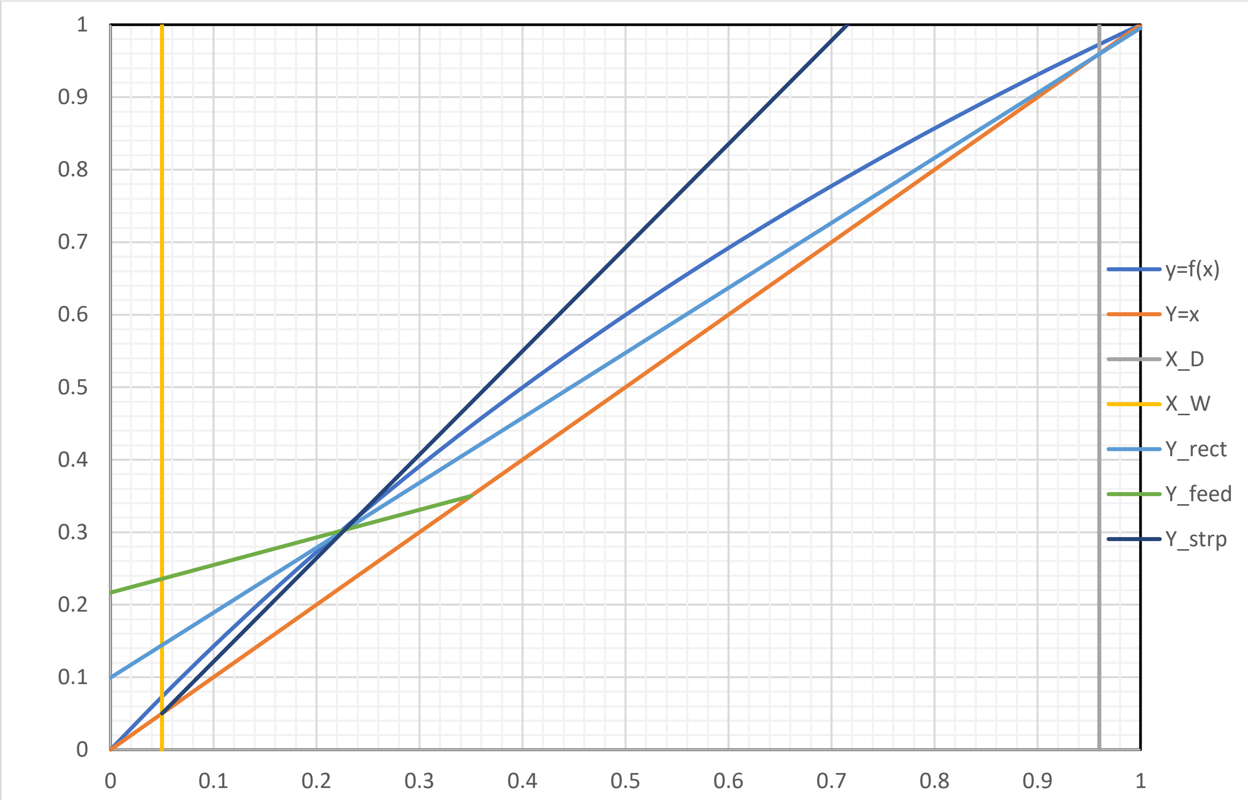
So, $y_{str} = \frac{2.234+1}{2.234}x - \frac{1}{2.234} * 0.05$

$$y_{str} = 1.447x - 0.0224$$

d) Plot of rectifying, stripping and feed lines:

By using Excel, we can plot the rectifying, stripping and feed lines

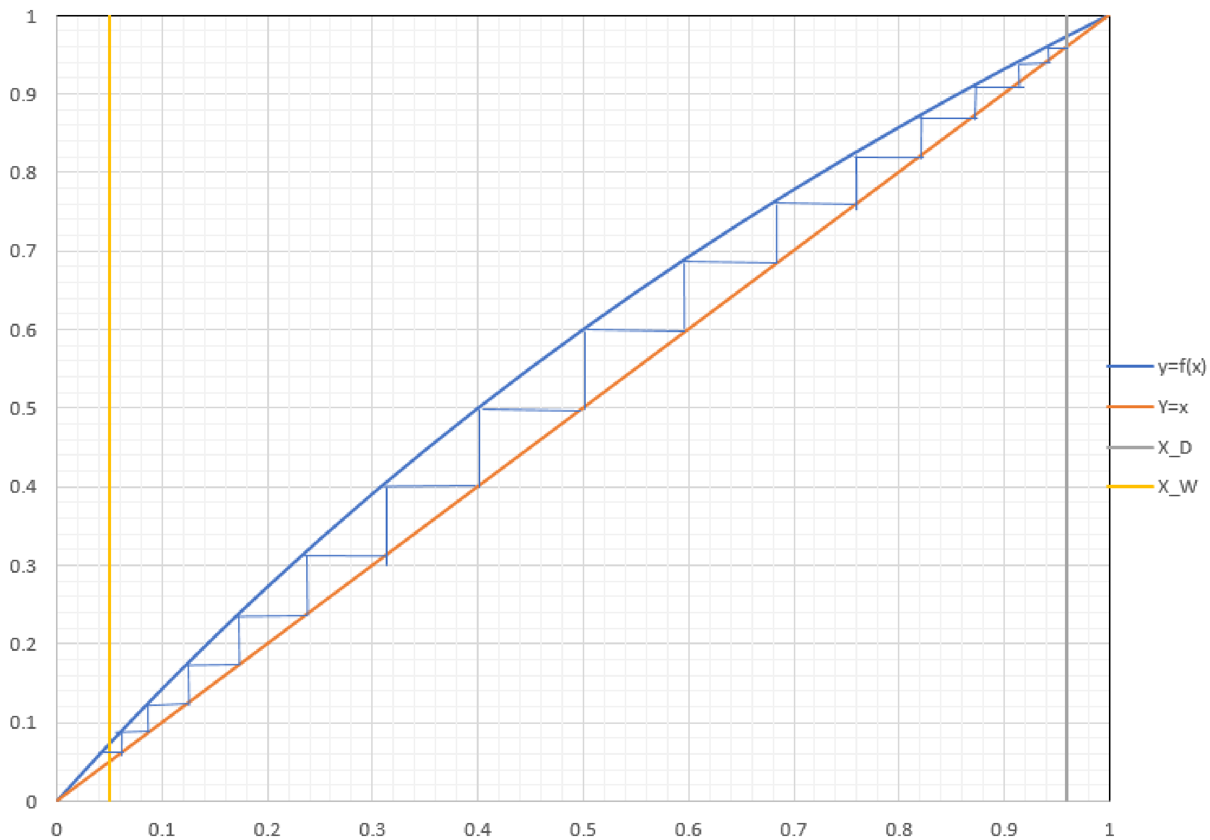
x	y_equ	X_D	X_W	Y_rect	Y_str	Y_feed
0	0	0.96	0.05	0.0994	-0.0214	0.2167
0.05	0.07307578	0.96	0.05	0.1442	0.05	0.235735
0.1	0.14268568	0.96	0.05	0.189	0.1214	0.25477
0.15	0.20907056	0.96	0.05	0.2338	0.1928	0.273805
0.2	0.27244948	0.96	0.05	0.2786	0.2642	0.29284
0.25	0.33302208	0.96	0.05	0.3234	0.3356	0.311875
0.3	0.39097071	0.96	0.05	0.3682	0.407	0.33091
0.35	0.44646226	0.96	0.05	0.413	0.4784	0.349945
0.4	0.49964975	0.96	0.05	0.4578	0.5498	0.36898
0.45	0.55067379	0.96	0.05	0.5026	0.6212	0.388015
0.5	0.59966372	0.96	0.05	0.5474	0.6926	0.40705
0.55	0.64673881	0.96	0.05	0.5922	0.764	0.426085
0.6	0.69200918	0.96	0.05	0.637	0.8354	0.44512
0.65	0.73557665	0.96	0.05	0.6818	0.9068	0.464155
0.7	0.77753554	0.96	0.05	0.7266	0.9782	0.48319
0.75	0.81797331	0.96	0.05	0.7714	1.0496	0.502225
0.8	0.85697122	0.96	0.05	0.8162	1.121	0.52126
0.85	0.89460482	0.96	0.05	0.861	1.1924	0.540295
0.9	0.93094447	0.96	0.05	0.9058	1.2638	0.55933
0.95	0.96605578	0.96	0.05	0.9506	1.3352	0.578365
1	1	0.96	0.05	0.9954	1.4066	0.5974



6. The minimum number of stages and the actual number of stages: (19 bar)

Using Excel to determine the minimum number of stages and the actual number of stages.

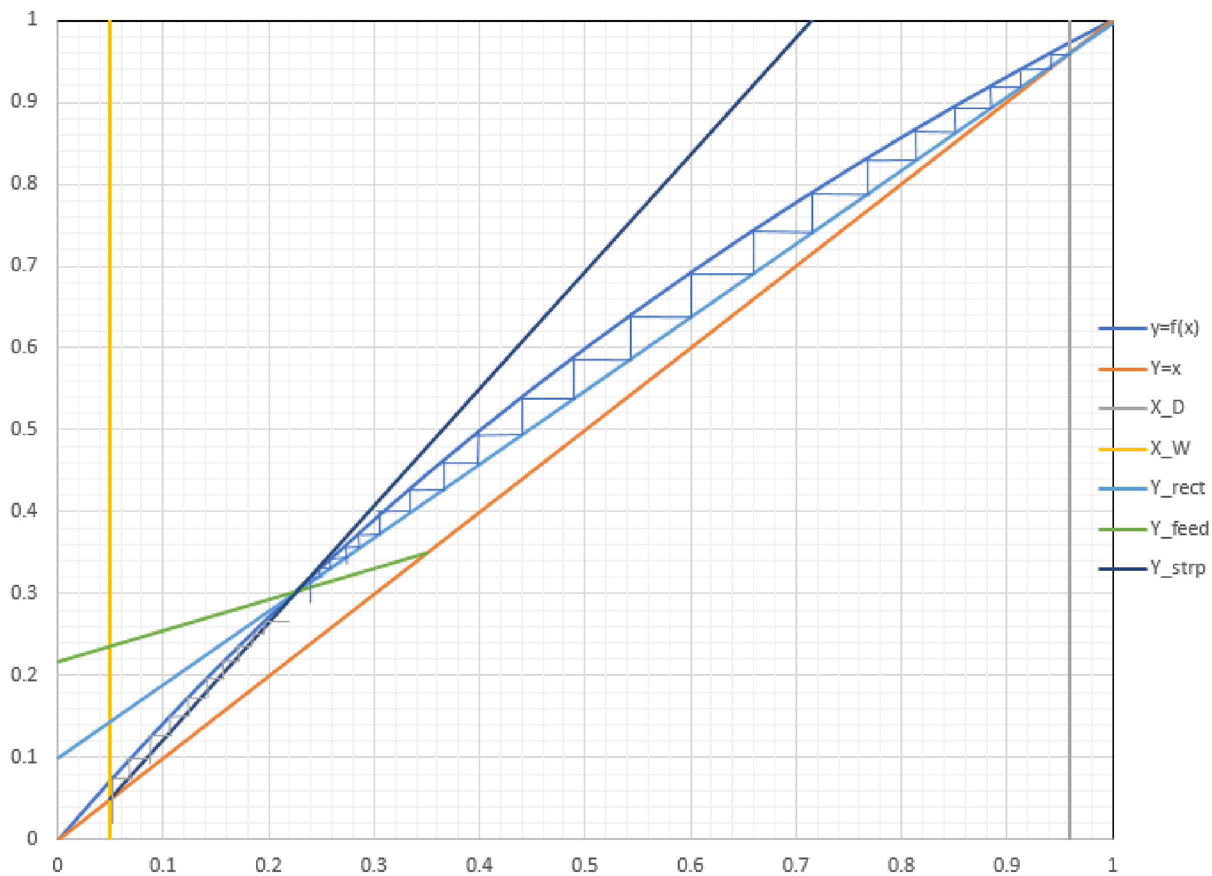
a) Minimum number of stages:



So, the minimum number of stages is: N_{min}=16 stages.

b) Actual number of stages:

To determine the actual number of stages we need to determine the number of stages in the rectifying and stripping section.

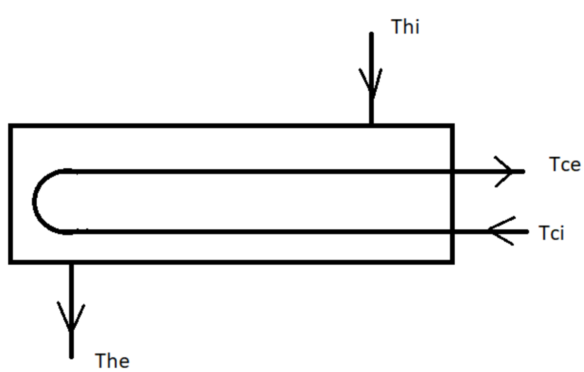


N_{rect}=21 and N_{str}=10

$$\Rightarrow N_{actual} = 21 + 10 = 31\ stages$$

IV. Part C: Design of the condenser and reboiler:

1. Condenser :(19 bar)



T_{hi}=T_{Top}=-26.625 °C

T_{he}=$T_{sat, @19bar}$=-30.687 °C (saturated liquid)

T_{Ci}=-35 °C

$\Delta T_C = 7.5$ °C

In the shell we have the mixture (ethane/ethene) and in the tubes the water-glycol (because the temperature is very low).

$Cp_{water\text{-}glycol}$=1.005 KJ/Kg. K

$$\dot{m}_{mix} = 0.329\ kg/s$$

By EES, we determine Δh:

```
T[1]=-26.625
P[1]=19
P[2]=P[1]
x[2]=0
T[2]=-30.687
h[1]=ENTHALPY(Ethylene,T=T[1],P=P[1])
h[2]=ENTHALPY(Ethylene,x=x[2],T=T[2])
x[1]=QUALITY(Ethylene,T=T[1],P=P[1])
h=h[2]-h[1]
```

	1 h_i [kJ/kg]	2 P_i	3 T_i	4 x_i
[1]	-74.99	19	-26.63	100
[2]	-468.2	19	-30.69	0

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

h = -393.2

$$\dot{m}_w = \frac{\dot{m}_{mix} * \Delta h}{C_p * \Delta T} = 17.16\ kg/s$$

We consider that the fouling resistance of 0.000176 m^2. K/W is suggested.

$$R_{Ci} = \frac{1}{h_i A_i}\ ;\ R_{fi} = \frac{R"_f}{A_i}\ ;\ R_{Cond} = \frac{\ln\left(\frac{R_0}{R_i}\right)}{2\pi K L}\ ;\ R_{f0} = \frac{R"_f}{A_0}\ ;\ R_{C0} = \frac{1}{h_0 A_0}$$

In the preliminary analysis we will consider $A_i = A_0$

<u>With fouling:</u>

$$U_{fouling} = \frac{1}{\frac{1}{h_i} + R"_f + R_{Cond} * A + R"_f + \frac{1}{h_0}}$$

h_i and h_0 can be evaluated from table 9.4 and 9.5

TABLE 9.4

Typical Film Heat Transfer Coefficients for Shell-and-Tube Heat Exchangers

	Fluid Condition	W/(m² · K)
Sensible heat transfer		
Water	Liquid	5,000–7,500
Ammonia	Liquid	6,000–8,000
Light organics	Liquid	1,500–2,000
Medium organics	Liquid	750–1,500
Heavy organics	Liquid	
	Heating	250–750
	Cooling	150–400
Very heavy organics	Liquid	
	Heating	100–300
	Cooling	60–150
Gas	1–2 bar abs	80–125
Gas	10 bar abs	250–400
Gas	100 bar abs	500–800
Condensing heat transfer		
Steam, ammonia	No noncondensable	8,000–12,000
Light organics	Pure component, 0.1 bar abs, no noncondensable	2,000–5,000
Light organics	0.1 bar, 4% noncondensable	750–1,000
Medium organics	Pure or narrow condensing range, 1 bar abs	1,500–4,000
Heavy organics	Narrow condensing range, 1 bar abs	600–2,000
Light multicomponent mixture, all condensable	Medium condensing range, 1 bar abs	1,000–2,500
Medium multicomponent mixture, all condensable	Medium condensing range, 1 bar abs	600–1,500
Heavy multicomponent mixture, all condensable	Medium condensing range, 1 bar abs	300–600
Vaporizing heat transfer		

$$h_i = \frac{600 + 1500}{2} = 1050 \frac{W}{m^2}.K$$

$$h_0 = \frac{1500 + 4000}{2} = 2750 \frac{W}{m^2}.K$$

$$U_{fouling} = 599.514 \frac{W}{m^2}.K$$

<u>For clean surface:</u>

$$U_{clean} = \frac{1}{\frac{1}{h_i} + \frac{1}{h_0}} = 759.87 \frac{W}{m^2}.K$$

$$\Delta T_{LMTD} = \frac{(T_{hi} - T_{ce}) - (T_{he} - T_{ci})}{\ln\left(\frac{T_{hi} - T_{ce}}{T_{he} - T_{ci}}\right)} = 2.67$$

$$q = \dot{m} * C_p * \Delta T = 129.3435\, KW$$

$$A_{clean} = \frac{q}{F * U_{clean} * \Delta T_{LMTD}} = 63.7\, m^2$$

With F=1 (condensation)

$$A_{fouling} = \frac{q}{F * U_{fouling} * \Delta T_{LMTD}} = 80.8\, m^2$$

To determine the shell diameter:

$$D_s = 0.637\sqrt{\frac{CL}{CTP}}\left[\frac{A_0 (PR)^2 d_0}{L}\right]^{0.5}$$

With CL=1 for 90° and CTP=0.9 for two tube passes

We assume L=2.9 m

$$\Rightarrow D_s = 0.6\, m$$

$$\frac{L}{D_s} = 5$$

It is necessary that the ratio $5 < \frac{L}{D_s} < 15$

So, we can take L=2.9 m

Now, we will determine the number of tubes:

$$N_t = 0.785\left(\frac{CTP}{CL}\right)\frac{D_S^2}{(PR)^2 D_0^2} = 529.3 tubes$$

From table 9.3:

TABLE 9.3 (CONTINUED)

Tube-Shell Layouts (Tube Counts)

Shell ID (in.)	1-P	2-P	4-P	6-P	8-P
3/4-in. OD tubes on 1-in. square pitch					
8	32	26	20	20	
10	52	52	40	36	
12	81	76	68	68	60
13 ¼	97	90	82	76	70
15 ¼	137	124	116	108	108
17 ¼	177	166	158	150	142
19 ¼	224	220	204	192	188
3/4-in. OD tubes on 1-in. square pitch					
21 ¼	277	270	246	240	234
23 ¼	341	324	308	302	292
25	413	394	370	356	346
27	481	460	432	420	408
29	553	526	480	468	456
31	657	640	600	580	560
33	749	718	688	676	648
35	845	824	780	766	748
37	934	914	886	866	838
39	1049	1024	982	968	948

So, the shell ID=31 in (787.4 mm) and $N_t = 640\ tubes$

Thus, the baffle spacing is considered $0.7D_s \Rightarrow B = 0.42\ m$

The coolant velocity inside tube is limited to 1.5m/s

$$v = \frac{\dot{m_w}}{\rho * N_t * S_{tube}} = \frac{17.16}{996 * 640 * \pi \frac{0.016^2}{4}} = 0.14 m/s < 1.5\ m/s$$

<u>By using Aspen:</u>

		Hotside	ColdSide	Recent Hotside	Recent ColdSide	Previous Hotside	Previous ColdSide
Calculation mode		Design (Sizing)					
Process Conditions							
Mass flow rate	kg/s	0.329	17.16	0.329	17.16	0.329	17.16
Mass flow rate multiplier							
Inlet pressure	bar	19	1	19	1	19	1
Outlet pressure	bar			18.71	0.89	18.71	0.89
Pressure at liquid surface in column	bar						
Inlet Temperature	°C	-26.625	-35	-26.62	-35	-26.62	-35
Outlet Temperature	°C			-30.69	-27.5	-30.69	-27.5
Inlet vapor mass fraction				0	0	0	0
Outlet vapor mass fraction		0		0	0	0	0
Heat exchanged	kW						
Heat exchanged multiplier							
Process Input							
Allowable pressure drop	bar			0.29	0.20684	0.29	0.20684
Fouling resistance	m^2-K/W	0.000176	0.000176	0.00018	0.00018	0.00018	0.00018
Calculated Results							
Pressure drop	bar					0.21362	0.35496

Calculation mode: Design (Sizing) — Recent — Previous — Setting Plan — Tube Layout

Configuration				
TEMA Type		B - / E - / M -		
Tube layout option		New (optimum) layout		
Location of hot fluid		Tube side		
Tube OD / Pitch	mm	19.05 / 23.81	/	/
Tube pattern		90-Square		
Tubes are in baffle window		Yes		
Baffle type		Single segmental		
Baffle cut orientation		Horizontal		
Default exchanger material				

Get Properties

Overwrite Properties

Restore Defaults

Pivot Table

Temperature Points

Number: 5

Temperatures: Specify range

Range: -26.51 -30.51 °C

Pressure Levels

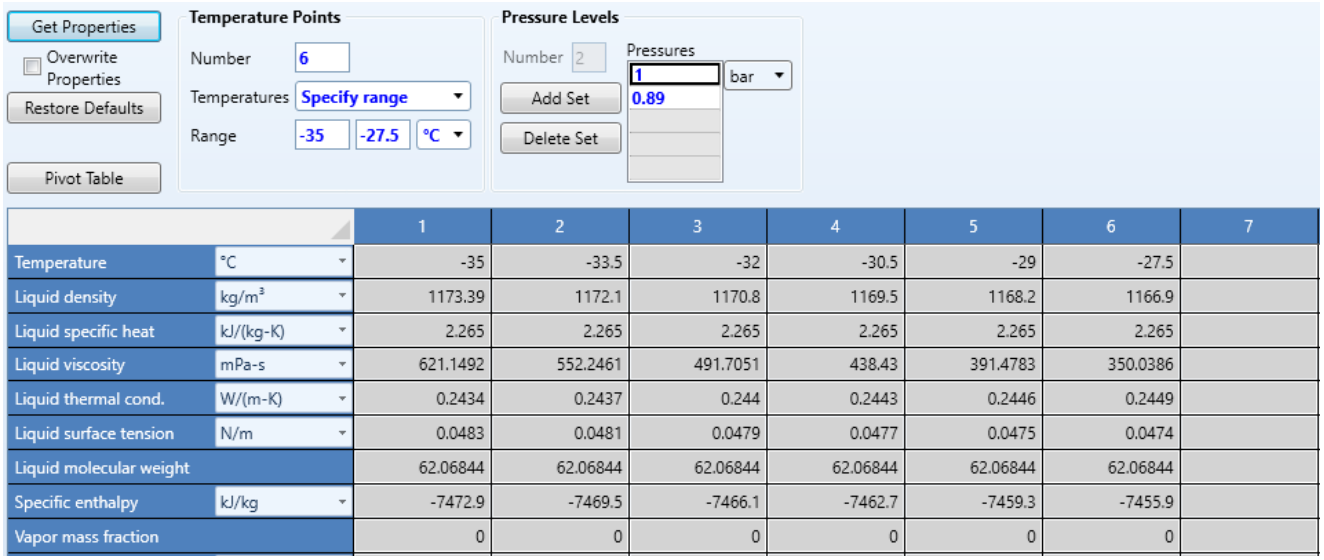
Number: 2

Pressures: 19, 18.62 bar

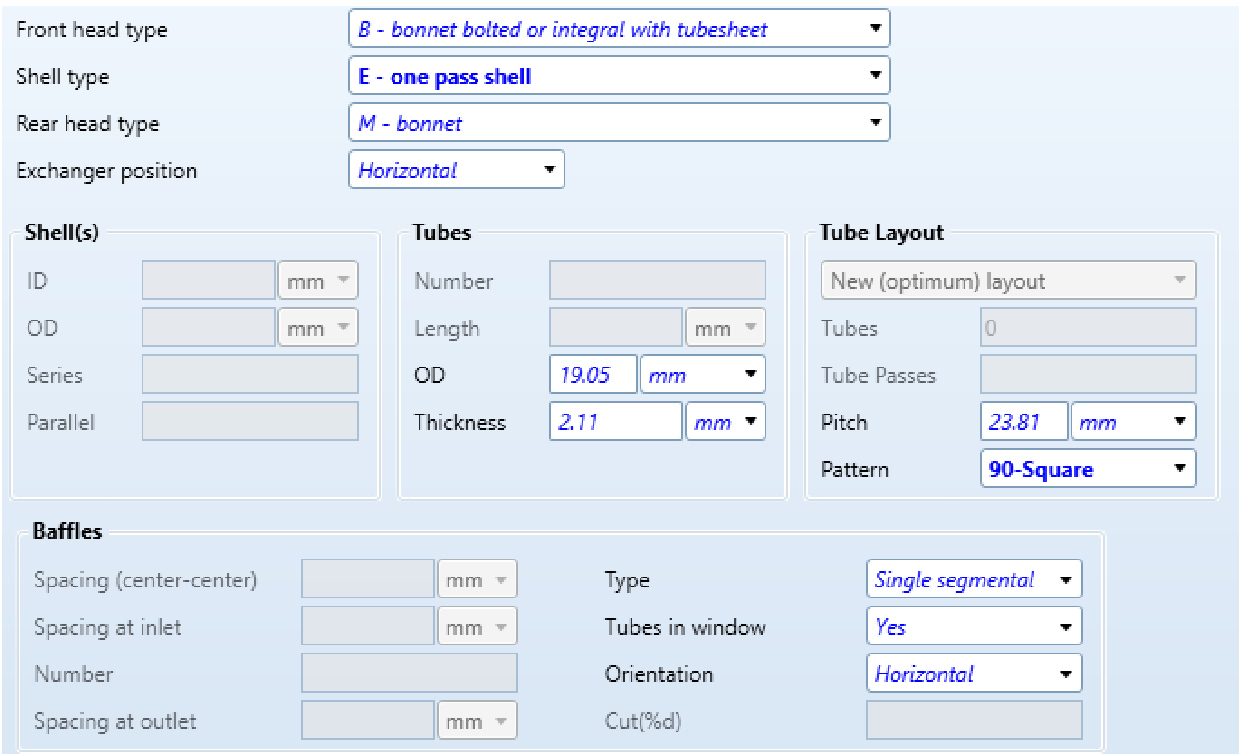
Add Set

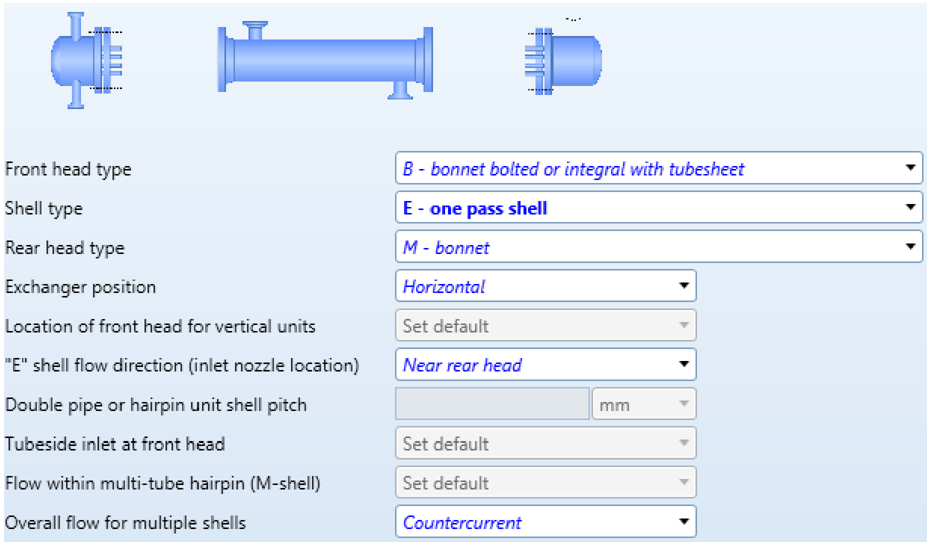
Delete Set

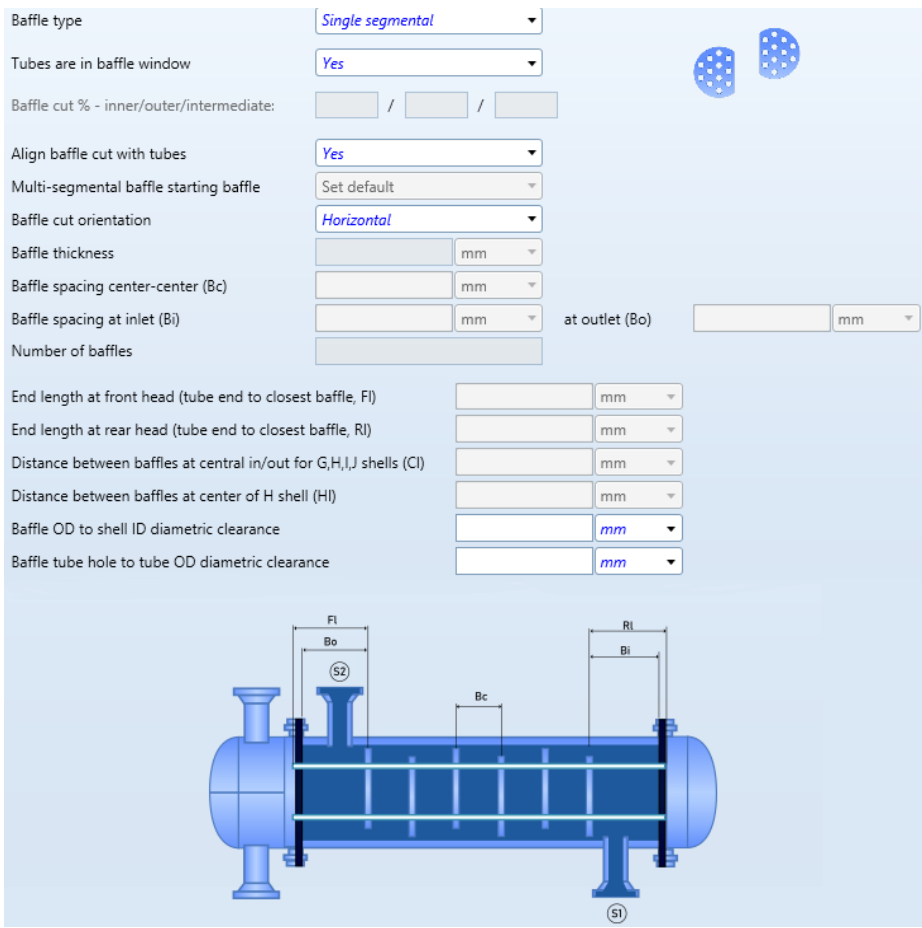
		1	2	3	4	5	6
Temperature	°C	-26.51	-27.51	-28.51	-29.51	-30.51	
Liquid density	kg/m^3	1166.04	1166.91	1167.78	1168.64	1169.51	
Liquid specific heat	kJ/(kg-K)	2.265	2.264	2.264	2.264	2.264	
Liquid viscosity	mPa-s	325.2679	350.1942	377.2584	406.6626	438.6297	
Liquid thermal cond.	W/(m-K)	0.2451	0.2449	0.2447	0.2445	0.2443	
Liquid surface tension	N/m	0.0472	0.0474	0.0475	0.0476	0.0477	
Liquid molecular weight		62.06844	62.06844	62.06844	62.06844	62.06844	
Specific enthalpy	kJ/kg	-7452.1	-7454.4	-7456.6	-7458.9	-7461.2	
Vapor mass fraction		0	0	0	0	0	



		1	2	3	4	5	6	7
Temperature	°C	-35	-33.5	-32	-30.5	-29	-27.5	
Liquid density	kg/m^3	1173.39	1172.1	1170.8	1169.5	1168.2	1166.9	
Liquid specific heat	kJ/(kg-K)	2.265	2.265	2.265	2.265	2.265	2.265	
Liquid viscosity	mPa-s	621.1492	552.2461	491.7051	438.43	391.4783	350.0386	
Liquid thermal cond.	W/(m-K)	0.2434	0.2437	0.244	0.2443	0.2446	0.2449	
Liquid surface tension	N/m	0.0483	0.0481	0.0479	0.0477	0.0475	0.0474	
Liquid molecular weight		62.06844	62.06844	62.06844	62.06844	62.06844	62.06844	
Specific enthalpy	kJ/kg	-7472.9	-7469.5	-7466.1	-7462.7	-7459.3	-7455.9	
Vapor mass fraction		0	0	0	0	0	0	




Front head type
B - bonnet bolted or integral with tubesheet
Shell type
E - one pass shell
Rear head type
M - bonnet
Exchanger position
Horizontal
Location of front head for vertical units
Set default
"E" shell flow direction (inlet nozzle location)
Near rear head
Double pipe or hairpin unit shell pitch
mm
Tubeside inlet at front head
Set default
Flow within multi-tube hairpin (M-shell)
Set default
Overall flow for multiple shells
Countercurrent

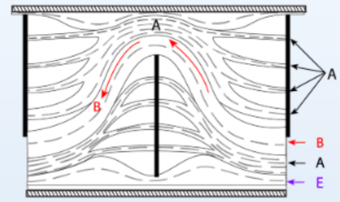

Baffle type
Single segmental
Tubes are in baffle window
Yes
Baffle cut % - inner/outer/intermediate:
Align baffle cut with tubes
Yes
Multi-segmental baffle starting baffle
Set default
Baffle cut orientation
Horizontal
Baffle thickness
mm
Baffle spacing center-center (Bc)
mm
Baffle spacing at inlet (Bi)
mm
at outlet (Bo)
mm
Number of baffles
End length at front head (tube end to closest baffle, Fl)
mm
End length at rear head (tube end to closest baffle, Rl)
mm
Distance between baffles at central in/out for G,H,I,J shells (Cl)
mm
Distance between baffles at center of H shell (Hl)
mm
Baffle OD to shell ID diametric clearance
mm
Baffle tube hole to tube OD diametric clearance
mm
Fl
Bo
S2
Bc
Rl
Bi
S1

		A	B
Shell ID	mm	736.6	736.6
Tube length - actual	mm	2438.4	2438.4
Tube length - required	mm	1103	1103
Pressure drop, SS	bar	0.35496	0.35496
Pressure drop, TS	bar	0.21362	0.21362
Baffle spacing	mm	596.9	596.9
Number of baffles		2	2
Tube passes		4	4
Tube number		624	624
Number of units in series		2	2
Number of units in parallel		1	1
Total price	Dollar(US)	83680	83680
Program mode		Design (Sizing)	Design (Sizing)
Calculation method		Advanced methoc	Advanced methoc
Area Ratio (dirty)	-	2.21	2.21
Film coef overall, SS	$W/(m^2\text{-}K)$	211.7	211.7
Film coef overall, TS	$W/(m^2\text{-}K)$	66.6	66.6
Heat load	kW	6.2	6.2
Recap case fully recoverable		Yes	Yes

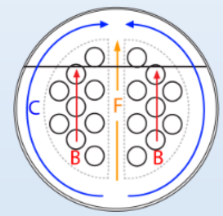
Design (Sizing)		Shell Side		Tube Side	
Total mass flow rate	kg/s	17.16		0.329	
Vapor mass flow rate (In/Out)	kg/s	0	0	0	0
Liquid mass flow rate	kg/s	17.16	17.16	0.329	0.329
Vapor mass fraction		0	0	0	0
Temperatures	°C	-35	-34.84	-26.62	-34.94
Bubble / Dew point	°C	/	/	/	/
Operating Pressures	bar	1	0.79316	19	18.78638
Film coefficient	$W/(m^2\text{-}K)$	211.7		66.6	
Fouling resistance	$m^2\text{-}K/W$	0.00018		0.00023	
Velocity (highest)	m/s	0.15		0.01	
Pressure drop (allow./calc.)	bar	0.20684 / 0.35496		0.29 / 0.21362	

Total heat exchanged	kW	6.2	Unit	BEM	4 pass	2 ser	1 par	
Overall clean coeff. (plain/finned)	$W/(m^2\text{-}K)$	50.5 /	Shell size	737 - 2438.4	mm		Hor	
Overall dirty coeff. (plain/finned)	$W/(m^2\text{-}K)$	49.5 /	Tubes	Plain				
Effective area (plain/finned)	m^2	173.3 /	Insert	None				
Effective MTD	°C	1.6	No.	624	OD	19.05	Tks	2.11 mm
Actual/Required area ratio (dirty/clean)		2.21 / 2.26	Pattern	90		Pitch	23.81 mm	
Vibration problem (HTFS)		No	Baffles	Single segmental		Cut(%d)	39.98	
RhoV2 problem		No	Total cost		83680	Dollar(US)		

Shell Side Flow Fractions	Inlet	Middle	Outlet	Diameter Clearance mm
Crossflow (B stream)	0.58	0.57	0.58	
Window (B+C+F stream)	0.99	0.96	0.99	
Baffle hole - tube OD (A stream)	0	0	0	0.4
Baffle OD - shell ID (E stream)	0.01	0.04	0.01	4.76
Shell ID - bundle OTL (C stream)	0.07	0.07	0.07	12.7
Pass lanes (F stream)	0.34	0.32	0.34	



Rho*V2 Analysis	Flow Area	Velocity	Density	Rho*V2	TEMA limit
	mm^2	m/s	kg/m^3	$kg/(m\text{-}s^2)$	$kg/(m\text{-}s^2)$
Shell inlet nozzle	18639	0.78	1173.39	722	2232
Shell entrance	24422	0.6	1173.39	421	5953
Bundle entrance	96624	0.15	1173.39	27	5953
Bundle exit	80202	0.18	1173.25	39	5953
Shell exit	24422	0.6	1173.25	421	5953
Shell outlet nozzle	18639	0.78	1173.25	722	
	mm^2	m/s	kg/m^3	$kg/(m\text{-}s^2)$	$kg/(m\text{-}s^2)$
Tube inlet nozzle	279	1.01	1166.15	1193	8928
Tube inlet	25577	0.01	1166.15	0	
Tube outlet	29379	0.01	1173.34	0	
Tube outlet nozzle	151	1.86	1173.34	4043	



Fluid Elastic Instability Analysis

Vibration tube number		1	2	4	5	6	8
Vibration tube location		Inlet row, centre	Outer window, top	Baffle overlap	Top row	Inlet row, end	Outer window, bottom
Vibration		No	No	No	No	No	No
W/Wc for heavy damping (LDec=0.1)		0.02	0.09	0.03	0.02	0.02	0.09
W/Wc for medium damping (LDec=0.03)		0.04	0.16	0.06	0.03	0.04	0.16
W/Wc for light damping (LDec=0.01)		0.06	0.27	0.1	0.06	0.06	0.28
W/Wc for estimated damping		0.01	0.04	0.02	0.01	0.01	0.04
Estimated log Decrement		0.55	0.55	0.37	0.55	0.55	0.55
Tube natural frequency	cycle/s	36.27	36.27	81.27	36.27	36.27	36.27
Natural frequency method		Exact Solution	Exact Solution	Exact Solution	Exact Solution	Exact Solution	Exact Solution
Dominant span							
Tube effective mass	kg/m	1.59	1.59	1.59	1.59	1.59	1.59

By comparison between manual calculation and aspen results we can deduce that the results are very close.

2. Reboiler :(19 bar)

$T_{ci}=T_{bott}=-11\ °C$

$T_{ce}=T_{sat,\ @19bar}=-9\ °C$

$T_{hi}=9.6\ °C$

```
T[1]=-11
P[1]=19
P[2]=P[1]
X[2]=1
T[2]=T_SAT(ethane,P=P[2])
h[1]=ENTHALPY(Ethane,T=T[1],P=P[1])

h[2]=ENTHALPY(Ethane,x=x[2],P=P[2])
h=h[2]-h[1]
```

Solution

Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

h = 336.1

$$\Delta h = 336.1\ KJ/Kg.K$$

Cp_{water}=4.179 KJ/Kg. K

$$\dot{m_w} = 0.67\ kg/s$$

$$\dot{m_{mix}} = 0.75\ kg/s$$

		Hotside	ColdSide	Recent Hotside	Recent ColdSide	Previous Hotside	Previous ColdSide
Calculation mode		Design (Sizing)					
Process Conditions							
Mass flow rate	kg/s	0.67	0.75	0.67	0.75		
Mass flow rate multiplier		1	1				
Inlet pressure	bar	1	19	1	19		
Outlet pressure	bar	0.89	18.71	0.89	18.71		
Pressure at liquid surface in column	bar						
Inlet Temperature	°C	9.6	-11	9.6	-11		
Outlet Temperature	°C			99.6	-9		
Inlet vapor mass fraction				1	0		
Outlet vapor mass fraction		1		1	1		
Heat exchanged	kW						
Heat exchanged multiplier		1					
Process Input							
Allowable pressure drop	bar	0.11	0.49987	0.11	0.49987		
Fouling resistance	m^2-K/W	0	0	0	0		
Calculated Results							
Pressure drop	bar						

	Shell	Tube Length			Pressure Drop				Baffle		Tube		Units		Total	Operational Issues			
Item	Size	Actual	Reqd.	Area ratio	Shell	Dp Ratio	Tube	Dp Ratio	Pitch	No.	Tube Pass	No.	P	S	Price	Vibration	Rho-V-Sq	Unsupported tube length	Design
	mm	mm	mm		bar		bar		mm						Dollar(US)				
1	438.15	6096	6451.2	0.94 *	0.04102	0.37	0.04014	0.08	596.9	8	1	211	1	1	25513	Possible	No	No	Near
2	488.95	5486.4	5314.9	1.03	0.03587	0.33	0.04011	0.08	539.75	8	1	278	1	1	28584	Possible	No	No	(OK)
3	539.75	6096	5151.1	1.18	0.03059	0.28	0.04011	0.08	596.9	8	1	342	1	1	33241	Possible	No	No	(OK)
4	307.09	6096	5500.4	1.11	0.16304	1.48 *	0.08952	0.18	609.6	8	1	88	1	2	35020	Possible	Yes	No	Near
5	307.09	6096	6575.4	0.93 *	0.15773	1.43 *	0.09625	0.19	609.6	8	2	82	1	2	34826	Possible	Yes	No	Near
2	488.95	5486.4	5314.9	1.03	0.03587	0.33	0.04011	0.08	539.75	8	1	278	1	1	28584	Possible	No	No	(OK)

		A	B
Shell ID	mm	488.95	488.95
Tube length - actual	mm	5486.4	5486.4
Tube length - required	mm	5314.9	5314.9
Pressure drop, SS	bar	0.03587	0.03587
Pressure drop, TS	bar	0.04011	0.04011
Baffle spacing	mm	539.75	539.75
Number of baffles		8	8
Tube passes		1	1
Tube number		278	278
Number of units in series		1	1
Number of units in parallel		1	1
Total price	Dollar(US)	28584	28584
Program mode		Design (Sizing)	Design (Sizing)
Calculation method		Advanced methoc	Advanced methoc
Area Ratio (dirty)	-	1.03	1.03
Film coef overall, SS	$W/(m^2\text{-}K)$	113.8	113.8
Film coef overall, TS	$W/(m^2\text{-}K)$	162.3	162.3
Heat load	kW	25.6	25.6
Recap case fully recoverable		Yes	Yes

Unit Configuration

Exchanger type		BEM	Tube number		278
Position		Hor	Tube length actual	mm	5486.4
Arrangement	1 parallel 1	series	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		8	Tube O.D.	mm	19.05
Spacing (center-center)	mm	539.75	Tube pitch	mm	23.81
Spacing at inlet	mm	806.45	Tube pattern		90

		Shell	Kettle	Front head	Rear Head
Outside diameter	mm	508		508	508
Inside diameter	mm	488.95		488.95	488.95

		Shell Side			Tube Side	
Nozzle type		Inlet	Outlet		Inlet	Outlet
Number of nozzles		1	1		1	1
Actual outside diameter	mm	168.28	168.28		33.4	42.16
Inside diameter	mm	154.05	154.05		24.31	35.05
Height under nozzle	mm	44.45	44.45			
Dome inside diameter	mm					
Vapor belt inside diameter	mm					
Vapor belt inside width	mm					
Vapor belt slot area	mm^2					
Impingement protection		No impingement	No impingement	No impingement		
Distance to tubesheet	mm	5276.85	203.2			

Weights	kg	Cost data	Dollar(US)
Shell	749.2	Labor cost	20112
Front head	77.5	Tube material cost	3665
Rear head	82.8	Material cost (except tubes)	4807
Shell cover			
Bundle	1554.3		
Total weight - empty	2463.8	Total cost (1 shell)	28584
Total weight - filled with water	3328.8	Total cost (all shells)	28584