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## EXECUTIVE SUMMARY

A distillation column that will separate the four hydrocarbons are n-Pentadecane (n-C15), n-octadecane (n-C18), n-Eicosane (n-C20) and n-docosane (n-C22) to recover 98% of light key and 95% of heavy key. The calculation will be done by using Aspen HYSYS simulation and manual calculation which is Fenske-Underwood-Gilliland (FUG) method and Kirkbride equation to determine the minimum stage required, minimum reflux ratio, actual theoretical stages, and the optimum feed stage location. Heat duties of condenser and reboiler will also be calculated by using manual calculations and Aspen Hysys.

Fluid property package for Aspen HYSYS simulation we choose is Peng Robinson. This is because it is the most advanced fluid package, and it is suitable for hydrocarbons. Vapour-Liquid Equilibrium Data (VLE) for dew point and bubble point can be obtained in Aspen HYSYS simulation. The liquid composition of n-C20 which is a Heavy Key has been adjusted using the ADJUST tool in Aspen Hysys to get the desired value of 0.4500.

The effect of multiple feed stream on reflux ratio when designing the column is determined. With the specification of recovery of light key and heavy key components, which is 98 % and 95 %, the reflux ratio will increase when the number of feed stream increase. The number of feed stream we carried out were 1,2,4 and 5. The higher the reflux ratio, the more efficiency the separation process are. The effect of liquid fraction for the heat duty of condenser and reboiler were figured out. The heat duty of condenser will increase while the heat duty of reboiler will decrease according to the plot graph. When designing a distillation column, some factors need to take note to prevent the malfunction of column. The factors are types of trays with sizes and pattern of the holes in the tray, tray spacing, weir height, downcomers size, allowable vapor and liquid flow and the column diameter need to decide carefully. Sieve tray is the most common tray, and it is widely used in industry.

## INTRODUCTION

Separation is an important process in industry. The mixture of liquid with different boiling points is converted into a gas phase when distillation takes place. The gas phase which at the upper part of the distillation column will become distillate and cooled and recovered as liquid by condenser. (ThoughtCO, n.d.). The four hydrocarbon components which are n-Pentadecane (n-C15), n-octadecane (n-C18), n-Eicosane (n-C20) and n-C22 will be chosen in our distillation column.

The temperature, theoretical stages, feed stage location, total condenser and total heat duty will be calculated by using Aspen Hysys and manual calculation. Both results will be compared and tabulated in a table. Besides, a Process Flow Diagram (PFD) with temperature, theoretical stages, feed stage location, total condenser and total heat duty which calculated by Aspen Hysys was created to tabulate all the data clearly.

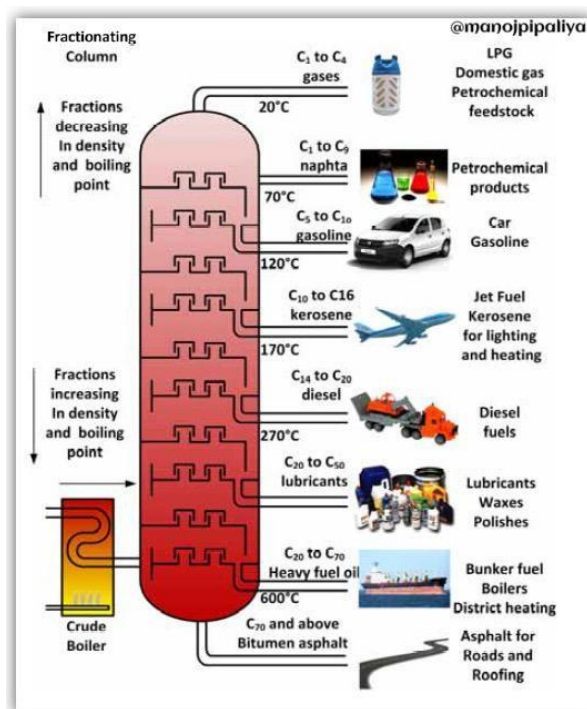
The relationship between the number of feed stream on the reflux ratio is carried out. Besides, case study about the effect of feed vapour fraction of reboiler and condenser are carried out. The column design needs to be considered in a proper way to avoid accident to occurs. Type of trays, size and pattern of holes, tray spacing, weir height, downcomer size, allowable vapour flow rate and column diameter need to consider accordingly to increase the efficiency and lower the cost of the column.

## SECTION A

### Section Ai Justification of Components for Distillation Column

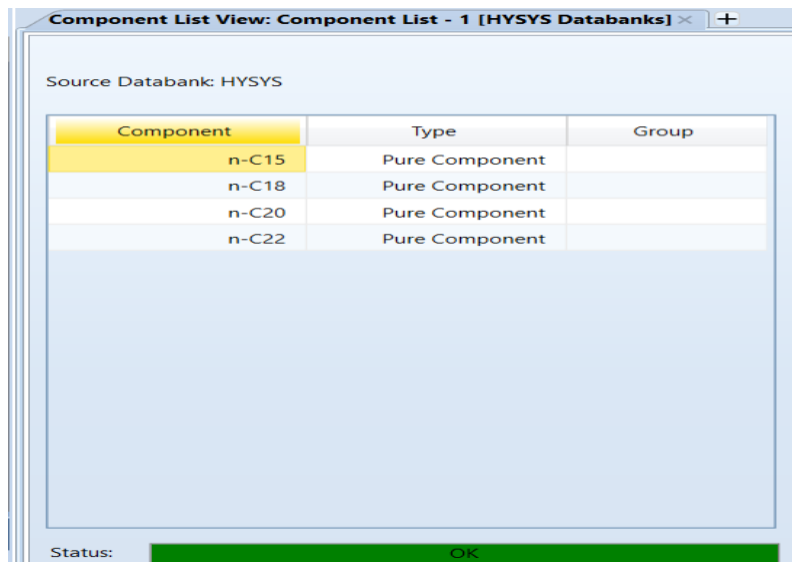
The distillation column is modelled after the petroleum sector. The separation of n--Pentadecane (n-C15), n-octadecane (n-C18), n-Eicosane (n-C20) and n-C22 were required. The components have different boiling point that n-C15 has a boiling point of 270.6 °C and n-C18 has a boiling point of 316.7 °C. Finally, there is n-C22, which has a boiling point of 368.6 °C, and n-Eicosane (n-C20), which has a boiling point of 343.8 °C which was obtained from Aspen Hysys. The four components that were chosen are in a liquid state at 150 °C and 1 atm and have very different boiling points. Higher volatilities between the components and the larger difference in boiling point make the separation process to be more efficient.

The second justification for the selection of the four components are those that can be found in a petroleum industry. Paraffin is one of the components of crude oil used in fractional distillation by the petroleum industry (Melissa Petruzzello, n.d.). Alkane, or paraffin, is a substance with the general formula  $C_nH_{2n+2}$ . The chosen components are all hydrocarbons as a result. Additionally, based on Figure A1, which separates n-C15 and n-C18 as diesel oils and n-C20 and n-C22 as lubricating oils, the four hydrocarbons chosen are based on improving the viability of the new distillation column in real-world business.



**Figure A1: Fractional Distillation Process of Crude Oil**

(oilandgasinfo.ca, n.d.)

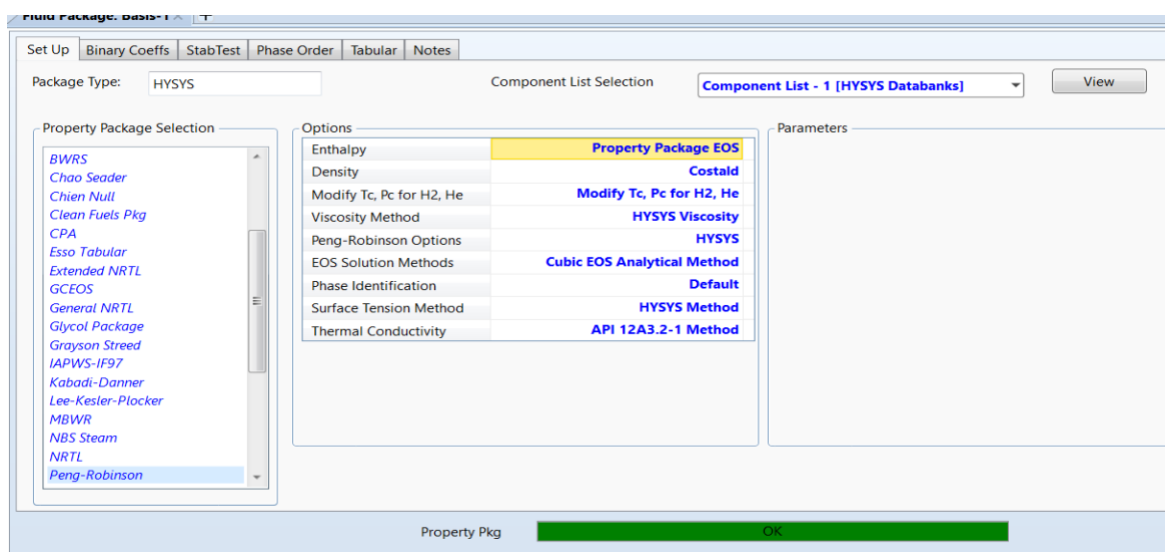


**Figure A2: Selection of Component**

## Section Aii Selection of Fluid Property Package

A Fluid property package needs to be chosen before using the Aspen HYSYS simulation. In Aspen Hysys, there are a lot of fluid property packages that can be chosen. The fluid property package needs to choose carefully before running a process because it will affect the result of the process and it may be inaccurate. Different types of fluid property packages will use different equations to produce data on the vapour-liquid equilibrium.

The Equation of State model is typically utilised as the fluid property package since the components chosen in Section Ai are exclusively hydrocarbons. NRTL, is a subpar model for hydrocarbons. Peng-Robinson, PRSV, SRK, and other models are examples of Equation of State models. The reason we choose Peng-Robinson as the fluid package available in Aspen HYSYS is because it is the most advanced. It has the widest range of pressure and temperature and has good hydrocarbon standards that are suited for the petroleum industry because all of our components are made of hydrocarbons. PRSV fluid package can also be chosen in this case, but the disadvantage is it has a slower rate of calculation than the Peng-Robinson method. The answer obtained will also imperfect.



**Figure A3: Fluid Property Package Selection in Aspen HYSYS (Peng-Robinson)**

## Section Aiii Feed Stream Properties and Vapour-Liquid Equilibrium Data

The components we choose are n-C15, n-C18, n-C20, and n-C22 and Peng Robinson is the fluid package of choice. The material stream was then generated in the Aspen Hysys simulation and given the name Feed with a pressure of 1 atm and a molar flow of 100 kgmole/h. Except for the heavy key (n-C20) which was set to 0.40, all the components have molar compositions of 0.20.

The first liquid droplet develops at the dew point, or when the vapour mixture starts to condense. As a result, the Feed stream's vapour fraction is set to be 1. Figures A.4 and A.5 shows the feed stream characteristics and their vapour-liquid equilibrium data for dew point at constant pressure.

Material Stream: feed				
Worksheet	Attachments	Dynamics		
Worksheet	Stream Name		Vapour Phase	Liquid Phase
Conditions	Vapour / Phase Fraction	1.0000	1.0000	0.0000
Properties	Temperature [C]	337.4	337.4	337.4
Composition	Pressure [kPa]	101.3	101.3	101.3
Oil & Gas Feed	Molar Flow [kgmole/h]	100.0	100.0	0.0000
Petroleum Assay	Mass Flow [kg/h]	2.685e+004	2.685e+004	0.0000
K Value	Std Ideal Liq Vol Flow [m3/h]	34.10	34.10	0.0000
User Variables	Molar Enthalpy [kJ/kgmole]	-2.424e+005	-2.424e+005	-3.127e+005
Notes	Molar Entropy [kJ/kgmole-C]	1180	1180	1233
Cost Parameters	Heat Flow [kJ/h]	-2.424e+007	-2.424e+007	0.0000
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	34.07	34.07	0.0000
Emissions	Fluid Package	Basis-1		
	Utility Type			

Figure A4: Properties of Dew Point Stream

Material Stream: feed				
Worksheet	Attachments	Dynamics		
Worksheet		Mole Fractions	Vapour Phase	Liquid Phase
Conditions	n-C15	0.2000	0.2000	0.0623
Properties	n-C18	0.2000	0.2000	0.1368
Composition	n-C20	0.4000	0.4000	0.4461
Oil & Gas Feed	n-C22	0.2000	0.2000	0.3548
Petroleum Assay				
K Value				
User Variables				
Notes				
Cost Parameters				
Normalized Yields				
Emissions				

Figure A5: Vapour-Liquid Equilibrium Data for Dew Point

The first bubble in a liquid form at the bubble point, or when a mixture of liquids starts to vaporise. As a result, the Feed stream's vapour fraction is set to zero. Figures A6 and A7 show the feed stream characteristics and their vapour-liquid equilibrium data for the bubble point at constant pressure.

Material Stream: feed				
Worksheet	Attachments	Dynamics		
Worksheet	Stream Name		Liquid Phase	Vapour Phase
Conditions	Vapour / Phase Fraction	0.0000	1.0000	0.0000
Properties	Temperature [C]	318.0	318.0	318.0
Composition	Pressure [kPa]	101.3	101.3	101.3
Oil & Gas Feed	Molar Flow [kgmole/h]	100.0	100.0	0.0000
Petroleum Assay	Mass Flow [kg/h]	2.685e+004	2.685e+004	0.0000
K Value	Std Ideal Liq Vol Flow [m3/h]	34.10	34.10	0.0000
User Variables	Molar Enthalpy [kJ/kgmole]	-3.161e+005	-3.161e+005	-2.396e+005
Notes	Molar Entropy [kJ/kgmole-C]	1057	1057	992.5
Cost Parameters	Heat Flow [kJ/h]	-3.161e+007	-3.161e+007	0.0000
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	34.07	34.07	0.0000
Emissions	Fluid Package	Basis-1		
	Utility Type			

Figure A6: Properties of Bubble Point Stream

Material Stream: feed				
Worksheet Attachments Dynamics				
Worksheet		Mole Fractions	Liquid Phase	Vapour Phase
Conditions	n-C15	0.2000	0.2000	0.4793
Properties	n-C18	0.2000	0.2000	0.2063
Composition	n-C20	0.4000	0.4000	0.2413
Oil & Gas Feed	n-C22	0.2000	0.2000	0.0731
Petroleum Assay				
K Value				
User Variables				
Notes				
Cost Parameters				
Normalized Yields				
Emissions				

**Figure A7: Vapour-Liquid Equilibrium Data for Bubble Point**

## SECTION B

### Section Bi Specification of Recovery for Key and Non-Key Components

The four components—n-C15, n-C18, n-C20 and n-C22 are chosen. Since it has more than 2 components, multicomponent distillation takes place. The light key (LK), light non-key (LNK), heavy key (HK) and heavy non-key (HNK) can be categorised based on the component volatility which is based on their boiling point. Heavy key (HK) is less volatile than the light key (LK). While heavy non-key (HNK) is the component that is less volatile than HK and is fully recovered in the bottoms, light non-key (LNK) is the component that is more volatile than LK and is totally recovered in the distillate.

The boiling points for n-C15, n-C18, n-Eicosane (n-C20), and n-C22 are 270.6 °C, 316.7 °C, 343.8 °C, and 368.6 °C, respectively. n-C18 is more appropriate to be chosen as the light key (LK) in this multiple distillation process because of its lower boiling point and greater volatility. n-C20 is chosen as the heavy key (HK) due to its higher boiling point and lower volatility. n-C15 and n-C22, are categorised as light non-keys and heavy non-keys.

The amount of light key and heavy key will be recovered in the distillate and bottom products, respectively. Therefore, the important components, n-C18 and n-C20, will be the primary components that are targeted. As a result, the heavy key (n-C20) will be specified to recover almost 95% in the bottom product stream while the light key (n-C18) will be set to recover nearly 98% in the distillate stream. The distillate will entirely recover the light non-key (n-C15) and heavy non-key (n-C22) components will entirely recover at the bottom.

Sharp separation can achieve where the only components appear in both distillate and bottoms stream. However, it is not practical in real industry for the distillation column to recover 100 % of distillate. The operation cost also needs to be considered. After made a balance between recovery rate and operation cost, it is desired to recover 98 % of n- C18 in distillate and 95 % of n- C20 in bottoms.

**Table B1: Recovery Rate for Different Types of Components in Distillate and Bottom.**

Components	Condition	Recovery in Distillate, %	Recovery in Bottom, %
n-C15	LNK	100	0
n-C18	LK	98	2
n-C20	HK	5	95
n-C22	HNK	0	100

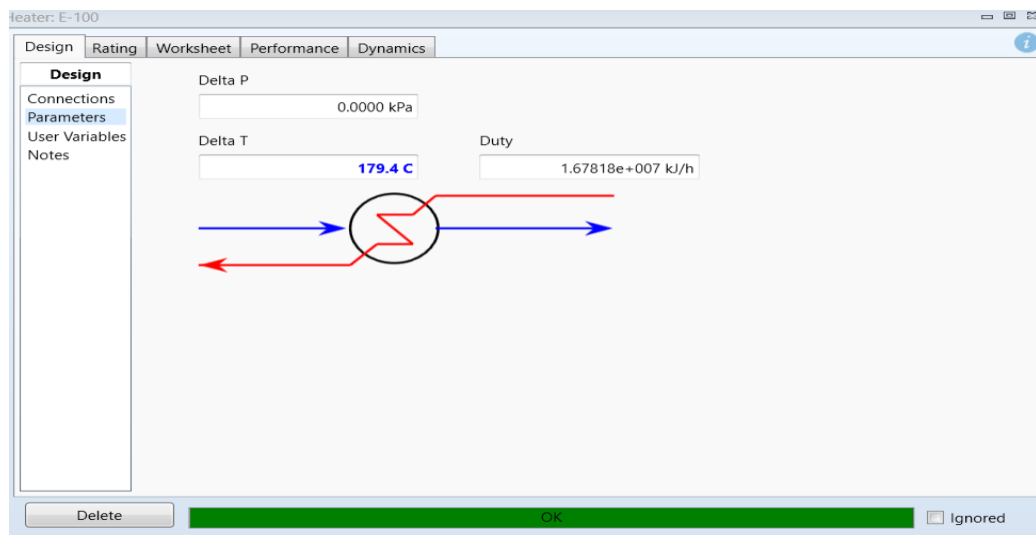
### **Section Bii Determination of Feed Temperature in HYSYS**

The temperature of the feed stream is set to 150 °C, and the vapour fraction is set to empty. A heater named E-100 is used to produce a heavy key's liquid composition, which is 0.45. To increase the liquid composition of the heavy key from 0.40 to 0.45, the temperature of the mixture is increased to allow light non-key and light key evaporate into vapour. The "feed" is chosen as the inlet and the "heated feed" is named as the outlet at the Design tab. The heater with an energy stream named it as "q1" The pressure for "heated feed" is then set to 1 atm in the Worksheet.

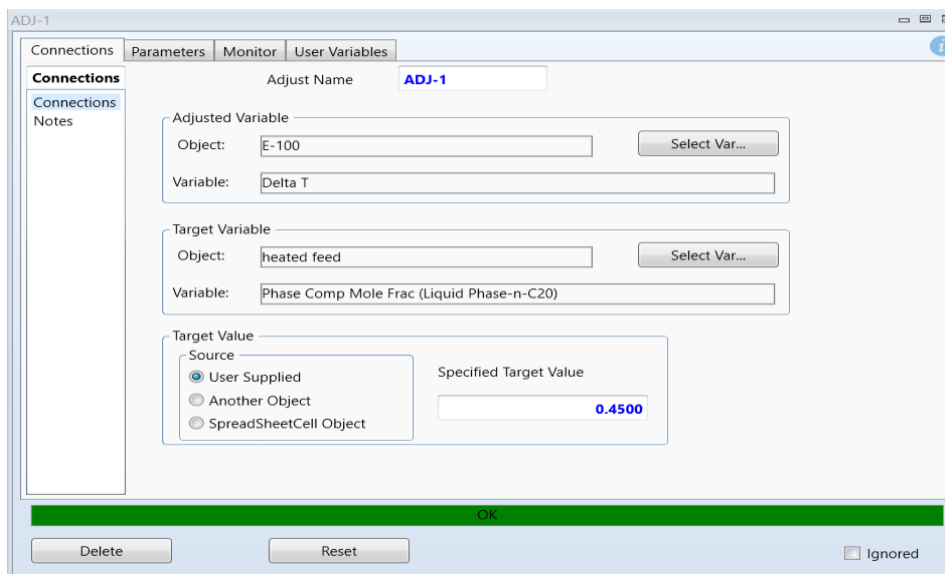
An ADJUST tool is developed to determine the amount of duty or delta T required to get the liquid composition of n-C20 to be 0.45. E-100 and Delta T are selected as the object and variable, in the Connections tab > Adjusted Variable while heated Feed and Phase Comp Mole Frac (Liquid Phase-n-C20) are chosen as the object and variable in the Connections tab > Target Variable. The specific goal value is then changed to 0.4500. The minimum and maximum temperatures for "Heated Feed" are set to 168°C and 187.4°C, respectively in the Parameters tab. The maximum temperature of heated feed cannot be lower than the bubble point and the minimum temperature cannot be higher than the dew point. The dew point temperature is 337.4 °C and bubble point temperature is 318 °C which can be obtained in Section Aiii. The dew and bubble point temperature minus the initial temperature which is 150 °C to become 168 °C for minimum and 187.4 for maximum.

Delta T will be given a value that is between 168 and 187.4 °C in the Heater: E-100 > Design > Parameters tab. The status indicator displays the green word "OK" once all iterations have been completed. The Delta T value needs to be guessed continuously to get the n liquid C20 composition to reach 0.4500 in the heated feed stream. If its composition reaches 0.45, check for the delta T value and record it. The heated feed stream temperature is 179.4 °C to produce liquid composition of heavy key (n-C20) equal to 0.45.





**Figure B1: Heater (E-100)**



**Figure B2: ADJUST tool (ADJ-1)**

Material Stream: heated feed

Worksheet		Mole Fractions		Vapour Phase		Liquid Phase	
n-C15		0.2000		0.3040		0.1065	
n-C18		0.2000		0.2254		0.1772	
n-C20		0.4000		0.3444		0.4500	
n-C22		0.2000		0.1262		0.2663	
Total						1.00000	

Buttons: Edit..., View Properties..., Basis...

Bottom bar: Delete, Define from Stream..., View Assay, OK, Navigation arrows.

**Figure B3: Composition of Each Component in Heated Feed Stream**

## Section Biii Calculation of Actual Theoretical Stages Required

Given:

LNK: n-C15 ; LK: n-C18 ; HK: n-C20 ; HNK: n-C22

Distillate, D: 98% LK ; Bottom, B : 95% HK

P = 1 atm ; T = 179.4 °C ; F = 100 kgmole/h

Vapour fraction and liquid fraction of the feed is obtained from HYSYS.

**Table B2: Vapour Composition and Liquid Composition of The Feed (refer Figure B3)**

Component	Vapour Composition, $y_i$	Liquid Composition, $x_i$
n-C15	0.3040	0.1065
n-C18	0.2254	0.1772
n-C20	0.3444	0.4500
n-C22	0.1262	0.2663

### Sample Calculation for n-C15

$$K_{179.4}^{\circ\text{C}} = \frac{y_i^l}{x_i}$$

$$= 2.8545$$

**Table B3: Composition and K-value of Each Component**

Component	$x_F$	$Fx_F$ (kgmole/h)	Molar Flow of D (kgmole/h)	$x_D$	Molar Flow of B (kgmole/h)	$x_B$	$K_{298.8}^{\circ\text{C}}$
n-C15	0.2	20	20.00	0.4808	0.00	0.0000	2.8545
n-C18	0.2	20	19.60	0.4712	1.40	0.0236	1.2729
n-C20	0.4	40	2.00	0.0481	38.00	0.6397	0.7653
n-C22	0.2	20	0.00	0.0000	20.00	0.3367	0.4739
Total		100	41.60		59.40		

### Calculation for $N_{min}$ using Fenske Equation

Assumption:

- Constant molal overflow (CMO) is valid.
- Relative volatility is taken as constant.
- The temperature of the distillation column is kept constant.

$$\alpha_{LK,HK} = \frac{1.2729}{0.7653} = 1.6633$$

$$N_{min} = \frac{\ln \left[ \left( \frac{x_{D,LK}}{x_{B,LK}} \right) \left( \frac{x_{B,HK}}{x_{D,HK}} \right) \right]}{\ln(\alpha_{LK,HK})} = \frac{\ln \left[ \left( \frac{0.4712}{0.0236} \right) \left( \frac{0.6397}{0.0481} \right) \right]}{\ln(1.6633)} = 10.97$$

### Calculation for $R_{min}$ using Underwood Equation

Assumption:

- Constant molal overflow (CMO) is valid.
- $K_{HK}$  is usually taken as  $K_{ref}$ .
- Relative volatility,  $\alpha$  is the same in upper and lower invariant zone,  $\alpha_i = \frac{K_i}{K_{ref}}$

### Sample Calculation for $\alpha_i$

For n-C15,

$$\alpha_{LNK} = \frac{K_{LNK}}{K_{HK}} = \frac{2.8545}{0.7653} = 3.7299 \quad ; \text{The } K_{ref} = \text{Heavy Key}$$

**Table B4: Relative Volatility of Each Component**

Component	$\alpha_i$
n-C15	3.7299
n-C18	1.6633
n-C20	1.0000
n-C22	0.6192

### Calculation of $\phi$ using Solver Function in Excel

Range for  $\phi$

$$\alpha_{HK} < \phi < \alpha_{LK}$$

$$1 < \phi < 1.6633$$

Initial guess of  $\phi = 1.5$  is taken. Underwood Equation:

$$1 - q = \sum \left( \frac{\alpha_i x_{F,i}}{\alpha_i - \phi} \right)$$

$q$  is the liquid fraction in feed,  $1 - q$  is the vapour fraction in feed.

Vapour fraction,  $f$  is obtained from HYSYS.

$$1 - q = 0.4734$$

$$q = 0.5266$$

Material Stream: heated feed				
Worksheet	Attachments	Dynamics		
Worksheet	Stream Name	heated feed	Vapour Phase	Liquid Phase
Conditions	Vapour / Phase Fraction	0.4734	0.4734	0.5266
Properties	Temperature [C]	329.4	329.4	329.4
Composition	Pressure [kPa]	101.3	101.3	101.3
Oil & Gas Feed	Molar Flow [kgmole/h]	100.0	47.34	52.66
Petroleum Assay	Mass Flow [kg/h]	2.685e+004	1.224e+004	1.462e+004
K Value	Std Ideal Liq Vol Flow [m3/h]	34.10	15.59	18.51
User Variables	Molar Enthalpy [kJ/kgmole]	-2.800e+005	-2.415e+005	-3.145e+005
Notes	Molar Entropy [kJ/kgmole-C]	1118	1088	1145
Cost Parameters	Heat Flow [kJ/h]	-2.800e+007	-1.143e+007	-1.656e+007
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	34.07	15.57	18.49
Emissions	Fluid Package	Basis-1		
	Utility Type			

**Figure B4 Vapour Fraction**

	A	B	C	D	E	F	G	H	I
	Compon ent	$x_F$	$Fx_F$ (kgmole/h)	Molar Flow of D (kgmol e/h)	$x_D$	Molar Flow of B (kgmole/h )	$x_B$	$K_{298.8^\circ\text{C}}$	
1									
2	n-C <sub>15</sub>	0.2	20	20	0.4808	0	0	2.8545	
3	n-C <sub>18</sub>	0.2	20	19.6	0.4712	1.4	0.0236	1.2729	
4	n-C <sub>20</sub>	0.4	40	2	0.0481	38	0.6397	0.7653	
5	n-C <sub>22</sub>	0.2	20	0	0	20	0.3367	0.4739	
6	Total		100	41.6		59.4			
7									
8	alpha	1.6633	phi value	1.5					
9	f	0.4734							
10									
11	Compone $\alpha_i$		$\alpha_i x_F i / \alpha_i - \phi i$						
12	n-C <sub>15</sub>	3.7299	0.3345						
13	n-C <sub>18</sub>	1.6633	2.0371						
14	n-C <sub>20</sub>	1	-0.8000						
15	n-C <sub>22</sub>	0.6192	-0.1406						
16	Total		1.4310						
17									

Figure B5: Calculation of Initial Guess  $\phi = 1.5$  using Solver Function in Excel

Solver Parameters

Set Objective:

To: ☐ Max ☐ Min ☒ Value Of:

By Changing Variable Cells:

Subject to the Constraints:

☒ Make Unconstrained Variables Non-Negative

Select a Solving Method:  Options

Solving Method  
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Buttons: Help, Solve, Close

Figure B6: Solver Function in Excel

	A	B	C	D	E	F	G	H	I
	Compon ent	$x_F$	$Fx_F$ (kgmole/h)	Molar Flow of D (kgmol e/h)	$x_D$	Molar Flow of B (kgmole/h )	$x_B$	$K_{298.8^\circ\text{C}}$	
1									
2	n-C <sub>15</sub>	0.2	20	20	0.4808	0	0	2.8545	
3	n-C <sub>18</sub>	0.2	20	19.6	0.4712	1.4	0.0236	1.2729	
4	n-C <sub>20</sub>	0.4	40	2	0.0481	38	0.6397	0.7653	
5	n-C <sub>22</sub>	0.2	20	0	0	20	0.3367	0.4739	
6	Total		100	41.6		59.4			
7									
8	alpha	1.6633	phi value	1.40625					
9	f	0.4734							
10									
11	Compone $\alpha_i$		$\alpha_i x_F i / \alpha_i - \phi i$						
12	n-C <sub>15</sub>	3.7299	0.3210						
13	n-C <sub>18</sub>	1.6633	1.2941						
14	n-C <sub>20</sub>	1	-0.9846						
15	n-C <sub>22</sub>	0.6192	-0.1573						
16	Total		0.4732						

Figure B7: Solver Function,  $\phi = 1.4063$

Value for  $\frac{\alpha_i x_{F,i}}{\alpha_i - \phi}$  when  $\phi = 1.5$  and  $\phi = 1.4063$  are tabulated in Table B5.

**Table B5: Value for  $\frac{\alpha_i x_{F,i}}{\alpha_i - \phi}$**

Component	$\frac{\alpha_i x_{F,i}}{\alpha_i - \phi}$	
	$\overline{\alpha_i - \phi}$	
	$\phi = 1.5$	$\phi = 1.4063$
n-C15	0.3345	0.3210
n-C18	2.0371	1.2941
n-C20	-0.8000	-0.9846
n-C22	-0.1406	-0.1573
Total	1.4310	0.4722

$$\alpha_{HK} < \phi < \alpha_{LK}$$

$$1.0000 < 1.4063 < 1.6633$$

$\phi = 1.4063$  is between the range, so it is valid:

$$R_{min} + 1 = \sum \left( \frac{\alpha_i x_{D,i}}{\alpha_i - \phi} \right)$$

$$R_{min} + 1 = \left( \frac{3.7299(0.4808)}{3.7299 - 1.4063} \right) + \left( \frac{1.6633(0.4712)}{1.6633 - 1.4063} \right) + \left( \frac{1(0.0481)}{1 - 1.0463} \right) + \left( \frac{0.6192(0)}{0.6192 - 1.0463} \right)$$

$$R_{min} = 1.7825$$

### Calculation of Reflux Ratio

The reflux ratio is fixed at 1.7 times the minimum reflux ratio,

$$R = 1.7 \times R_{min} = 1.7 \times 1.7825 = 3.0303$$

### Calculation of N using Gilliland Correlation

Assumption:

- Constant relative volatility.

Range and condition for Gilliland correlation:

- Number of components = 2 to 11 (4 components)
- $0.28 < q < 1.42$  ( $q = 0.5266$ )
- Vacuum  $< P < 600$  psig ( $P = 1$  atm)
- $1.11 < \alpha_{LK}, Hk < 4.05$  ( $\alpha_{LK}, Hk = 1.6633$ )
- $0.53 < R_{min} < 9.09$  ( $R_{min} = 1.7825$ )
- $3.4 < N_{min} < 60.3$  ( $N_{min} = 10.97$ )

The value we found is all within the range, this is valid;

Gilliland Correlation:

$$X = \frac{R-R_{min}}{R+1} = \frac{3.0303-1.7825}{3.0303+1} = 0.3096$$

$$Y = \frac{N-N_{min}}{N+1} = 1 - \exp\left[\left(\frac{1+54.4X}{11+117.2X}\right)\left(\frac{X-1}{X^{0.5}}\right)\right]$$

$$Y = \frac{N-10.97}{N+1} = 1 - \exp\left[\left(\frac{1+54.4(0.3096)}{11+117.2(0.3096)}\right)\left(\frac{0.3096-1}{0.3096^{0.5}}\right)\right]$$

$$Y = 0.3739 = \frac{N-10.97}{N+1}$$

$$N = 18.1184$$

$$N \approx 19$$

The actual theoretical stages needed are 19.

#### Section Biv Estimation Feed Stage Location and Heat Duties

##### Calculation of Optimum Feed Stage Location using Kirkbride Equation

Assumption:

- i. Fairly symmetrical feeds and separations.

Kirkbride Equation :

$$\frac{N_R}{N_S} = \left[ \left( \frac{x_{F,HK}}{x_{F,LK}} \right) \left( \frac{x_{B,LK}}{x_{D,HK}} \right)^2 \left( \frac{B}{D} \right) \right]^{0.206}$$

Where  $N_R$  is stages of rectifying section and  $N_S$  is stages of stripping section

$$\begin{aligned} N &= N_R + N_S \\ N_S &= N - N_R \\ \frac{N_R}{N_S} &= \frac{N_R}{N - N_R} = \frac{N_R}{18 - N_R} = \left[ \left( \frac{0.4}{0.2} \right) \left( \frac{0.0236}{0.0481} \right)^2 \left( \frac{59.40}{41.60} \right) \right]^{0.206} \end{aligned}$$

$$\frac{N_R}{18 - N_R} = 0.9257$$

$$\begin{aligned} N_R &= 0.9257 (18 - N_R) \\ &= 8.6529 \\ &\approx 8 \end{aligned}$$

Optimum feed stage location is at the 8-stage.

##### Calculation of Heat Duty of Total Condenser and Total Reboiler

Assumption:

- i. Kinetic energy, potential energy and work term are negligible.
- ii. Column is adiabatic and well insulated.

Required enthalpy data is obtained from HYSYS.

**Table B6: Molar Enthalpy of Each Stream**

Stream	Molar Enthalpy (kJ/kgmole)
Heated Feed	$HF = -2.800 \times 10^5$
To condenser	$Hy = -2.429 \times 10^5$
Distillate	$HD = -3.083 \times 10^5$
Bottoms	$HB = -3.081 \times 10^5$

### Heat Duty of Total Condenser

$$qc = (1 + R) D (Hy - HD)$$

$$qc = (1 + 3.0303) \times 41.60 \times [(-2.429 \times 10^5) - (-3.083 \times 10^5)]$$

$$qc = 10.9645 \times 10^6 \text{ kJ/h}$$

Heat duty of total condenser required to achieved desired reflux ratio is  $10.9645 \times 10^6 \text{ kJ/h}$ .

### Heat Duty of Total Reboiler

$$qr = DHD + BHB + qc - FHF$$

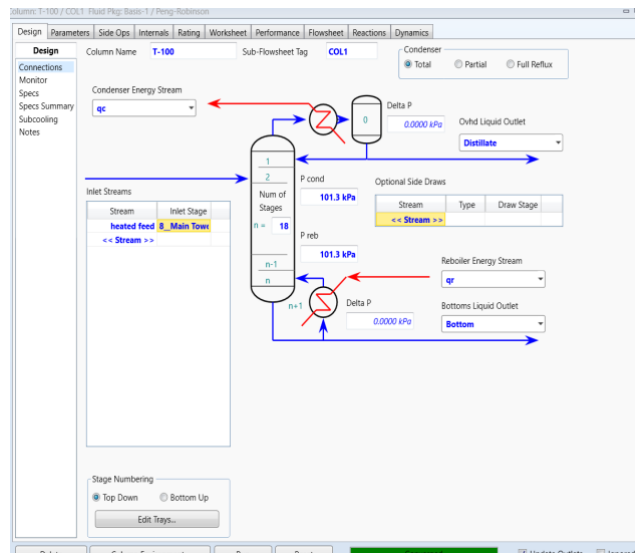
$$qr = 41.60(-3.083 \times 10^5) + 59.40(-3.081 \times 10^5) + 10.9645 \times 10^6 - 100(-2.800 \times 10^5)$$

$$qr = 7.8381 \times 10^6 \text{ kJ/h}$$

Heat duty of total reboiler required to achieved desired boil up ratio is  $5.013 \times 10^6 \text{ kJ/h}$

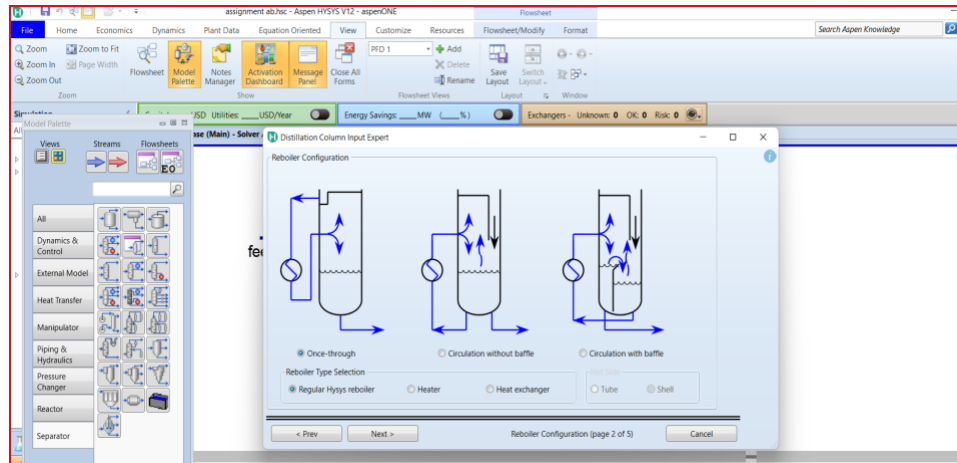
## Section Bv HYSYS Simulation

First, the distillation column is selected in the "Palette" window. The "Distillation Column Input Expert" box will pop up after selecting the kind of distillation column. The name of the column is T-100. Total condenser is selected. The energy stream of a condenser is named as qc. The Overhead Liquid Outlet which is located at the top of the column is named it as distillate. The bottom liquid outlet is named as Bottom. The energy stream for the reboiler is named as qr. The ideal feed stage placement was found in Section Biv, and the inlet stream is heated feed, and the inlet stage is then the eighth stage of the distillation column. Since the reboiler is treated as an additional stage, leaving 19 stages in total. There are 18 trays, or number of stages.



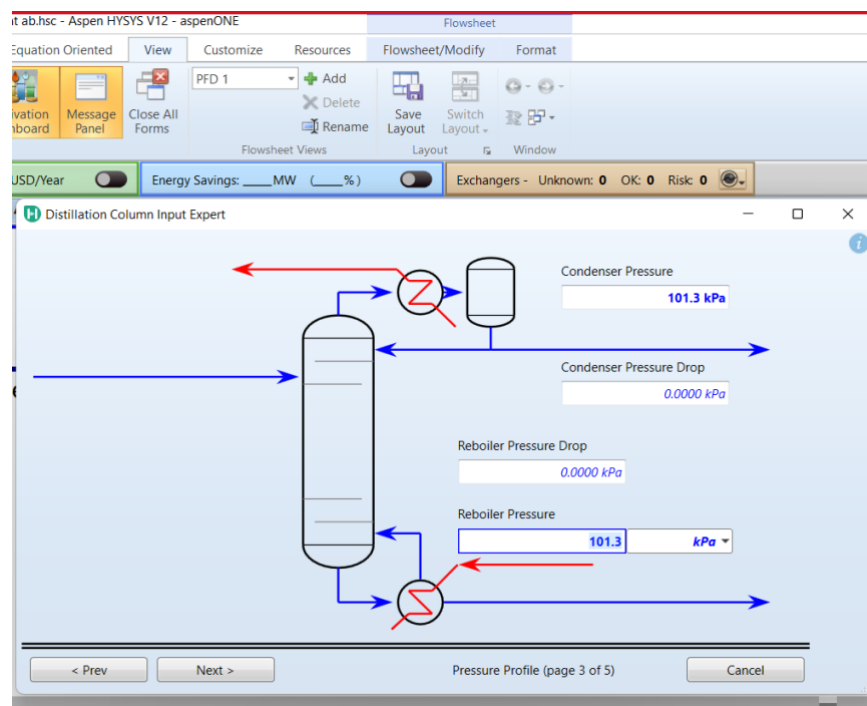
**Figure B8: Connections Page of Distillation Column Input Expert**

Click next to get to the reboiler configuration page. The once-through reboiler arrangement is used.



**Figure B9: Reboiler Configuration Page of Distillation Column Input Expert**

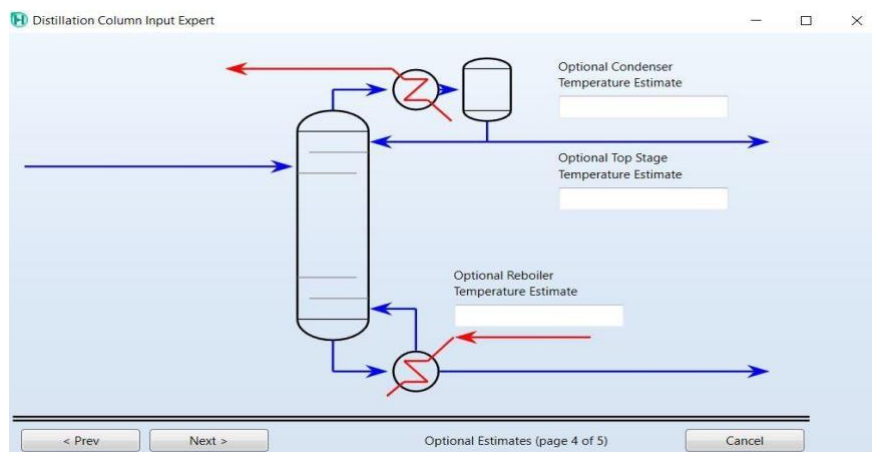
Click next to the pressure profile page. Pressure drop for condenser and reboiler are set to zero indicating that there is no pressure drop in this distillation column. Both the reboiler and condenser pressures are set to 101.3 kPa.



**Figure B10: Pressure Profile Page of Distillation Column Input Expert**

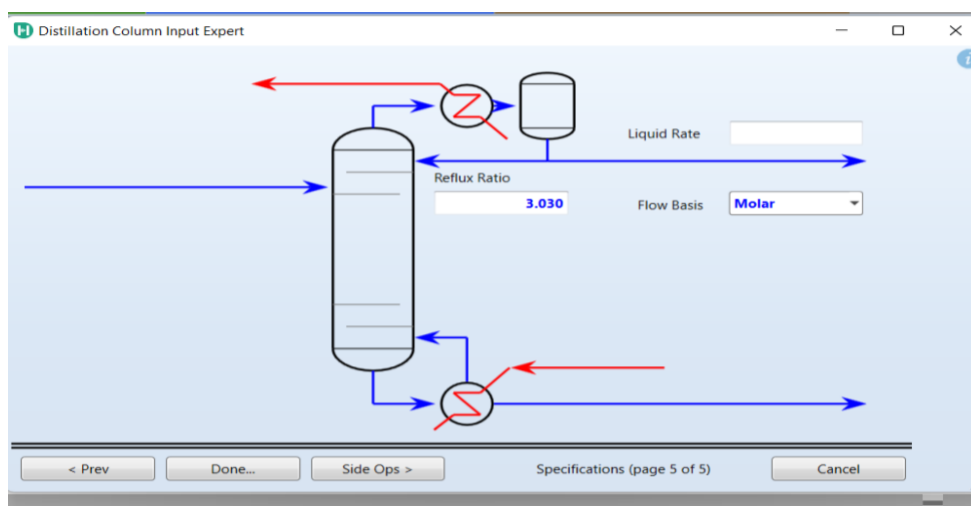
Since the temperature for the condenser, top stage, and reboiler are optional inputs, they are left as blank on the optional estimates page for Aspen Hysys to estimate.



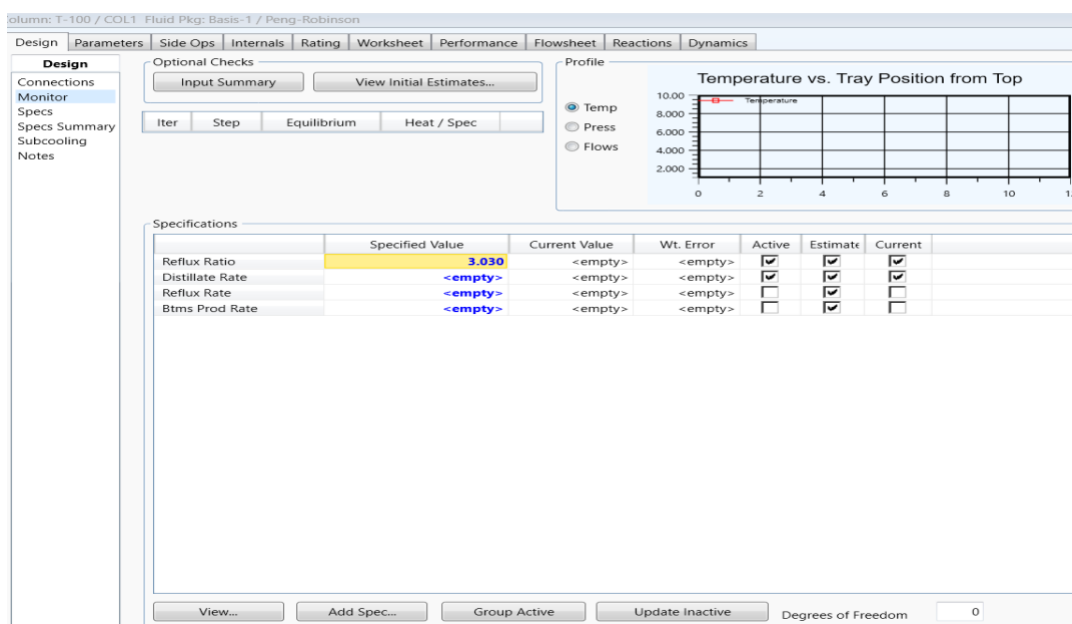


**Figure B11: Optional Estimates Page of Distillation Column Input Expert**

The reflux ratio, which was determined in Section Biii, is set as 3.0303 on the Specifications page. The flow basis we choose is molar. Because it is not one of the parameters that will be used, the liquid rate is left blank.

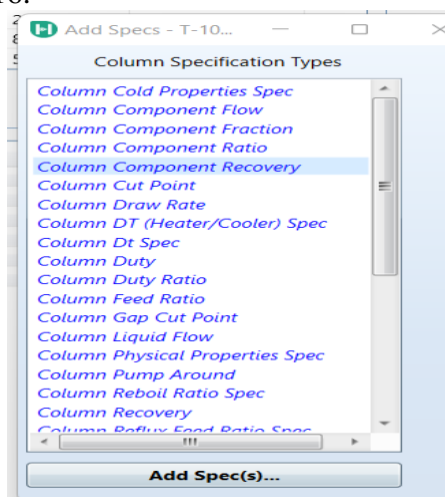


**Figure B12: Specifications Page of Distillation Column Input Expert**

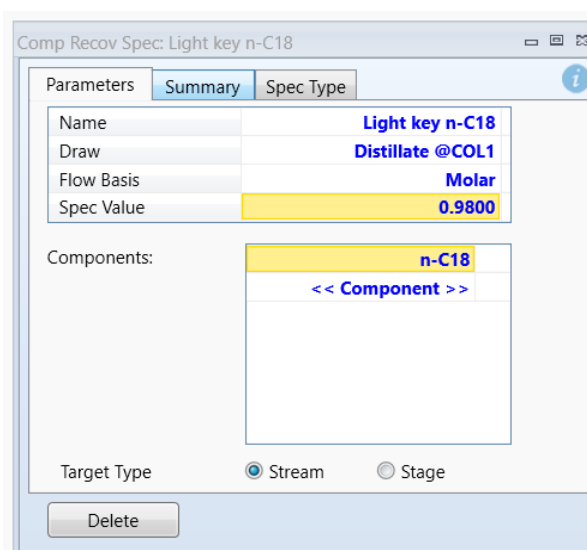


**Figure B13: Specification Page**

After that, click the “done” icon and a page will pop out. When you select a design for a monitor, the degrees of freedom value is displayed as "0," indicating that there is no more specification that needs to be made clear. To add a standard, select the "Add Spec..." button at the bottom of the specifications table. After that, a window labelled "Add Spec" will appear; select “column component Recovery ” from the list and click on add spec as Figure B14 below. Light Key and Heavy Key component are added into the specification as Figure B15 and B16.



**Figure B14: Column Specification Types List**



**Figure B15: Light Key Component Recovery Specification**

Comp Recov Spec: Heavy Key n-C20

Parameters Summary Spec Type

Name	Heavy Key n-C20
Draw	Bottom @COL1
Flow Basis	Molar
Spec Value	0.9500

Components:

n-C20
<< Component >>

Target Type ☒ Stream ☐ Stage

Delete

Figure B16 Heavy Key Component Recovery Specification

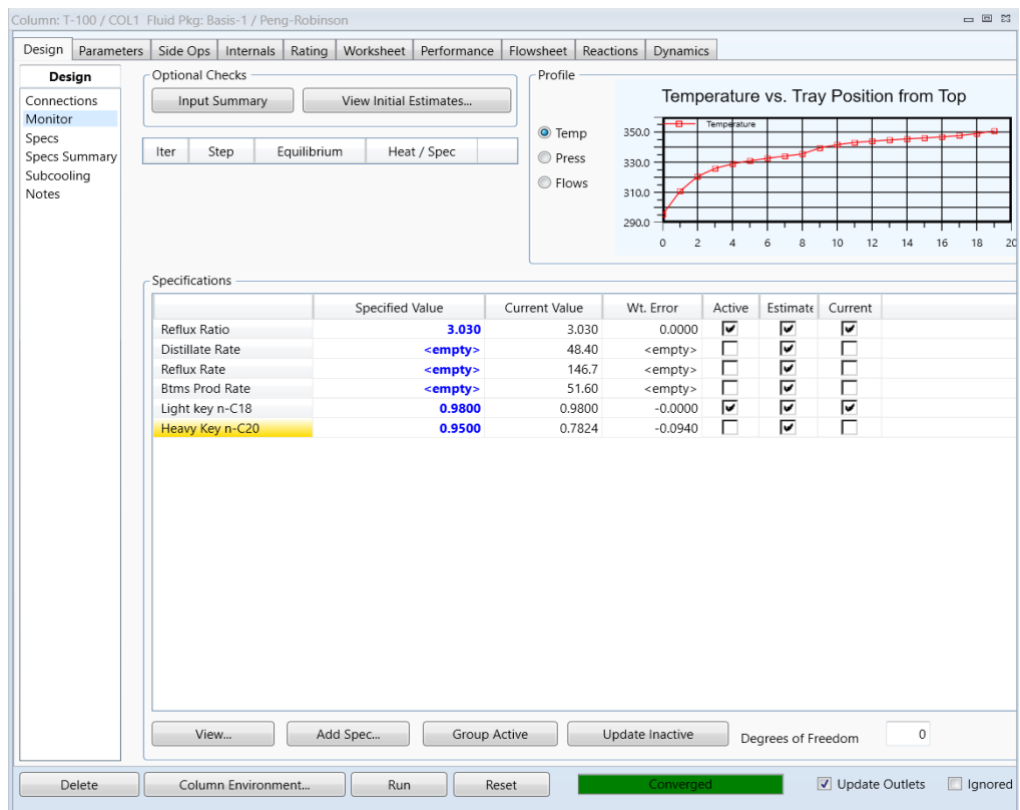


Figure B17: Column Window for Reflux Ratio and Light Key Recovery

Column: T-100 / COL1 Fluid Pkg: Basis-1 / Peng-Robinson

Design	Parameters	Side Ops	Internals	Rating	Worksheet	Performance	Flowsheet	Reactions	Dynamics																									
<div> <div>Worksheet</div> <div> Conditions Properties Compositions PF Specs </div> </div> <table> <tr> <th></th><th>heated feed</th><th>Distillate</th><th>Bottom</th><th></th></tr> <tr> <td>n-C15</td><td>0.2000</td><td>0.4133</td><td>0.0000</td><td></td></tr> <tr> <td>n-C18</td><td>0.2000</td><td>0.4050</td><td>0.0078</td><td></td></tr> <tr> <td>n-C20</td><td>0.4000</td><td>0.1799</td><td>0.6064</td><td></td></tr> <tr> <td>n-C22</td><td>0.2000</td><td>0.0019</td><td>0.3858</td><td></td></tr> </table>											heated feed	Distillate	Bottom		n-C15	0.2000	0.4133	0.0000		n-C18	0.2000	0.4050	0.0078		n-C20	0.4000	0.1799	0.6064		n-C22	0.2000	0.0019	0.3858	
	heated feed	Distillate	Bottom																															
n-C15	0.2000	0.4133	0.0000																															
n-C18	0.2000	0.4050	0.0078																															
n-C20	0.4000	0.1799	0.6064																															
n-C22	0.2000	0.0019	0.3858																															

A Process Flow Diagram is generated in Aspen Hysys. The streams and unit activities are dark blue and dark red in colour means that the distillation column run smoothly.



**Table B7: Comparison of Manual Calculation and HYSYS Simulation**

20

The recovery of the light key, n-C18, is stated in the manual calculation from Section Biii is set to be 98%, while the recovery of the heavy key, n-C19, is specified to be 95 %. Reflux ratio and recovery of light key in distillate in the HYSYS simulation from obtained at Section Bv. As a result, the recovery of the light key, n-C18, in the HYSYS simulation is exactly 98% as accurate as the manual calculation. However, n- C20 (heavy key) recovery in the HYSYS simulation was 78.24 %.

The Fenske Equation makes the assumptions that continuous molal overflow and relative volatility is assumed to be constant (Quiroz, 2014). So, the system would be affected by feed-phase conditions. In addition, the manual calculation for Underwood Equation assumes that each component is the same in the upper and lower invariant zones. This is because in a distillation column's upper and lower invariant zones, each component should have distinct values in a practical circumstance. Rmin is calculated by using Underwood Equation and this will increase the risk of inaccurate data for recovery in the distillation process. Another factor that will affect the recovery discrepancy between HYSYS simulation and manual computation is Gilliland Correlation. The number of stages, N, that was determined via Gilliland Correlation might not be the best choice for HYSYS simulation because the error was quite big.

**Table B8: Compositions of Components in Manual Calculation and HYSYS Simulation**

Components	Manual Calculation		HYSYS Simulation	
	$x_B$	$x_D$	$x_B$	$x_D$
n-C12	0.0000	0.4808	0.0000	0.4133
n-C15	0.0236	0.4712	0.0078	0.4050
n-C19	0.6397	0.0481	0.6064	0.1799
n-C20	0.3367	0.0000	0.3858	0.0019

The distillate rate and bottoms rate in manual calculations are 41.60 kgmole/h and 59.40 kgmole/h respectively while in HYSYS simulation are 48.40 kgmole/h and 51.60 kgmole/h respectively. In manual calculations, there will not be any heavy non-key in the distillate and light non-key in the bottoms. However, there is very little heavy non-key, n-C22 present in distillate in the HYSYS simulation. The increase in the recovery of heavy keys, from 0.95 to 0.9958 which means that the heavy keys will be separated in the bottoms. The difference in the distillate rate and bottom rate in hysys will affect the result for the recovery. In a manual calculation, the heat duty of the condenser and reboiler is  $10.9645 \times 10^6$  kJ/h and  $7.8381 \times 10^6$  kJ/h, respectively, whereas in a HYSYS simulation, it is  $1.2750 \times 10^7$  kJ/h and  $9.9250 \times 10^7$  kJ/h.

## SECTION C: Effect of multiple feed streams will affect reflux ration and separation efficiency in the column.

The reflux ratio can be used as a very helpful dependent variable to examine a distillation column's efficiency. Condensed vapors from the distillation column's top that needs to be returned to the column is referred to as a reflux. Reflux is used to produce distillate that is purer; it does this by encountering with the up-flowing vapors, which causes the light component to evaporate while the heavier component condenses. The product quality improves with an increase in reflux ratio because, as the reflux comes into touch with vapors moving up the column, mass transfer between the vapors and the reflux occurs, raising the concentration of the vapors that will be condensed (2015). However, because less distillate can be collected, the process is slowed down, and more vapors or liquid needs to be condensed or reboiler, which increases the heat duty on the condenser and reboiler.

The liquid extracted as a product divided by the liquid returned to the column is known as the reflux ratio. The equation below is the formula of reflux ratio (Porter, 2011).

$$\text{Reflux ratio, } R = \frac{L_a}{D}$$

Where R is reflux ratio,  $L_a$  is the rate of liquid returning to the top stage while D is the distillation rate.

A greater reflux ratio indicates a less efficient process since a larger proportion of condensed liquid will need to be returned to the top plate if the desired recovery and other factors are constant. A smaller reflux ratio, on the other hand, indicates a more effective procedure. Given that all other variables remain constant, a simulation can be performed by altering the feed mode from single feed stream to multiple feed stream while observing the change in reflux ratio and separation efficiency in the column.

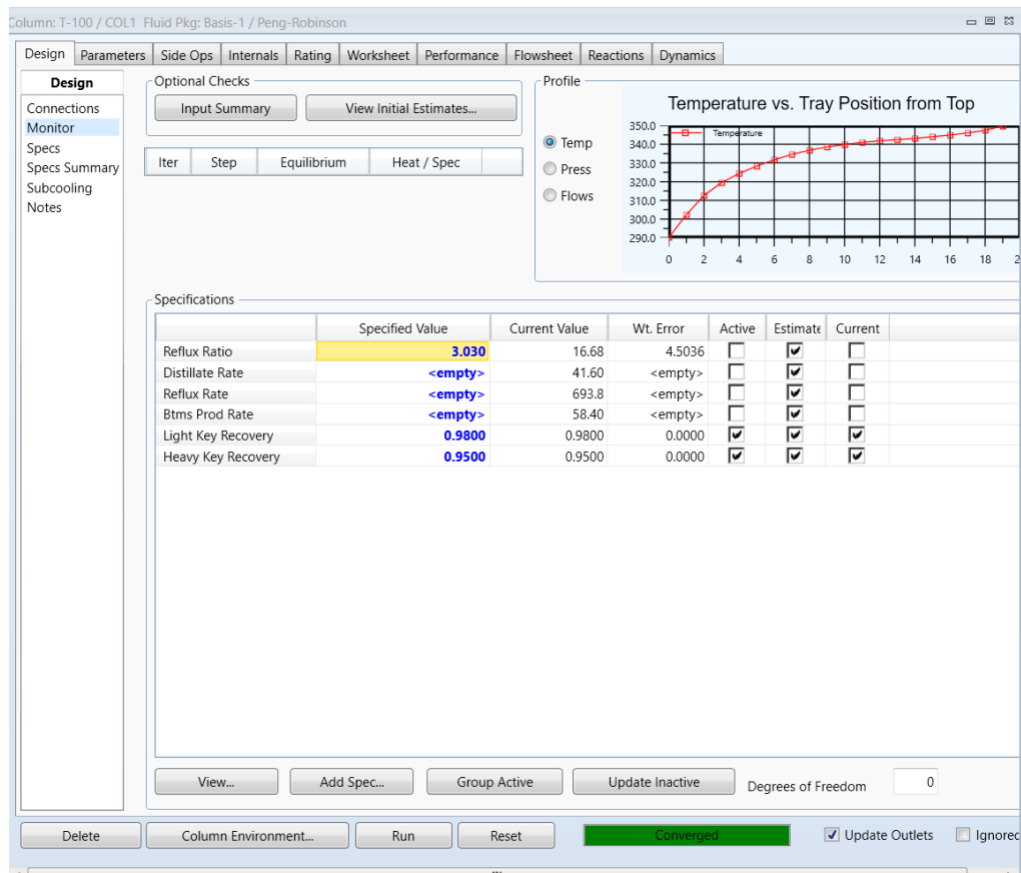


Figure C1: Reflux Ratio, Distillate Ratio and Bottom Rate of 5 feed stream

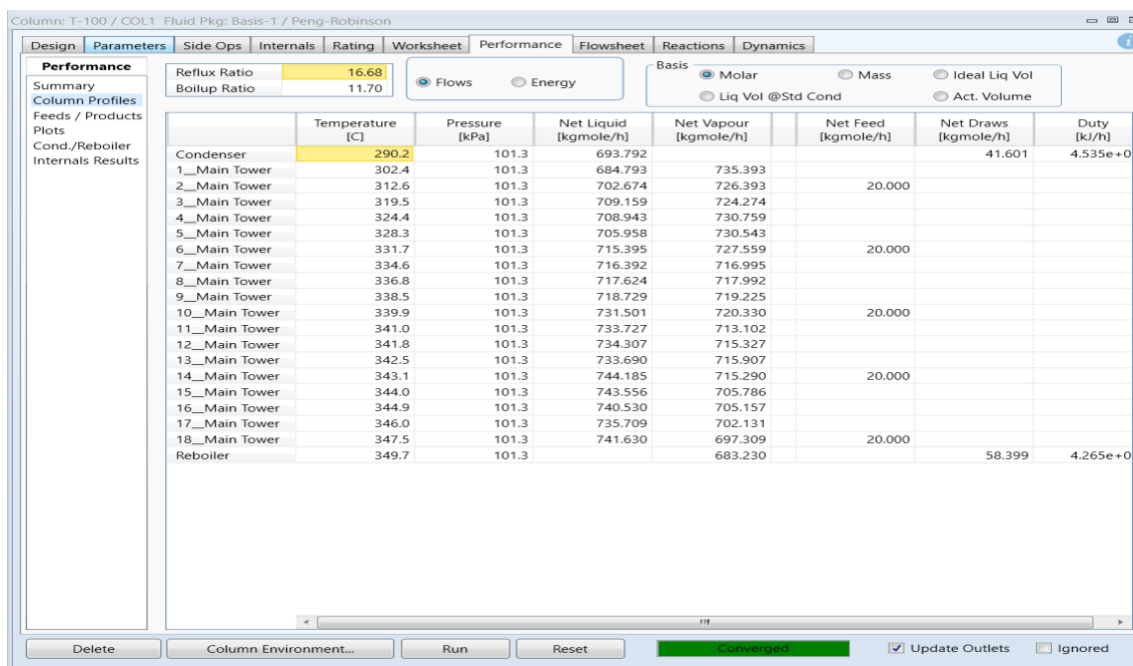
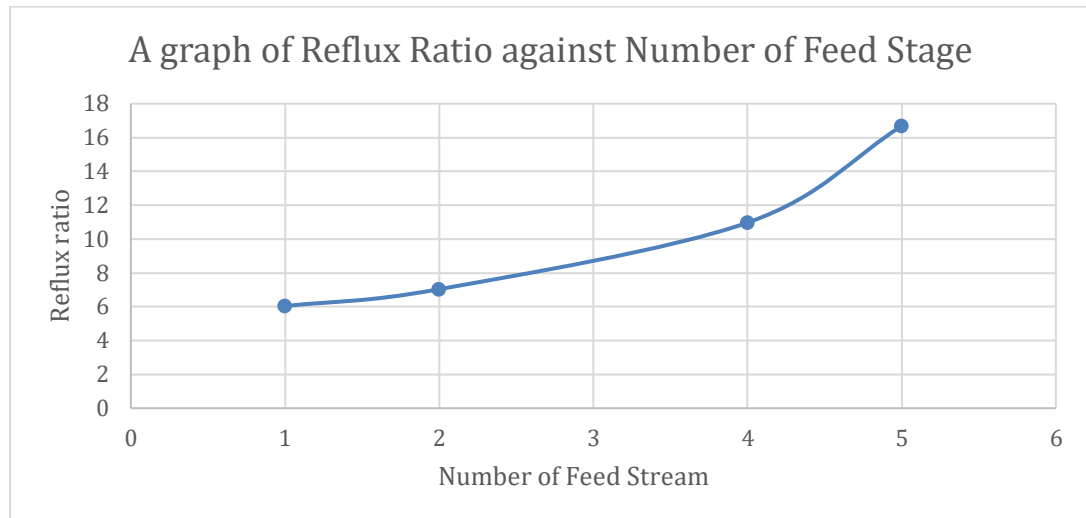


Figure C2: Heat Duty of Condenser and Reboiler of 5 feed streams

Table C1: Number of Feed Stream, Location of Feed Stage, Reflux Ratio, Distillation Rate, Bottom Rate, Flow Ratio of Tee, Heat Duty of Condenser and Heat Duty of Reboiler.

Number of Trials	1	2	3	4
Number of Feed Stream	1	2	4	5
Feed Stage	8	6,12	2,6,12,16	2,6,10,14,18
Reflux Ratio	6.036	7.035	10.97	16.68
Distillation Rate (kmol/h)	41.610	41.64	41.66	41.60
Bottom Rate (kmol/h)	58.390	58.36	58.34	58.40
Flow Ratio TEE	1	0.500	0.250	0.200
Heat Duty of Reboiler x 10 <sup>7</sup> (kJ/h)	1.534	1.794	2.809	4.265
Heat Duty of Condenser x 10 <sup>-6</sup> (kJ/h)	1.804	2.062	3.078	4.535

From table C1, we can know that reflux ratio is strongly influenced by the number of feed streams. The reflux ratio is the relationship between the distillate rate,  $D$ , and the liquid flow,  $L$ , in the rectifying section. Reflux ratio is a crucial factor in controlling the product's purity. It can also be used to calculate the amount of energy needed in the reboiler, which has an impact on how well a distillation column separates substances. Figure C3 shows the graph of reflux ratio versus number of feed streams based on reflux ratio.



**Figure C3: Shows the graphs of reflux ratio vs number of feed stream**

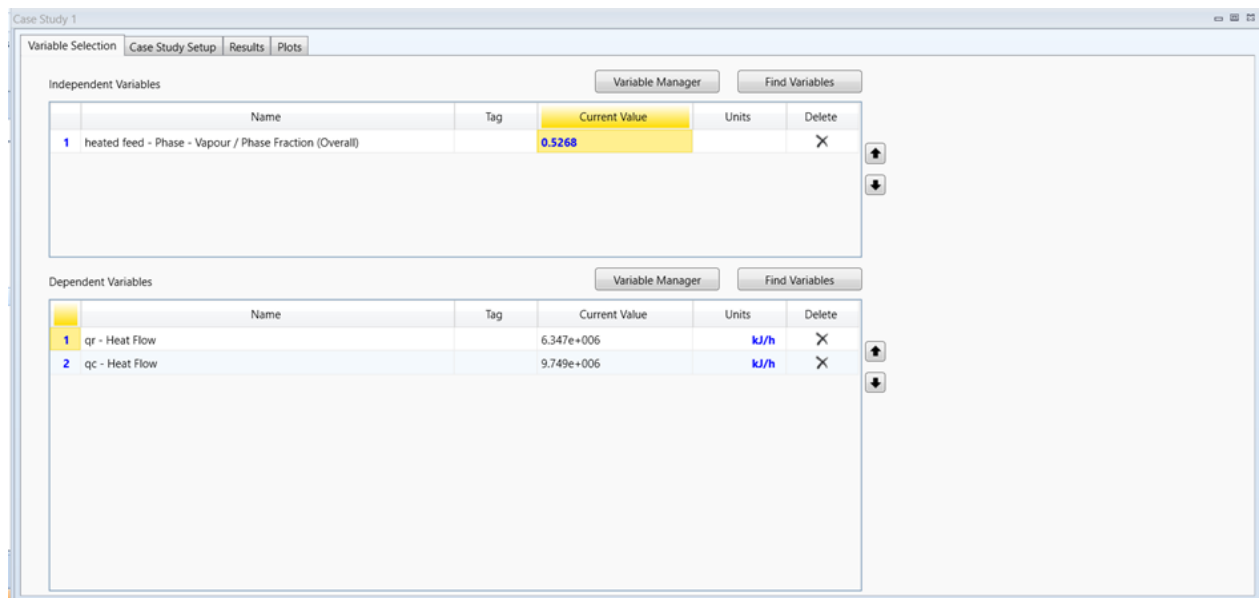
Figure C3 illustrates how the reflux ratio will increase as the number of feed streams rises. Reflux ratio is a crucial factor in determining how pure a product is, as was previously noted. To illustrate the change in reflux ratio, the recovery of the light key and heavy key in this HYSYS simulation is required to be 98% and 95%, correspondingly. Refluxed liquid is abundant in the desirable top products, which include light key and light non-key, but some heavy key may also be present in the top product. Condensation occurs because of the reflux liquid flowing downward cooling the vapor that is flowing upward. Since the light key and light non-key will have a lower boiling point than the heavy key, part of the light key and light non-key in the reflux will vaporize upon contact with the up flowing vapors. Meanwhile, the large key will become compact and drop back to the column. This is the reason that when a lower reflux less liquid is refluxed back into the distillation column when a less ratio is desired. Alternatively, the lesser the requirement of reflux ratio, the heavier keys must be taken out of the desirable top items to produce a lower purity of distillate.

To put it briefly, a distillation column with multiple feed streams will decrease the reflux ratio and separation effectiveness to get a lesser purity of distillate. When the heat responsibilities for both condenser and reboiler raised, the reflux ratio will drop. The price of the reboiler and the water needed for condenser cooling drop as the reflux ratio grows. Cost and the effectiveness of the distillation column are the important things to consider. Therefore, when the price of the reboiler and the cooling water decreases, the cost of the distillation process also decreases.



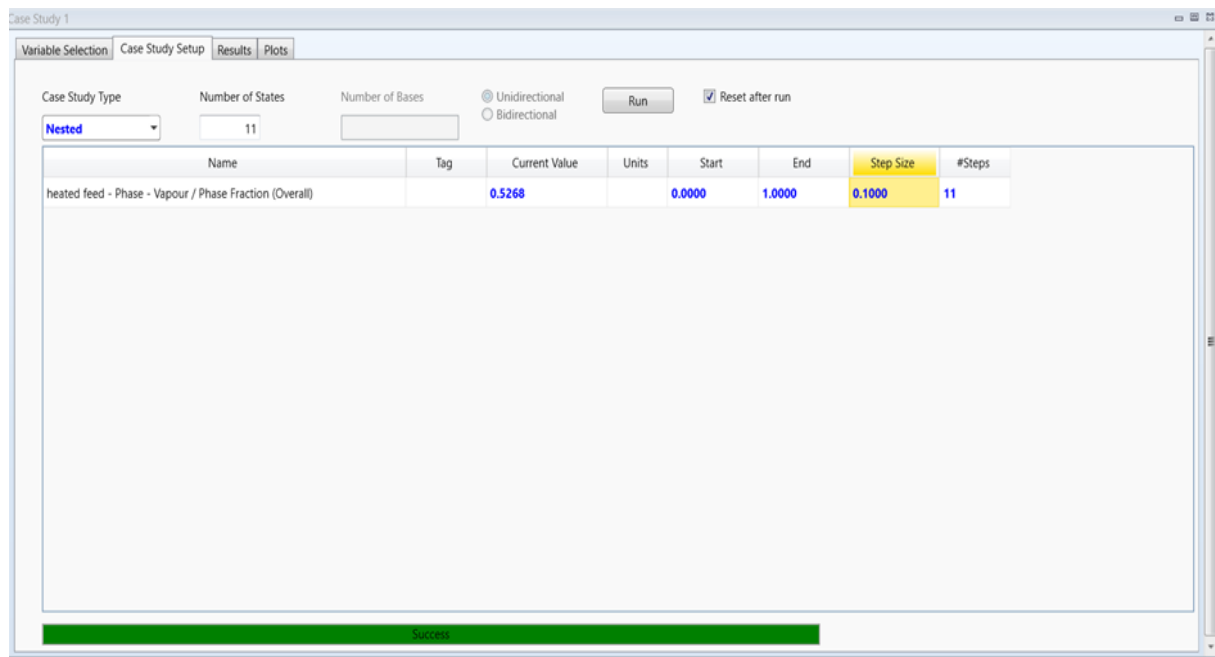
**SECTION D: Case Study in HYSYS: Effect of feed liquid fraction on the heat duty of reboiler and condenser.**

Case study in HYSYS, need to set independence and dependence variables to create a case study. Heated feed stream and phase – vapor/phase fraction(overall) are selected for independent variables. Qr and Qc of heat flow are selected as dependent variables. Figure 2.1 is showed the selection of independent and dependent variables.



**Figure D1: Independent and dependent variables selection**

The current value of the liquid fraction of heated feed are 0.5268 because the 0.4734 of vapour fraction are calculated at section (b). Therefore, 1 minus 0.4734 and get 0.5268 which is the liquid fraction of heated feed. For the case study setup, 0 is typed in start, 1 is typed in end and 0.1 is typed in step size. Press run after type in start, end, and step size.

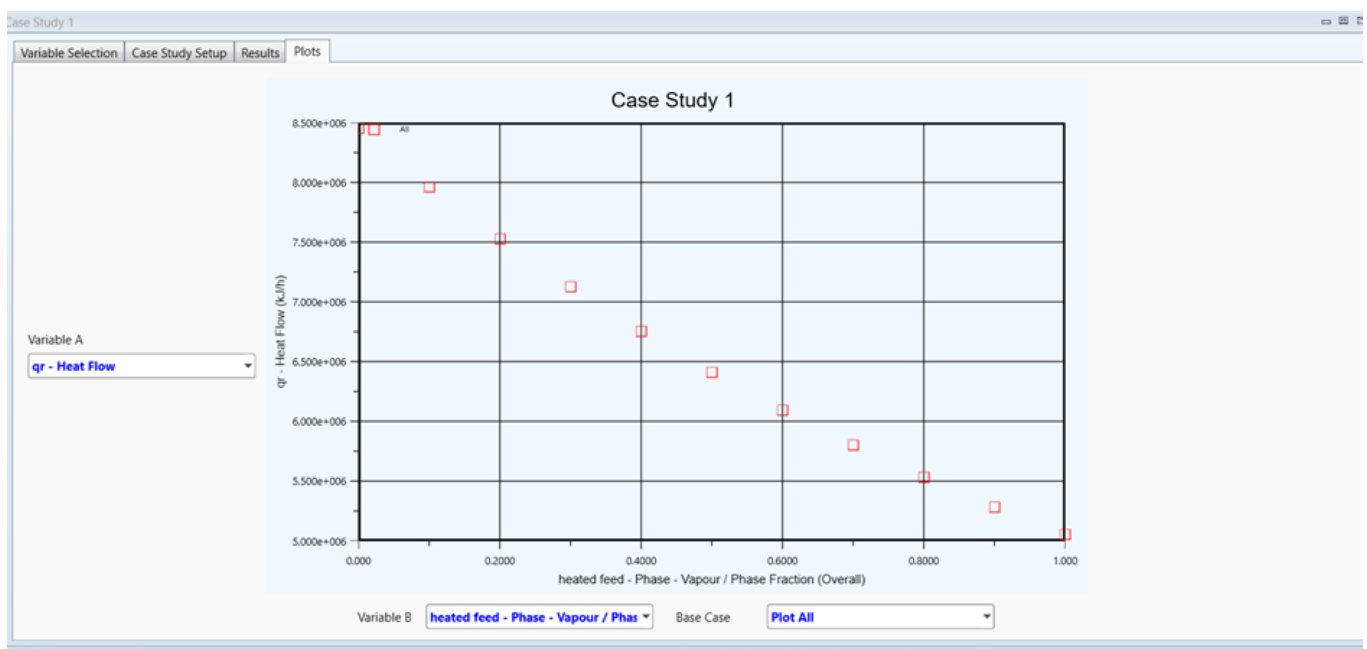


**Figure D2: 0 is typed in start, 1 is typed in end and 0.1 is typed in step size.**

Case Study 1			
Variable Selection Case Study Setup Results Plots			
Failed Cases: 0		Show: <b>All</b>	<input checked="" type="checkbox"/> Transpose results <input type="button" value="Send to Excel"/>
State	heated feed - Phase - Vapour / Phase Fraction (Overall)	qr - Heat Flow [kJ/h]	qc - Heat Flow [kJ/h]
Case 1	0.0000	8.454e+006	7.820e+006
Case 2	0.1000	7.964e+006	8.128e+006
Case 3	0.2000	7.529e+006	8.474e+006
Case 4	0.3000	7.128e+006	8.838e+006
Case 5	0.4000	6.755e+006	9.221e+006
Case 6	0.5000	6.411e+006	9.619e+006
Case 7	0.6000	6.094e+006	1.003e+007
Case 8	0.7000	5.802e+006	1.046e+007
Case 9	0.8000	5.532e+006	1.091e+007
Case 10	0.9000	5.283e+006	1.137e+007
Case 11	1.0000	5.054e+006	1.184e+007

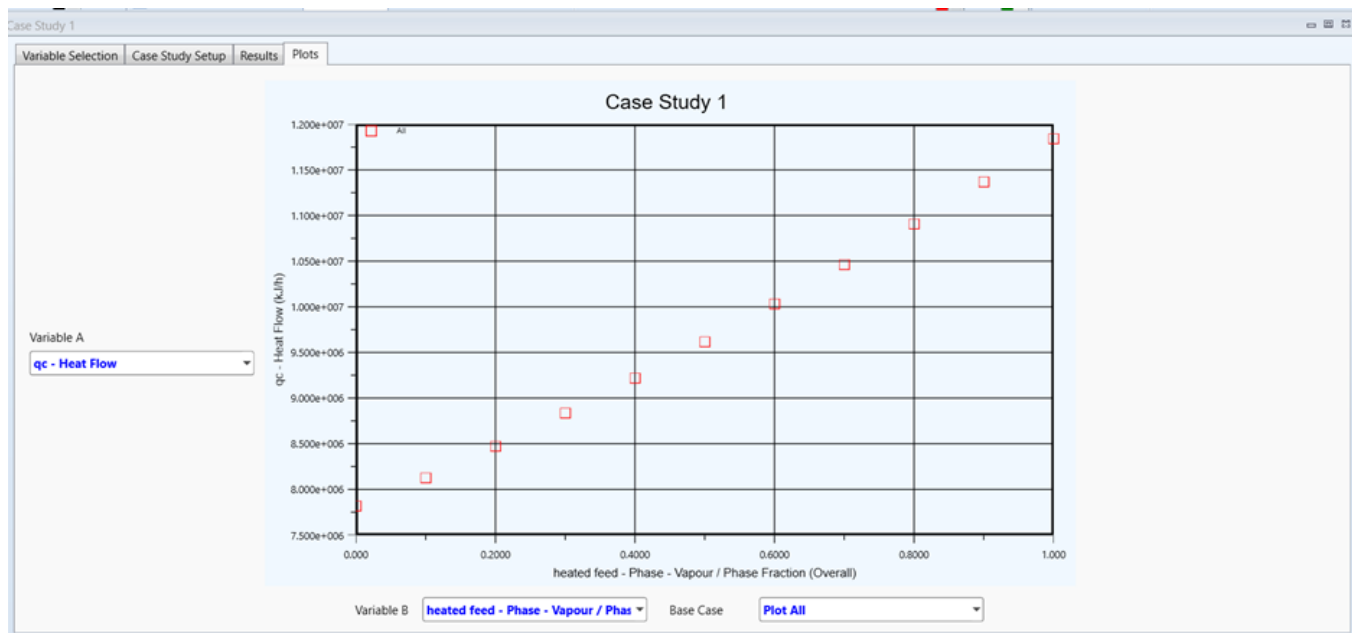
**Figure D3: The effect of liquid fraction on Qr and Qc**

Figure D3: Show that the effect of liquid fraction on heat duty of Qr (reboiler) and Qc (condenser). Heat duty is the heat required to be added or be removed from the process fluids to create the required change in temperature (*Process Heat Duty*, 2011).



**Figure D4: Graph of Heat Duty of Reboiler**

Figure D4: Shows that the relationship between heat duty of reboiler (Qr) and the liquid fraction of heated feed. When the heat duty on the reboiler drop as liquid fraction rises. These occurs so that a low feed liquid percentage causes more vapor to be separated into the reboiler, which then requires more energy to heated before returning to the distillation column for additional separation. The amount of liquid in the feed are increases with the liquid fraction. As a result, the liquid needs more fewer heat to boil up, which greatly reduced the heat duty of reboiler (Qr).



**Figure D5: Graph of Heat Duty of Condenser**

Figure D5: Shows that the relation between heat duty of condenser ( $Q_c$ ) and liquid fraction of heated feed. This occurs because when the feed's liquid percentage is high and fed into the distillation column, more liquid is present. As a result, more liquid is separated into the condenser, which forces the condenser to produce more energy. The feed has a low liquid fraction and includes more vapor, therefore less liquid will be removed from it. In conclusion, the heat duty of condenser ( $Q_c$ ) are greatly reduced.

Ultimately, according to figure D3 the heat duty of the reboiler ( $Q_r$ ) decreases as the liquid fraction increases. When the heat duty of the condenser increases, the liquid fraction also will increase according to figure 2.5.

## SECTION E

### Section Ei: Identification of Types of Trays with Size and Pattern of Hole

Tray design is one of the significant steps after the process design. By designing the tray able to implement the process requirements into actual hardware. Tray is one of the most popular pieces of hardware for mass transfer to take place. As a result, tray columns are widely used in different type of mass transfer operation. Therefore, engineer must take much of the consideration when designing the tray to achieve the desire efficiency for a particular service with least limitations. Firstly, tray design can be depending on the column size, density and the rate of vapor and liquid flow through the tray. It designed to facilitate contact vapour phase and liquid to enhance mass and heat transfer occurs.

Besides, the distillation column must be implemented with the tray to utilize a pressure and temperature differential to separate the products. As the structure of tray, bubbling area is the place for vapour- liquid contact take place and liquid flowing across the tray. When the foaming process occurs, high interfacial area can be obtained for mass transfer. Weir sustains a liquid level of it and the vapor must overcome the liquid head to transfer up the column and downcomers are act as a guidance from upper to lower tray. In the other words, the more stages in a column, the larger separation can be achieved but also high pressure drop. But there are few of the characteristic that can be consider by selecting a tray (Tham, 2016).

1. Trays may have downcomer capacity issues when heavy foaming occurs.
2. Trays are high in pressure drop by comparing to pack column
3. Higher resistance to corrosion
4. Trays have more entrainments can lead to efficiency loss.

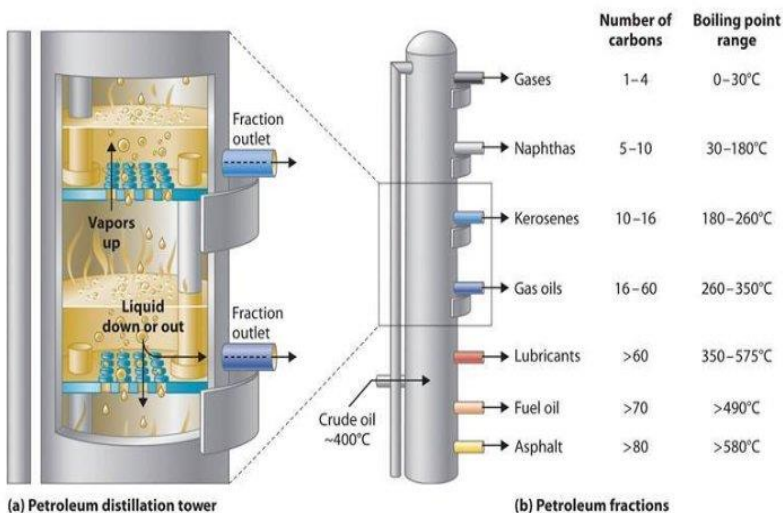


Figure E1: Distillation Tower in Petroleum Industry

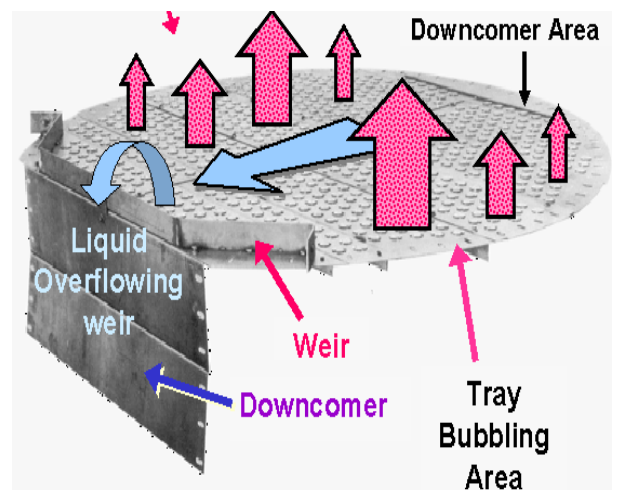


Figure E2: Tray

There are three main types of trays in use for the petroleum industry:

1. Sieve tray
2. Valve tray
3. Bubble tray

While discuss about trays type and its pattern, sieve tray is the simplest and cheapest tray type and its appearance as a sheet of metal which punched the hole with 0.5-inch perforation downward and 1/5 – 1 inch in hole diameter (5- 25mm). While vapor vaporize up through the hole constructed a multi orifice effect. This indicate that liquid will flowing down due to the velocity of vapor (weeping). Therefore, sieve tray can in contact between vapor and liquid by the number and size of the perforations. Sieve tray can be

achieved for 70% capacity and efficiency.

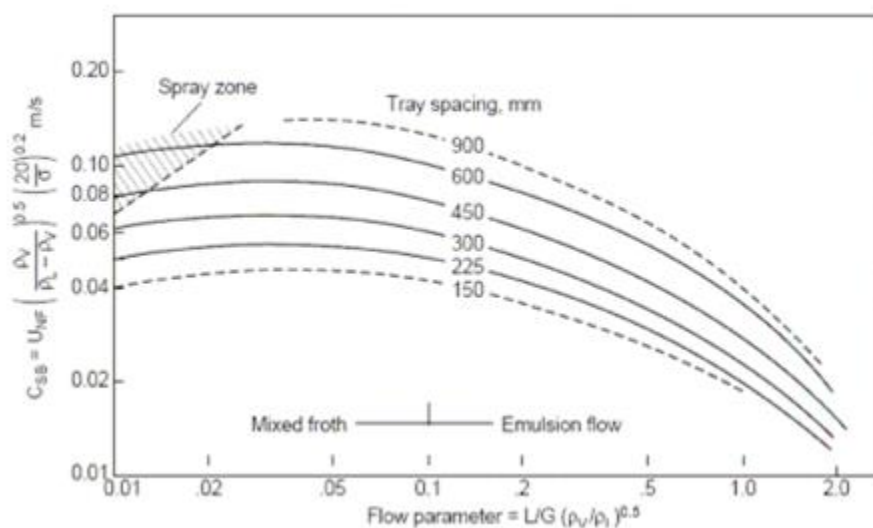
Secondly, bubble cap tray known as the oldest tray type for equilibrium- stage. Bubble cap tray is perforated a flat plate which consist of a riser among the cap covered holes. The main purpose of the cap is to allow passage of vapor to be mixed with the liquid flowing over the tray to form bubble and enhance mass transfer whereby liquid flowing through at least one downcomer. The size of the bubble caps commonly is 2-6 inch in diameter and with 1 mm thickness.

Valve tray uses as a valve where the disc can be moveable and hole diameter in between 0.2-0.5 inch. When the low vapor rate is obtained, the disc might be completely closes off tend to minimize the tray open area and vice versa. Shape of the valves can be in round or rectangular and might be caging structured tend to operate over wide range of flow rates and enhance separation efficiency. But its only have 60% capacity which is lower than the sieve tray.

### Section Eii: Identification of Tray Spacing, Weir Height and Downcomers Size

Now, tray properties such as spacing, weir height and downcomer size would be another consideration when choosing a suitable tray type. The space between two trays is known as the tray spacing. Typically, tray spacing is between 8 and 36 inches (0.2 m to 0.9 m) and 1 m in diameter. The cost-benefit analysis of the trade-off between column height and column diameter is the primary determinant of tray spacing. The typical column tray spacing is 0.6 m. By comparison, bubble cap tray requires a larger tray spacing than other design. This is due to the limitation of bubble cap tray such as coking, formation of polymer, high fouling mixtures lead to have a larger spacing for maintenance to take place (Technology, 2012). As a result, increasing the spacing between trays only lengthens the vapor's track before entraining liquid. This method does not result in a linear increase in capacity. In general, capacity rises with the square root of tray spacing. Smaller orifices are typically used in high-capacity deck designs.

A weir height is designed to keep the liquid level on the tray at the proper level. Weir heights typically range from 2 to 4 inches. Low weirs are widely employed in vacuum or low-pressure columns and vice versa. Fair's correlation was implemented for decades has been the standard for the industry for entrainment flood prediction. It tends to be conservative, especially at high pressure and liquid rate. Therefore, the weir height must be 15% shorter than the tray spacing. (Bander, 2005)



**Figure E3: Flow Parameter and tray spacing for the entrainment flood prediction**

. Calculate superficial velocity at flooding condition ( $u_{N, flood}$ ):

$$u_{N, flood} = C_{SB, flood} \left( \frac{\sigma}{20} \right)^{0.2} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}, \text{ m/s}$$

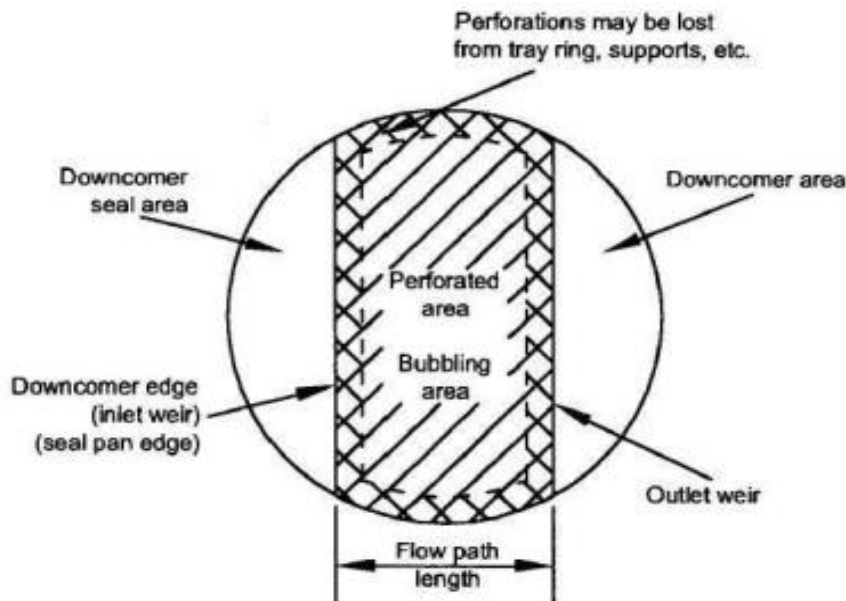
. Calculate actual superficial velocity ( $u_N$ ):

$$u_N = \frac{CFS}{A_N}$$

Calculate % Flood:

$$\% Flood = 100 * \frac{u_N}{SF * u_{N, flood}}$$

Downcomers allow liquid to flow from the top tray to the bottom tray. In a distillation column, downcomers are conduits with circular, segmental, or rectangular cross sections. For the liquid to enter the tray below relatively free of vapour, adequate time must also be allowed for proper vapour disengagement from the down-flowing liquid in the downcomer. A sufficient downcomer space can avoid downcomer choking and reduce the vapor entrainment. In contrast, liquid backs up into the tray above the downcomer and finally floods the column when downcomers space insufficient. In addition, the downcomer must have enough residence time to allow for adequate vapour disengagement from the descending liquid, ensuring that the liquid is largely vapour-free when it enters the beam below (Wankat, 2012). The downcomer could choke if the liquid's vapour is not removed sufficiently. As a conclusion, weir height, downcomers size and tray spacing are related with each other when designing the suitable tray column.



**Figure E4: Structure of Downcomer**

### **Section Eiii: Allowable vapour flow rate and column diameter**

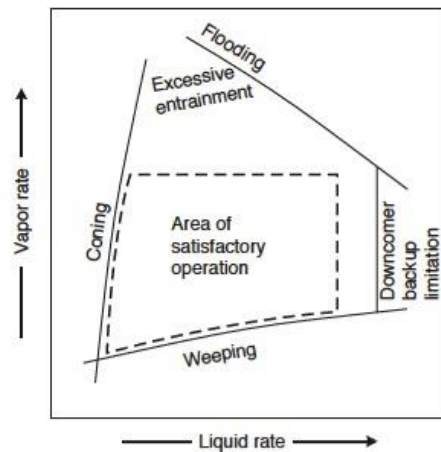
Based on our investigation, allowable vapour flow rate is the main consideration for the column separation to avoid excessive or inadequate vapour flow conditions. Column diameter affects the velocity of vapour flow. Column capacity is determined by weeping which establishes the minimal vapour flow necessary, and flooding which establishes the highest vapour flow permitted. As a result, the column will not function effectively if the column diameter is not sized properly. In addition to operational issues, it is possible that the planned separation duties won't be completed. Hence, flooding equation would be introduced to allocate the maximum vapour flow rate. In the other word, range of vapor and liquid flow rates in which the column needs to be operated must be specify. Instead, columns are typically designed for 80% of flooding at the maximum flow rate. Obtain a new velocity with this 80% and use the velocity

to calculate a maximum volumetric flowrate. Using this and the velocity, we can calculate a net area necessary for vapor flow through the plate (Stupin, 2003).

$$u_c = K_v \sqrt{\frac{\rho_L - \rho_V}{\rho_V} \left(\frac{\sigma}{20}\right)^{0.2}}$$

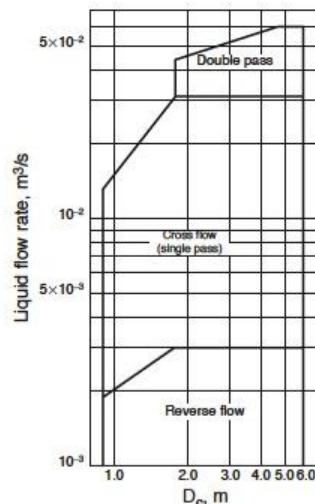
where,

$\sigma$  = surface tension of liquid, dym/cm, and  $K_v$  can be determine through graph.



**Figure E5: Weeping, Coking and Flooding occur in Tray**

In the oil refinery industry, the most column diameter is about 2.5 m but 6 m diameter is common place and tower of 12 m diameter have been built. But based on the economies of scale such as low-cost energy was used, well suited for energy integration into the surrounding process hence 2.5 m in diameter is preferable. In addition, based on the diameter of the column, flow arrangement such as single pass, double pass, reverse flow can be determined as shown in the graph below (Towler G, 2013).



**Figure E6: Different Flow Arrangement**

By computing all the discussion above, distillation is the most widely used separation process in oil refineries which is crude oil in our topic. To promote high efficiency, contact between liquid and vapor, sieve tray type is preferable compared to bubble tray and valve tray due to its optimum hole diameter (5-25mm). Generally, sieve tray is simple in design and lower in cost due to the low pressure drop across the tray and maintenance unlike the bubble tray present a high- pressure gradient through the tray which can

lead serious corrosion to happen, more space that require for the bubble cap to open in a single deck and extensive labour to manufacture the bubble cap tray. In addition, valve tray has high probability to fouling due to more free surface area to the decomposition of contaminants and lead to higher maintenance cost. As moving valves in a working condition, valve leg can contact the edges of the orifice which caused erosion and increase for the corrosion to happen.

**Table E1: Summaries of Different Tray with Different aspects**

Factors	Sieve Tray	Bubble- Cap Tray	Valve Tray
Capacity	High	Moderately High	High
Efficiency	High	Moderately High	High
Turndown	~ 50 %	10 %	~ 25 to 30 %
Entrainment	Moderate	High	Moderate
Pressure Drop	Moderate	High	Moderate
Cost	Low	~ 2 ~3 times of Sieve Tray	~ 1.2 times of Sieve Tray
Maintenance	Low	Relatively High	Low to moderate
Fouling Tendency	Low	High, able to collect solid.	Low to moderate
Effect of Corrosion	Low	High	Low to moderate
Design Information	Well Known	Well Known	Proprietary but readily available
Main Application	Often used when turndown is not critical.	Extremely low liquid flow and leakage must be minimized.	When high turndown is required.



## Conclusion

In conclusion, to recover 98% n-Pentadecane and 95% n-Eicosane, a distillation column is constructed to separate n-Pentadecane (n-C15), n-octadecane (n-C18), n-Eicosane (n-C20), and n-docosane (n-C22). Aspen HYSYS simulation is used to simulate the distillation column. Peng-Robinson is the fluid property package that was used in this simulation. The feed stream is fed unipolarly at a flow rate of 100 kgmole/h (n-Eicosane content is set to be higher than the other components, which is 0.4). In addition, the feed stream's bubble point is 318.0 °C, while the dew point is 337.4 °C. Light key (LK) is n-C18, while light-non key (LNK) is n-C15. The heavy key (HK) and heavy non-key (HNK) are both n-C20 and n-C22, respectively. The heated input stream temperature required to create liquid with a heavy key (n-C20) composition equal to 0.45 is 179.4 °C.

Reflux ratio is 3.0303 when calculated manually using the stated 98% recovery of LK and 95% recovery of HK, while real theoretical stages are 19 when calculated using Gilliland correlation. The Kirkbride equation determines that the ninth step is the ideal feed-stage. The overall condenser's heat duty is  $10.9645 \times 10^6$  kJ/h, whereas the total reboiler's heat duty is  $7.8381 \times 10^6$  kJ/h. Information from manual calculations is used in HYSYS simulation. A total of 19 equilibrium stages, a total condenser, and a partial reboiler are included in the distillation column's design. Additionally, the distillation column specifies the reflux ratio and recovery of LK. Assumptions made in manual calculation and differences in distillate and bottom composition are the main causes of the discrepancy between manual calculation and HYSYS simulation.

When the number of feed streams increase, the reflux ratio will increase. The heat duty of condenser and reboiler will also increase. This is because more energy is needed in separation process. Efficiency of the separation process will also increase when the reflux ratio increase. With the increasing of liquid fraction, the heat duty of condenser will increase too while the heat duty of reboiler will decrease. To choose a suitable tray to use, different aspect of the types of trays must be investigated in order to fit the suitable process. Sieve tray is chosen as the most suitable tray in separation process in different aspect such as cost, efficiency and so on.

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## Appendix

MONITOR					
Specifications Summary					
	Specified Value	Current Value	Wt. Error		
Reflux Ratio	3.030 *	3.030	1.397e-008		
Distillate Rate	---	48.40 kgmole/h	---		
Reflux Rate	---	146.7 kgmole/h	---		
Btms Prod Rate	---	51.60 kgmole/h	---		
Light key n-C18	0.9800 *	0.9800	-9.933e-006		
Heavy Key n-C20	0.9500 *	0.7824	-9.404e-002		
	Wt. Tol.	Abs. Tol.	Active	Estimate	Used
Reflux Ratio	1.000e-002	1.000e-002	On	On	On
Distillate Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Reflux Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Btms Prod Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Light key n-C18	1.000e-002	1.000e-003	On	On	On
Heavy Key n-C20	1.000e-002	1.000e-003	Off	On	Off

### MONITOR

Specifications Summary					
	Specified Value	Current Value	Wt. Error		
Reflux Ratio	3.030 *	3.030	1.397e-008		
Distillate Rate	---	48.40 kgmole/h	---		
Reflux Rate	---	146.7 kgmole/h	---		
Btms Prod Rate	---	51.60 kgmole/h	---		
Light key n-C18	0.9800 *	0.9800	-9.933e-006		
Heavy key n-C22	0.9500 *	0.9954	2.277e-002		
	Wt. Tol.	Abs. Tol.	Active	Estimate	Used
Reflux Ratio	1.000e-002	1.000e-002	On	On	On
Distillate Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Reflux Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Btms Prod Rate	1.000e-002	1.000 kgmole/h	Off	On	Off
Light key n-C18	1.000e-002	1.000e-003	On	On	On
Heavy key n-C22	1.000e-002	1.000e-003	Off	On	Off

### CONDITIONS

Name	heated feed @Main	Bottom @Main	Distillate @Main	qr @Main	qc @Main
Vapour	0.4734	0.0000	0.0000	---	---
Temperature (C)	329.4000	350.7333	295.3023	---	---
Pressure (kPa)	101.3000 *	101.3000	101.3000	---	---
Molar Flow (kgmole/h)	100.0000	51.6044	48.3956	---	---
Mass Flow (kg/h)	26851.1407	15127.4679	11723.6728	---	---
Std Ideal Liq Vol Flow (m3/h)	34.0954	19.0739	15.0215	---	---
Molar Enthalpy (kJ/kgmole)	-2.800e+005	-3.081e+005	-3.083e+005	---	---
Molar Entropy (kJ/kgmole-C)	1118	1298	818.5	---	---
Heat Flow (kJ/h)	-2.7996e+07	-1.5899e+07	-1.4920e+07	9.9255e+06	1.2747e+07

SUMMARY			
Flow Basis:		Molar	The composition option is selected
Feed Composition			
	heated feed		
Flow Rate (kgmole/h)	100.0000		
	---		
n-C15	0.2000		
n-C18	0.2000		
n-C20	0.4000		
n-C22	0.2000		
Flow Basis:		Molar	The composition option is selected
Feed Flows			
	heated feed		
Flow Rate (kgmole/h)	100.0000		
	---		
n-C15 (kgmole/h)	20.0000		
n-C18 (kgmole/h)	20.0000		
n-C20 (kgmole/h)	40.0000		
n-C22 (kgmole/h)	20.0000		
Products			
Flow Basis:		Molar	The composition option is selected
Product Compositions			
	Distillate	Bottom	
Flow Rate (kgmole/h)	48.3956	51.6044	
	---	---	
n-C15	0.4133	0.0000	
n-C18	0.4050	0.0078	
n-C20	0.1799	0.6064	
n-C22	0.0019	0.3858	
Flow Basis:		Molar	The composition option is selected
Product Flows			
	Distillate	Bottom	
Flow Rate (kgmole/h)	48.3956	51.6044	
	---	---	
n-C15 (kgmole/h)	20.0000	0.0000	
n-C18 (kgmole/h)	19.5996	0.4004	
n-C20 (kgmole/h)	8.7048	31.2952	
n-C22 (kgmole/h)	0.0912	19.9088	
Flow Basis:		Molar	The composition option is selected

#### COLUMN PROFILES

Reflux Ratio:		3.030	Reboil Ratio:		3.076	The Energy Option is Selected		Flow Basis:		Molar
Column Profiles Flows										
	Temp (C)	Pres (kPa)	Net Liq (kgmole/h)	Net Vap (kgmole/h)	Net Feed (kgmole/h)	Net Draws (kgmole/h)	Duty (kJ/h)			
Condenser	295.3	101.3	146.7	---	---	48.40	1.27e+007			
1__Main Tower	310.9	101.3	145.6	195.0	---	---	---			
2__Main Tower	320.6	101.3	147.8	194.0	---	---	---			
3__Main Tower	325.9	101.3	148.7	196.2	---	---	---			
4__Main Tower	328.9	101.3	148.5	197.1	---	---	---			
5__Main Tower	331.0	101.3	147.7	196.9	---	---	---			
6__Main Tower	332.6	101.3	146.6	196.1	---	---	---			
7__Main Tower	334.1	101.3	145.2	195.0	---	---	---			
8__Main Tower	335.5	101.3	200.4	193.6	100.0	---	---			
9__Main Tower	339.4	101.3	206.0	148.8	---	---	---			
10__Main Tower	341.7	101.3	208.8	154.4	---	---	---			
11__Main Tower	343.0	101.3	210.4	157.2	---	---	---			
12__Main Tower	344.0	101.3	211.3	158.8	---	---	---			
13__Main Tower	344.8	101.3	211.8	159.7	---	---	---			
14__Main Tower	345.5	101.3	212.1	160.2	---	---	---			
15__Main Tower	346.1	101.3	212.2	160.5	---	---	---			
16__Main Tower	346.8	101.3	211.9	160.5	---	---	---			
17__Main Tower	347.7	101.3	211.3	160.3	---	---	---			
18__Main Tower	348.9	101.3	210.3	159.7	---	---	---			
Reboiler	350.7	101.3	---	158.7	---	51.60	9.93e+006			

Column Profiles Energy				
	Temperature (C)	Liq Enthalpy (kJ/kgmole)	Vap Enthalpy (kJ/kgmole)	Heat Loss (kJ/h)
Condenser	295.3	-3.083e+005	-2.408e+005	---
1__Main Tower	310.9	-3.115e+005	-2.429e+005	---
2__Main Tower	320.6	-3.120e+005	-2.450e+005	---
3__Main Tower	325.9	-3.121e+005	-2.461e+005	---
4__Main Tower	328.9	-3.123e+005	-2.465e+005	---
5__Main Tower	331.0	-3.124e+005	-2.465e+005	---
6__Main Tower	332.6	-3.124e+005	-2.464e+005	---
7__Main Tower	334.1	-3.124e+005	-2.460e+005	---
8__Main Tower	335.5	-3.123e+005	-2.455e+005	---
9__Main Tower	339.4	-3.112e+005	-2.471e+005	---
10__Main Tower	341.7	-3.106e+005	-2.478e+005	---
11__Main Tower	343.0	-3.103e+005	-2.482e+005	---
12__Main Tower	344.0	-3.101e+005	-2.484e+005	---
13__Main Tower	344.8	-3.100e+005	-2.486e+005	---
14__Main Tower	345.5	-3.099e+005	-2.486e+005	---
15__Main Tower	346.1	-3.097e+005	-2.485e+005	---
16__Main Tower	346.8	-3.096e+005	-2.484e+005	---
17__Main Tower	347.7	-3.093e+005	-2.481e+005	---
18__Main Tower	348.9	-3.088e+005	-2.475e+005	---
Reboiler	350.7	-3.081e+005	-2.466e+005	---

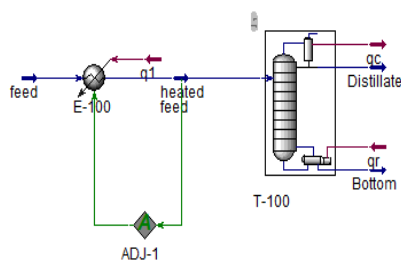
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#### Column K-Values Profile

Tray Number	n-C15	n-C18	n-C20	n-C22		
Condenser	1.623	0.6519	0.3600	0.2087		
1__Main Tower	2.127	0.8970	0.5167	0.3091		
2__Main Tower	2.487	1.081	0.6379	0.3890		
3__Main Tower	2.700	1.192	0.7123	0.4388		
4__Main Tower	2.829	1.260	0.7585	0.4699		
5__Main Tower	2.918	1.308	0.7908	0.4917		
6__Main Tower	2.989	1.346	0.8166	0.5093		
7__Main Tower	3.054	1.380	0.8405	0.5255		
8__Main Tower	3.120	1.416	0.8650	0.5423		
9__Main Tower	3.298	1.514	0.9336	0.5895		
10__Main Tower	3.402	1.572	0.9742	0.6177		
11__Main Tower	3.468	1.609	1.000	0.6358		
12__Main Tower	3.515	1.635	1.019	0.6487		
13__Main Tower	3.552	1.656	1.033	0.6590		
14__Main Tower	3.585	1.675	1.046	0.6680		
15__Main Tower	3.617	1.693	1.059	0.6768		
16__Main Tower	3.652	1.712	1.073	0.6865		
17__Main Tower	3.696	1.737	1.091	0.6990		
18__Main Tower	3.759	1.773	1.116	0.7166		
Reboiler	3.851	1.825	1.153	0.7427		



Material Streams					
		feed	heated feed	Bottom	Distillate
Vapour Fraction		0.0000	0.4734	0.0000	0.0000
Temperature	C	150.0	329.4	350.7	295.3
Pressure	kPa	101.3	101.3	101.3	101.3
Molar Flow	kgmole/h	100.0	100.0	51.60	48.40
Mass Flow	kg/h	2.685e+004	2.685e+004	1.513e+004	1.172e+004
Liquid Volume Flow	m3/h	34.10	34.10	19.07	15.02
Heat Flow	kJ/h	-4.478e+007	-2.800e+007	-1.590e+007	-1.492e+007

Energy Streams				
		q1	qc	qr
Heat Flow	kJ/h	1.678e+007	1.275e+007	9.925e+006

Compositions				
	feed	heated feed	Bottom	Distillate
Comp Mole Frac (n-C15)	0.2000	0.2000	0.0000	0.4133
Comp Mole Frac (n-C18)	0.2000	0.2000	0.0078	0.4050
Comp Mole Frac (n-C20)	0.4000	0.4000	0.6064	0.1799
Comp Mole Frac (n-C22)	0.2000	0.2000	0.3858	0.0019