DISTILLATION COLUMN DESIGN PROJECT
BY
GROUP – 1

MEMBERS

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DISTILLATION

- Distillation refers to the selective boiling and subsequent condensation of a component in a liquid mixture. The process of distillation exploits the difference in the boiling points of the components in the liquid mixture by forcing one of them into a gaseous state.

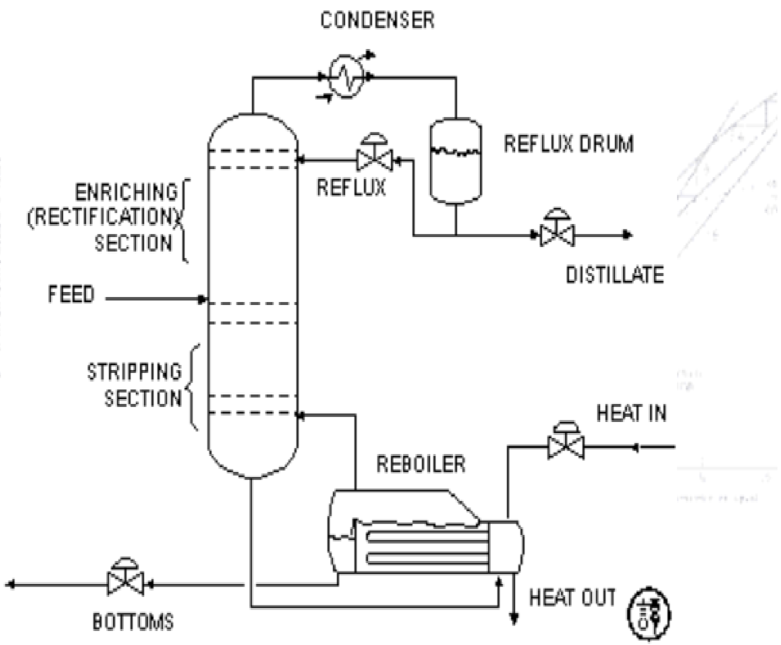
- It is an energy intensive process but high purity can be obtained by it

- Applications in Industry

A wide range of Petroleum Products can be obtained like:
Gasoline , Diesel fuel , Lubricating oil , Fuel oil , paraffin wax , petrochemicals

The main components are –

- a vertical shell where the separation of liquid components is carried
- column internals such as trays/plates and/or packings which are used to enhance component separations
- a reboiler to provide the necessary vaporization for the distillation
- a condenser to cool and condense the vapor leaving the top of the column
- a reflux drum to hold the condensed vapor from the top of the column liquid (reflux) can be recycled back to the column



The liquid mixture that is to be processed is known as the feed and this is introduced usually somewhere near the middle of the column to a tray known as the feed tray. The feed tray divides the column into a top (enriching or rectification) section and a bottom (stripping) section.

The liquid removed from the reboiler is known as the bottoms product or simply, bottoms.

The condensed liquid that is removed from the system is known as the distillate or top product.

SYSTEM CHOSEN – (ACETONE & BUTANOL)

- The system chosen is Acetone-Butanol because it is non-ideal and non-Azeotropic.
- Since it is non-azeotropic one can achieve high purity int terms of separating Acetone and Butanol (up to 99%)
- There is a large difference in the boiling point of both compounds (Acetone – 56 deg Celsius and Butanol – 118 deg Celsius) thus there is a large difference in the volatility of two compounds making it a suitable choice for Distillation process.
- The acetone is the light key component as it is more volatile and Butanol is heavy key component
- Acetone will be obtained as a top product in distillate while the Butanol will be obtained as a bottom product

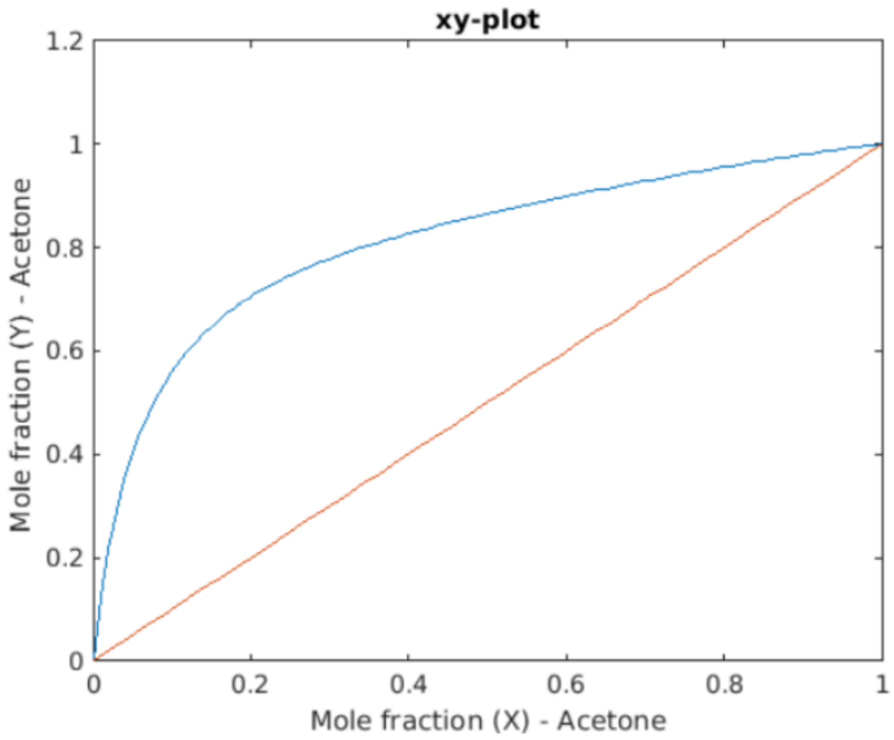
- The **xy equilibrium plot** for the acetone butanol mixture was obtained by solving the modified Raoult's Law by using WILSON for obtaining the activity coefficients and Soave-Redlich Kwong (SRK) equation of state for calculating the fugacity coefficient and ANTOINE'S parameters for calculating the saturation vapor pressure for each component.

$$y_i P = x_i \gamma_i P_i^{sat}$$

- The entire analysis was done at T=380 K in 0 Points were considered between 0 and 1 to get accurate results.

- At each point the activity and fugacity coefficients were calculated and applied in the modified Raoult's law equation to get the mole fraction in vapor phase for acetone and plot the curve.

- By Gibbs Phase rule F=C-P+2 . Here C=2 , P=2 thus we need to define only two independent intensive variables to define the whole system.



- The manual values of **feed composition** (xf=0.5), **distillate composition** (xd=0.99) , **bottoms composition** (xv=0.01) and (**q=0.6**) value of the feed were used. All these are the compositions for acetone (more volatile component)

- Then , draw the **q line** using the equation $\boxed{y = -\frac{q}{(1-q)}x + \frac{z_F}{1-q}}$

- To get the **reflux ratio** , we found the **minimum reflux ratio** first. Reflux ratio is minimum when top section line intersects the equilibrium curve

- We found the **intersection of q line with equilibrium curve** and passed a line from that intersection point and **(xd , xd)**. The y intercept of line is **xd/(Rmin+1)**

- By getting R min we got reflux ratio as **R=1.4 * Rmin**

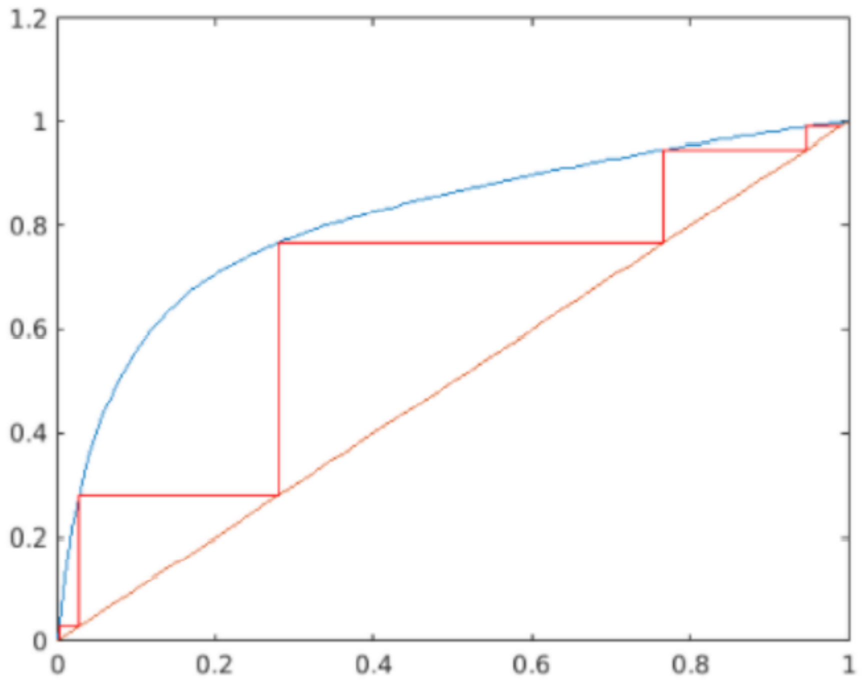
- After getting Reflux ratio , plot the **top section line** using the equation $y_{n+1} = \frac{R}{R+1}x_n + \frac{x_D}{R+1}$
- Then find the intersection point of the top line and the q-line and name it as **(x_intersect , y_intersect)**
- After that to calculate the top section stages , run a for loop till x coordinate is greater than the x_intersect as at x_intersect , the feed tray will be inserted . Keep on drawing horizontal lines and look for intersection point with curve and then drop a vertical line and so on. This gives us the **number of trays required for top section**
- Similarly to draw the bottom line use two points (xv , xv) and (x_intersect , y_intersect) and find the **number of stages for bottom section** as well

Actual Number of Stages = Top Section Stages + Bottom Section Stages

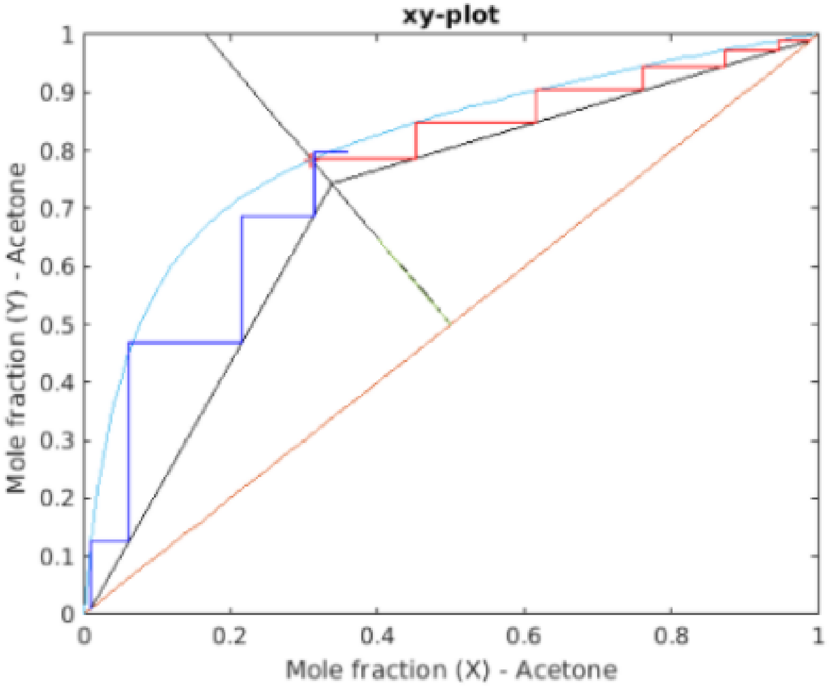
ACTUAL NUMBER OF STAGES & MINIMUM NUMBER OF STAGES

Minimum stages are calculated by intersecting the horizontal and vertical lines with y=x line as at minimum stages Reflux ratio is infinite so operating lines coincide with the y=x line

Minimum number of stages are 4.706



Actual number of stages are 9.3427



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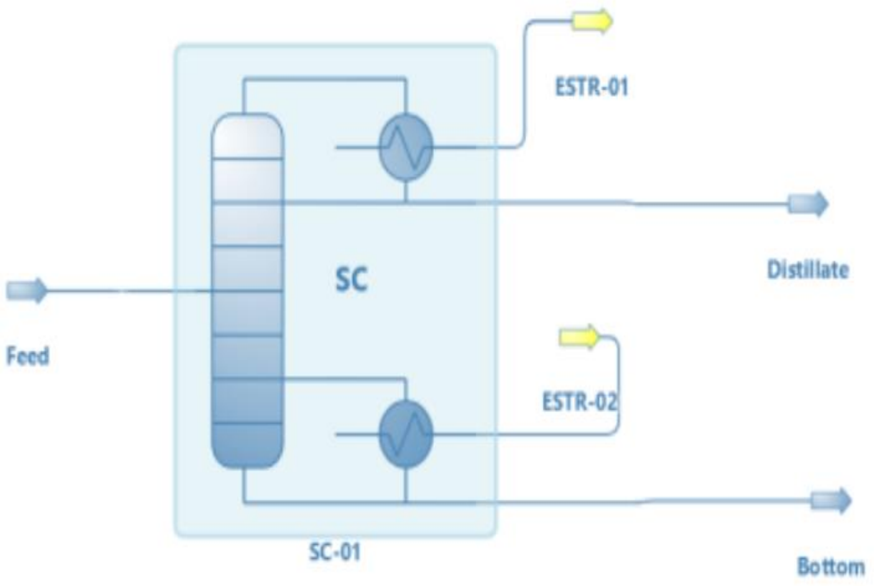
By performing the simulations on DWSIM software using Shortcut Column , the results matched with MATLAB code results which proves the accuracy of the code and method



MATLAB CODE RESULTS	DWSIM RESULTS	ERROR
The actual number of stages - 9.3472	9.89	5%
The minimum number of stages - 4.706	5.01	6.4%
Minimum Reflux Ratio - 0.43575	0.411	5.67%

In all 3 cases the error is around 5-6% which is acceptable

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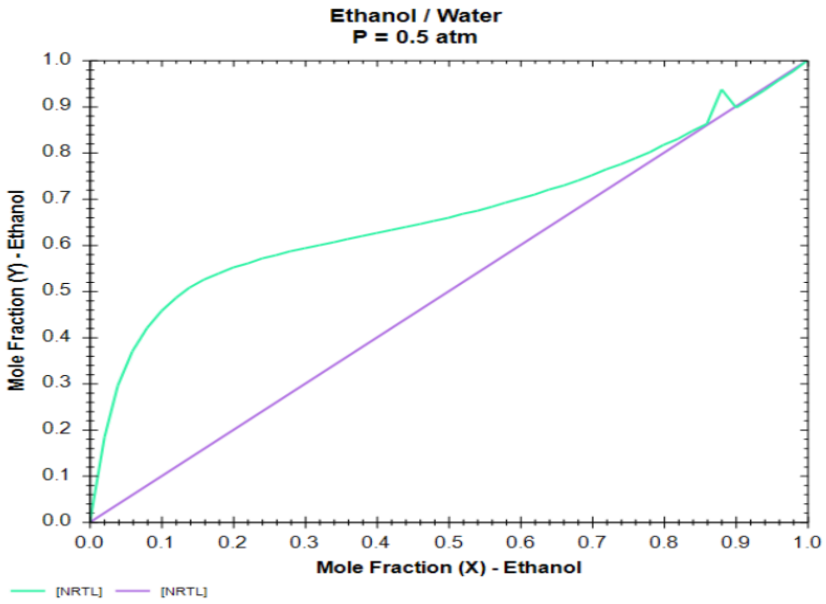
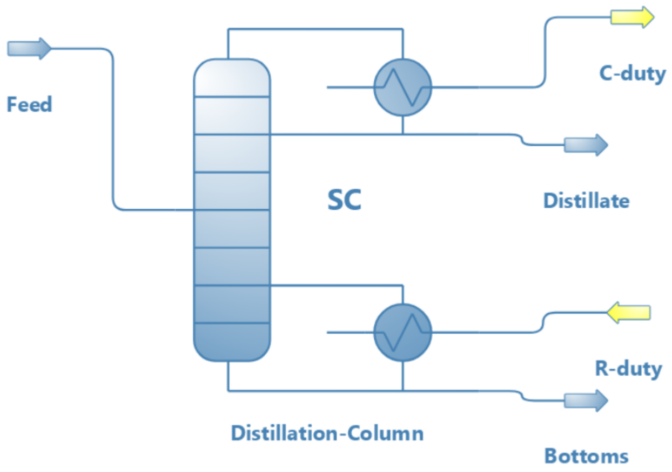
Ethanol & Water

- The azeotropic composition is found when the
  mole fraction (X)-Ethanol = mole fraction (Y)-Ethanol
- This happens at x=0.86 for Ethanol & Water mixture



Shortcut Column

- By simulating a shortcut column , the necessary parameters like actual number of stages , feed tray optimal position , reflux ratio gets known.



Property	Value	Units
Minimum Reflux Ratio	0.99867	
Minimum Number of Stages	1.97078	
Actual Number of Stages	10.3448	
Optimal Feed Stage	5.17238	
Stripping Liquid	56.1765	kmol/h
Rectify Liquid	56.1765	kmol/h
Stripping Vapor	0	kmol/h
Rectify Vapor	112.353	kmol/h
Condenser Duty	1253.31	kW
Reboiler Duty	-78.8039	kW

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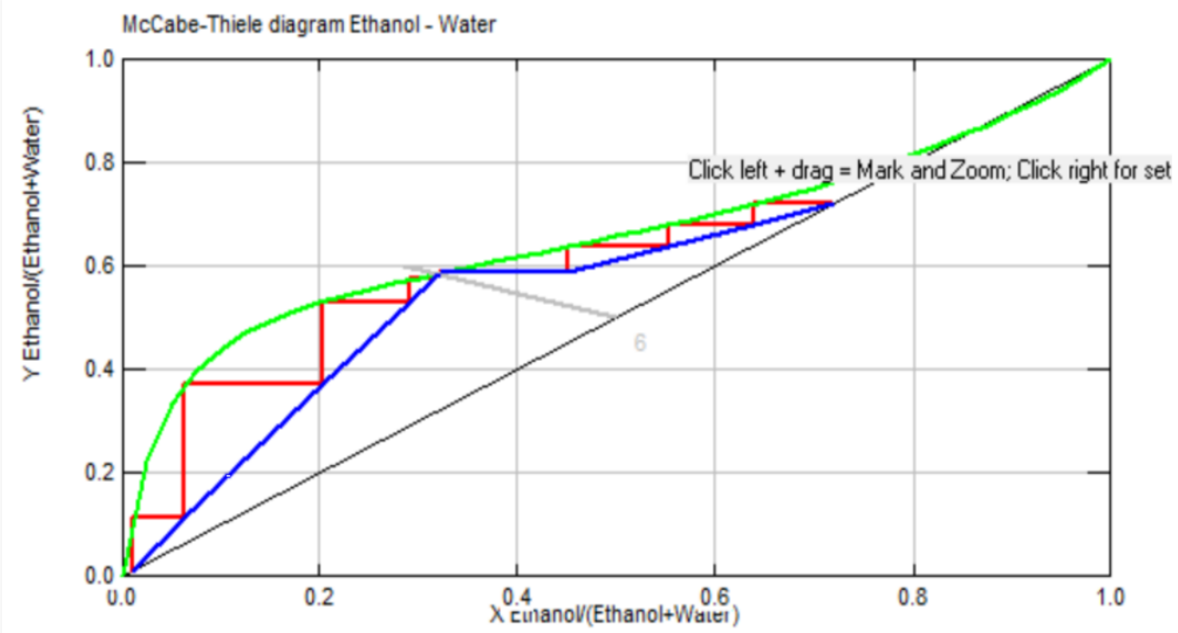
Ethanol & Water

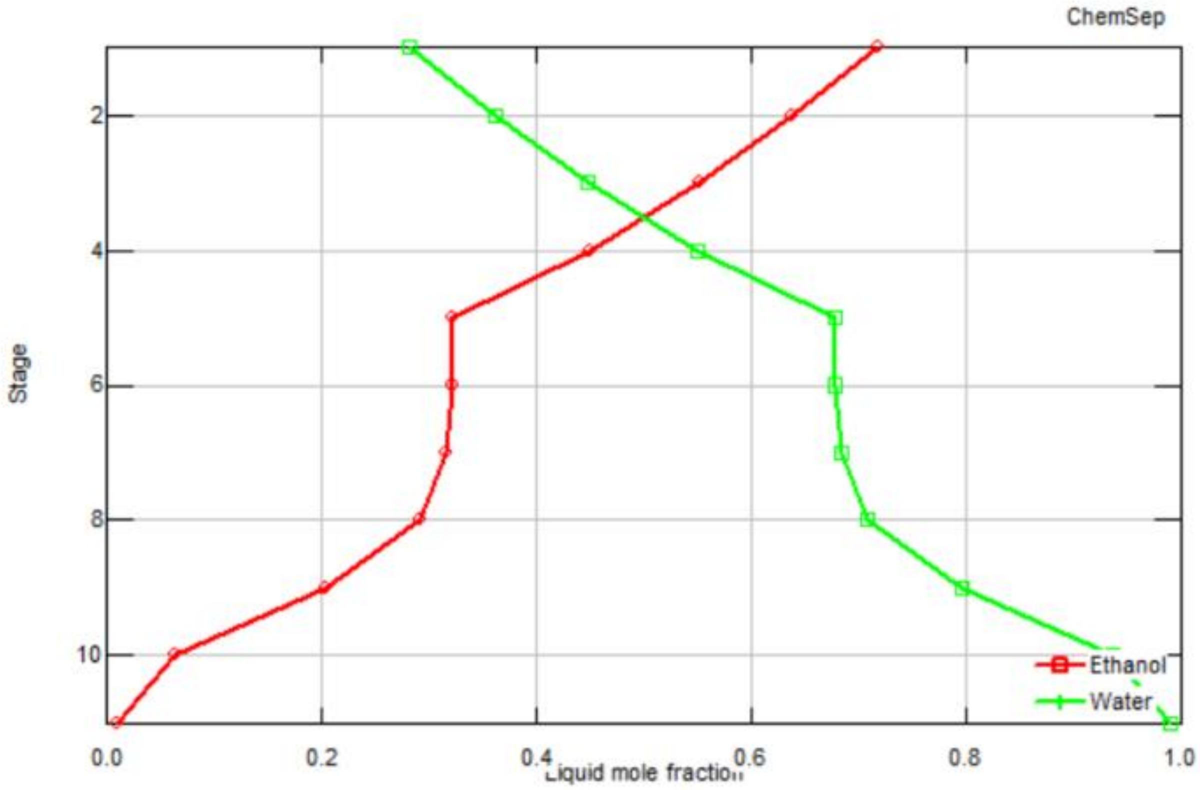
By putting the same parameters in Chem-Sep column as obtained from Shortcut column simulation one can achieve separation of Ethanol and Water with Ethanol being obtained as a top product (72%) and water as the bottom product (99%)



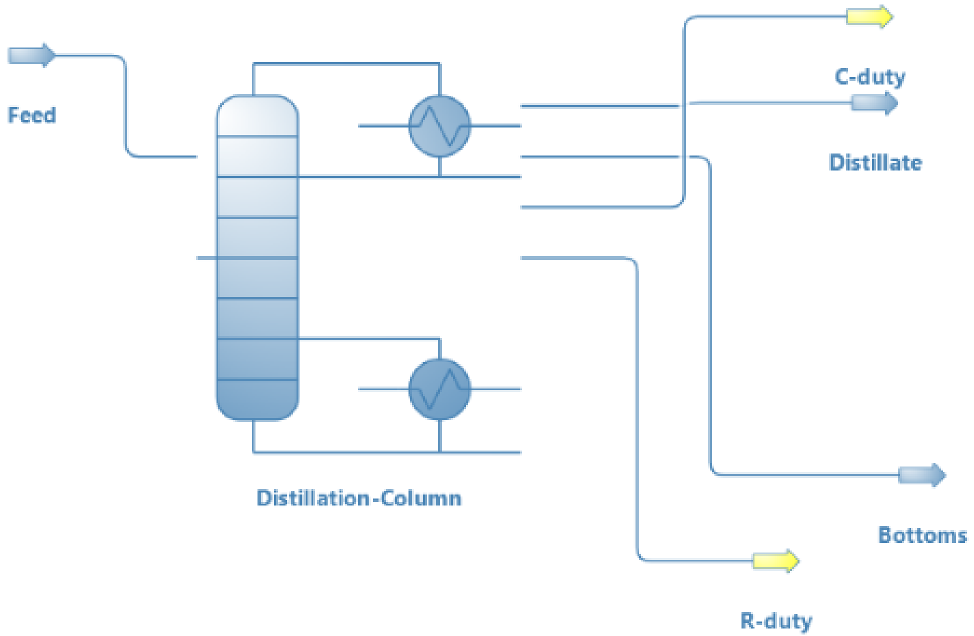
McCabe-Thiele Diagram

Stream	Feed1	V.Feed1	Top	Bottom
Stage	6	6	1	11
Pressure (N/m2)	50662.5	101325	101325	101325
Vapour fraction (-)	1.00000	1.00000	0.000000	0.000000
Temperature (K)	351.150	351.150	351.340	369.900
Enthalpy (J/kmol)	2.7343E+06		-3.567E+07	-3.835E+07
Entropy (J/kmol/K)	19874.6		-67515.3	-91694.7
Total molar flow (kmol/s)	0.0312092	0.0312092	0.0215585	0.00965071
Total mass flow (kg/s)	0.999989	0.999989	0.823424	0.176565
Vapour std.vol.flow (m3/s)	0.739352	0.739352		
Liquid std.vol.flow (m3/s)			0.00100729	1.7814E-04
Mole flows (kmol/s)				
Ethanol	0.0156046	0.0156046	0.0155081	9.6507E-05
Water	0.0156046	0.0156046	0.00605038	0.00955421
Mole fractions (-)				
Ethanol	0.500000	0.500000	0.719350	0.01000000
Water	0.500000	0.500000	0.280650	0.990000

Stream Results



Composition of Ethanol & Water at each stage in Chem-Sep Column



Chem-Sep Column Design

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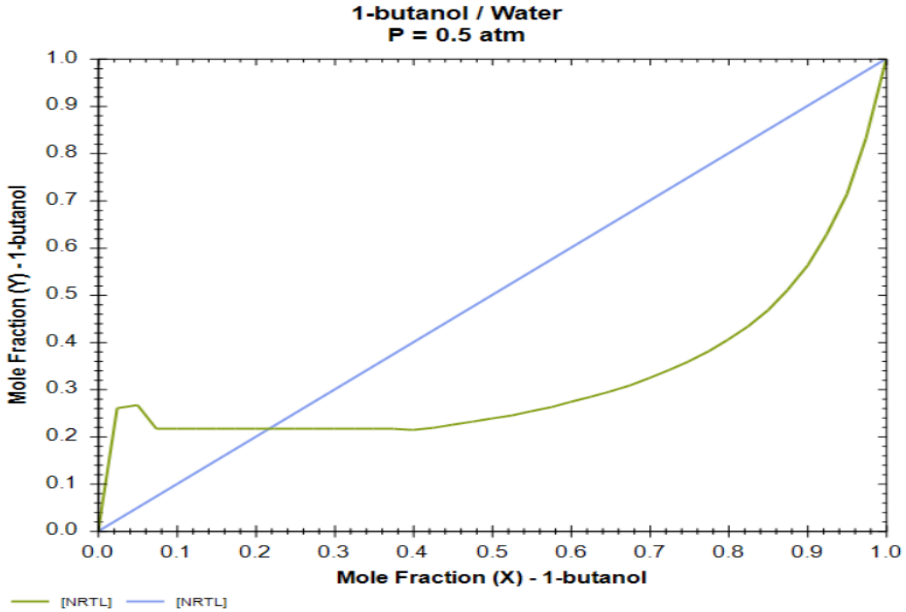
Butanol & Water

- The azeotropic composition is found when the
  mole fraction (X)-Butanol = mole fraction (Y)-Butanol
- This happens at x=0.21618 for Butanol & Water mixture



Shortcut Column

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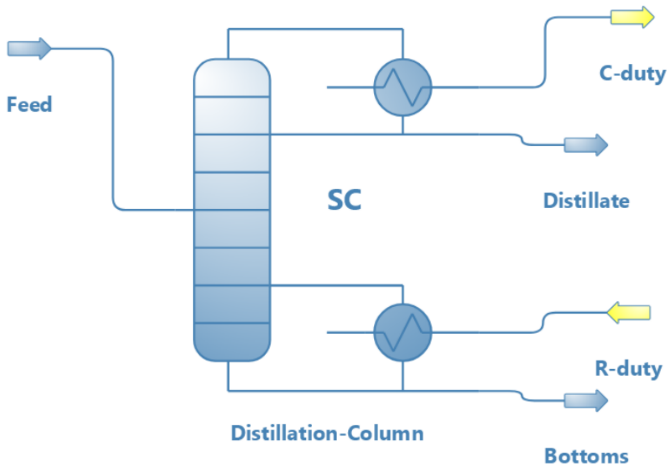
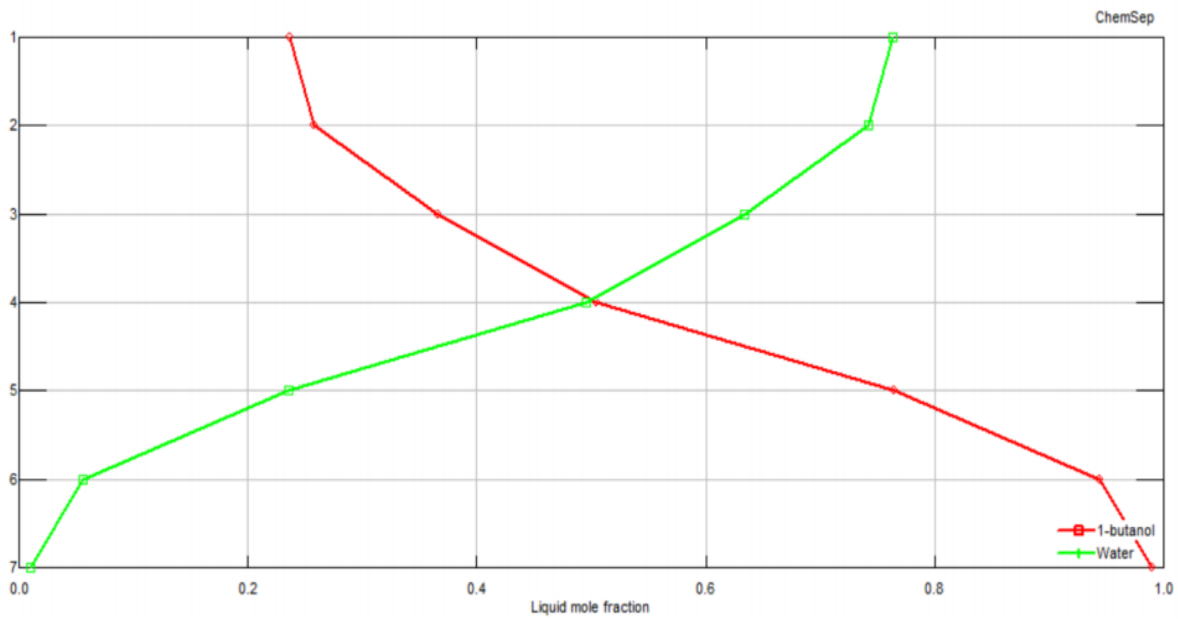


Property	Value	Units
Minimum Reflux Ratio	1.1749	
Minimum Number of Stages	3.82449	
Actual Number of Stages	6.89824	
Optimal Feed Stage	3.44912	
Stripping Liquid	78.1446	kmol/h
Rectify Liquid	78.1446	kmol/h
Stripping Vapor	39.0723	kmol/h
Rectify Vapor	117.217	kmol/h
Condenser Duty	1304.24	kW
Reboiler Duty	922.628	kW

Butanol & Water

By putting the same parameters in Chem-Sep column as obtained from Shortcut column simulation one can achieve separation of Butanol and Water with Water being obtained as a top product (76%) and butanol as the bottom product (99%)



Composition at each tray

Stream	Feed1	V.Feed1	L.Feed1	Top	Bottom
Stage	4	4	4	1	7
Pressure (N/m2)	50662.5	101325	101325	101325	101325
Vapour fraction (-)	0.461653	1.00000	0.000000	0.000000	0.000000
Temperature (K)	351.150	367.046	367.046	366.318	389.149
Enthalpy (J/kmol)	-1.992E+07			-3.765E+07	-3.214E+07
Entropy (J/kmol/K)	-24217.8			-71163.5	-43427.2
Total molar flow (kmol/s)	0.00119316	4.7966E-04	7.1349E-04	7.7658E-04	4.1657E-04
Total mass flow (kg/s)	0.0549669	0.0220972	0.0328697	0.0243232	0.0306437
Vapour std.vol.flow (m3/s)	0.0171630	0.0113634			
Liquid std.vol.flow (m3/s)	3.5657E-05		3.8950E-05	2.7481E-05	3.7654E-05
Mole flows (kmol/s)					
1-butanol	5.9657E-04	2.3983E-04	3.5674E-04	1.8416E-04	4.1241E-04
Water	5.9657E-04	2.3983E-04	3.5674E-04	5.9241E-04	4.1657E-06
Mole fractions (-)					
1-butanol	0.500000	0.500000	0.500000	0.237152	0.990000
Water	0.500000	0.500000	0.500000	0.762848	0.01000000
Mass flows (kg/s)					
1-butanol	0.0442196	0.0177767	0.0264429	0.0136509	0.0305687
Water	0.0107474	0.00432053	0.00642682	0.0106723	7.5046E-05
Mass fractions (-)					
1-butanol	0.804476	0.804476	0.804476	0.561229	0.997551
Water	0.195524	0.195524	0.195524	0.438771	0.00244899
Combined feed and product f					
Total molar	1.00000	1.00000	1.00000	0.650862	0.349138
Total mass	1.00000	1.00000	1.00000	0.442506	0.557494
Component molar					
1-butanol	1.00000	0.402009	0.597991	0.308707	0.691293
Water	1.00000	0.402009	0.597991	0.993017	0.00698276

Stream Results

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DIYA SINGHAL (190320)	DHANANJAY GUPTA (190280)
Wrote the MATLAB code for plotting vapor – liquid equilibrium curve of Acetone-Butanol mixture	Looked out for videos and resources for McCabe Thiele process simulation in MATLAB
Wrote the MATLAB code for getting the actual number of stages , Reflux ratio , Minimum Reflux Ratio	Wrote the MATLAB code for getting the minimum number of stages
Simulated the Shortcut column in DWSIM for acetone-butanol mixture and compiled all the results in a report	Simulated the xy - Equilibrium plot for azeotropic mixtures in DWSIM for Ethanol-Water and Butanol-Water mixture
Simulated the azeotropic mixtures in DWSIM using both Chemsep and Shortcut column for Ethanol-Water and Butanol-Water mixture	Simulated the azeotropic mixtures in DWSIM using only Shortcut column for Ethanol-Water and Butanol-Water mixture