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Simulation and Analysis of Ordinary Distillation of Close Boiling Hydrocarbons Using ASPEN HYSYS

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ABSTRACT: Effect of reflux ratio and number of stages on purity of ethylene in ethane-ethylene distillation using HYSYS process modeling software is presented in this paper. Results showed that purity of separation is directly proportional to reflux ratio as well as number of stages. A mixture of ethane and ethylene is pre flashed in a shortcut distillation column and parameters such as external reflux ratio, minimum reflux ratio, minimum number of stages, actual number of stages, optimal feed stage, condenser temperature, reboiler temperature and also condenser and reboiler duties are obtained. Then this feed is employed in a full scale distillation column to obtain the final results. Simulation shows that it is possible to achieve a purity as high as 99.2% using less than 100 plates, 84 plates to be precise. Optimum reflux ratio was also obtained. Results demonstrated that extra cost of using membrane systems to improve separation efficiencies can be avoided by using optimum reflux ratio in ordinary distillation.

KEYWORDS: Ethylene, ethane, ordinary distillation, HYSYS modeling, reflux ratio, number of stages.

1 INTRODUCTION

Distillation is a process in which components are separated based on the difference in their boiling temperatures and relative volatilities [1]. Separation is based on Raoult's law. When the boiling temperature difference is large, separation is easy and high purity is achieved. However, if a mixture contains close-boiling components, then the required purity is difficult to achieve. Numerous designs have been proposed to make separation of azeotropic mixtures more efficient. Many design parameters have been proposed [2] [3] [4].

The separation of ethylene from ethane by distillation is normally the final step in the production of ethylene. The critical temperature of ethylene is about 50°, therefore moderately low temperatures and moderately high pressures are typically used to provide optimum economic conditions. The optimum design can require thick walled and heavy pressure vessels which may be constructed of expensive alloy steels depending on the specific operating conditions. The required purity of ethylene usually exceeds 99.9%, and the economic level of recovery is approximately 99%. In addition, the relative volatility of ethylene to ethane 2 is moderately small ranging from about 1.13 for high pressure mixtures rich in ethylene to 2.34 for low pressure mixtures rich in ethane. The relatively high purity and recovery and relatively low relative volatility dictate a large distillation column with more than one hundred trays and a large diameter for world scale production levels of over a billion pounds per year of ethylene. The installed capital cost for a unit-of this type and size can exceed twenty million dollars, and utility costs can exceed one million dollars per year. New approaches for separating ethane/ethane mixture have been proposed like using MOF membrane ZIF-8 [5] and adsorption on the metal-organic framework ZIF-7 through a gate-opening mechanism [6]. Combination of membrane and distillation processes to form a hybrid separation system for separating ethane and ethene have also been proposed [7]. Separation by using molecular sieves [8] have also been reported as well as adsorption on Na-ETS-10 [9]. These techniques are costly and there is a dire need to find alternative economic designs.

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Boiling point of ethane is -88°C while that of ethylene is -103°C. Experiments were conducted at pressures of 200, 1000, and 2000 KPa. The change in purity of ethylene was observed for each case. Equilibrium stage analysis was also conducted to determine how the number of trays affects purity.

2 SIMULATION

A characteristic binary distillation is shown in fig 1.

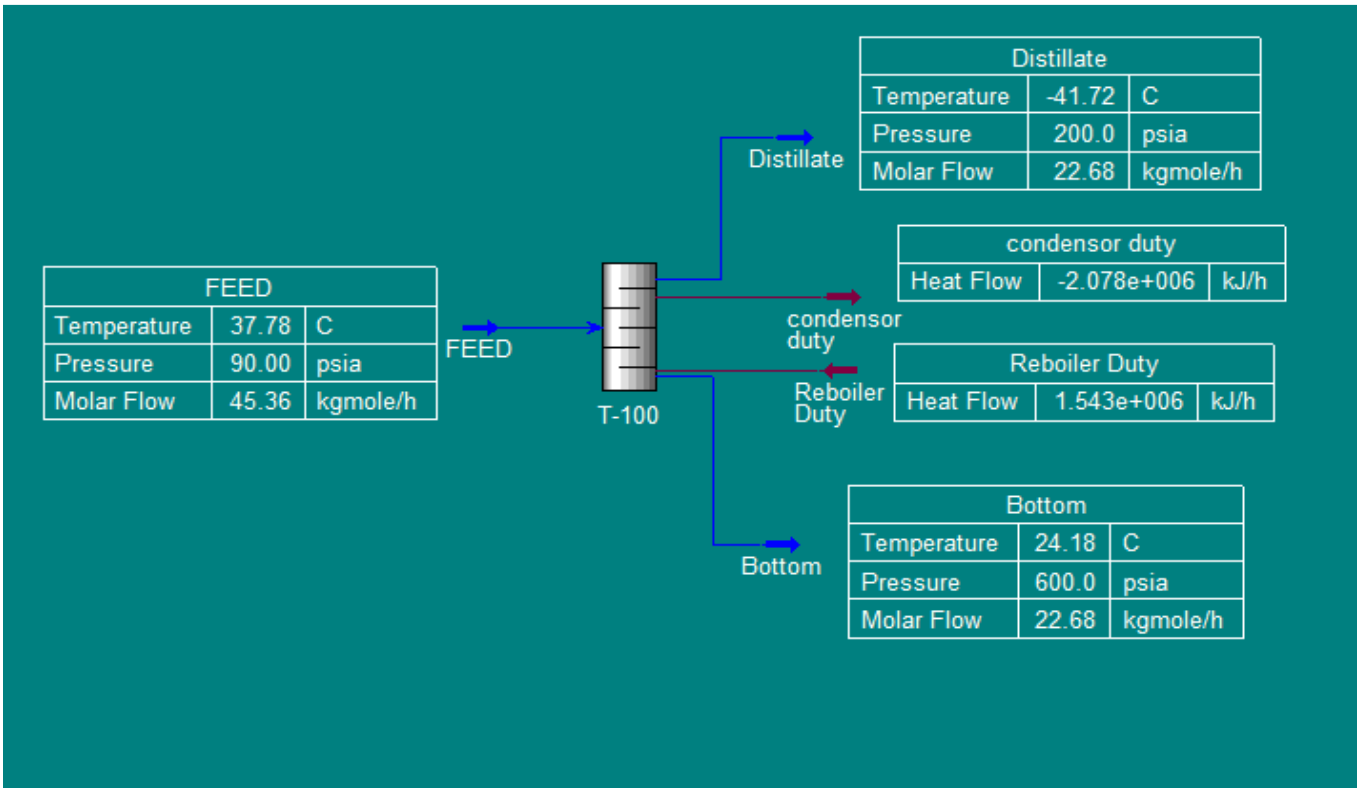

Figure 1: Shortcut distillation column

Heavy key in distillate is ethane with 0.001 mole fraction and light key in bottom is ethene with 0.0001 mole fraction. A shortcut distillation column is employed to find minimum reflux ratio, external reflux ratio, minimum number of trays, actual number of trays, optimal feed stage, condenser and reboiler temperature as well as condenser and reboiler duties. Column functions at reflux-drum pressure of 200 Psia. For insignificant pressure drop across the condenser and pressure drop of 0.1psi/tray for the vapor as it flows up the column, the pressure in the reboiler is 600 Psia. In this pressure range Ethane and Ethylene form near ideal mixtures with a relative volatility, a (1.19) at the bottom tray to 1.47 at the top tray as determined from Raoult's law. Performance of distillation column is shown in fig 2.

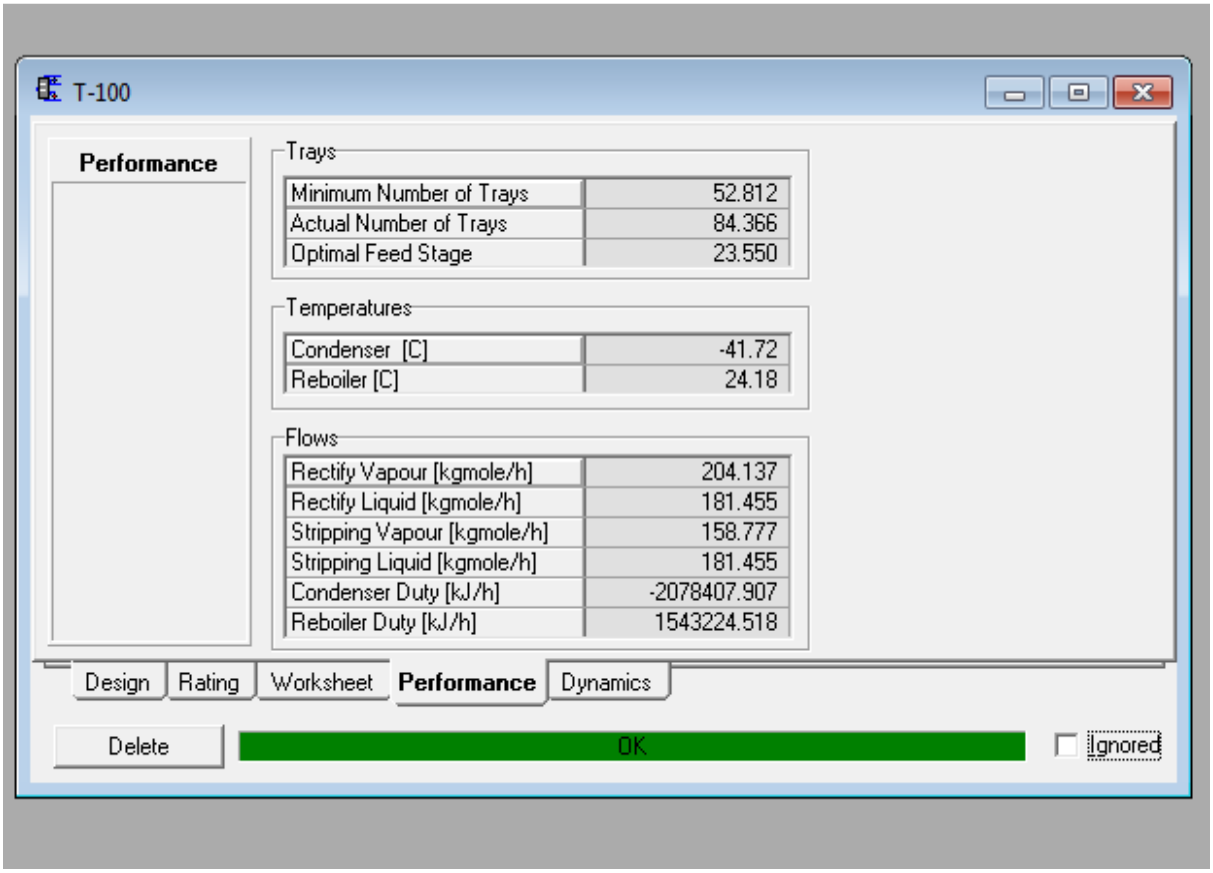

Figure 2: Performance of shortcut distillation column

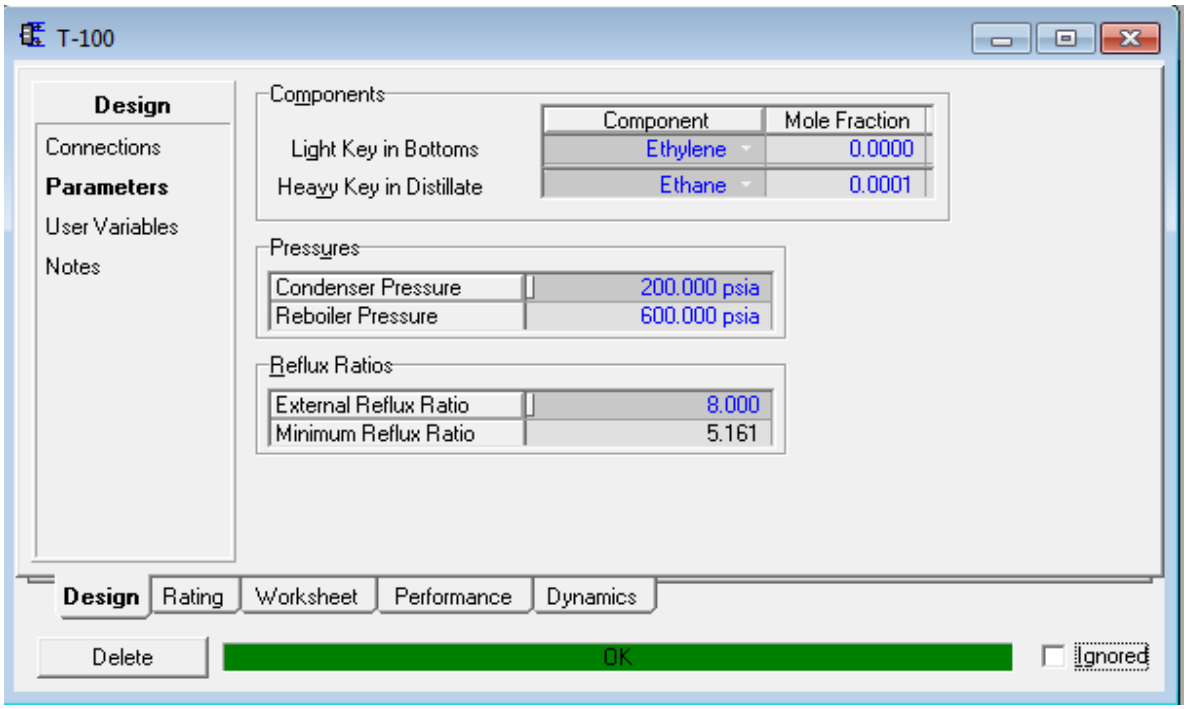

Figure 3: Design parameters of shortcut distillation column

Design parameters of distillation column are shown in fig. 3.

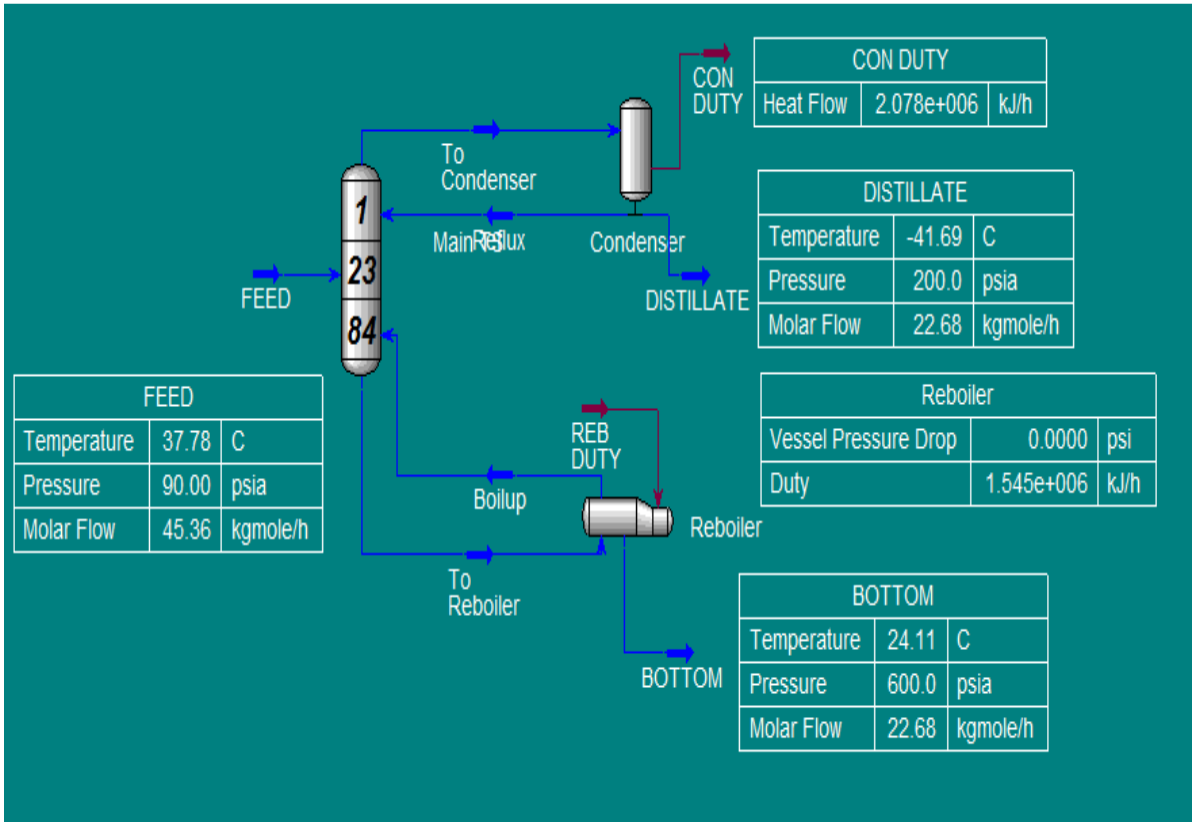

Figure 4: Distillation column for separation of ethane and ethylene

Now feed is entered in to the distillation column to separate the feed into a liquid distillate having 99.9 mol% of ethene and a liquid bottom product containing 99.9 mol% of ethane. All the parameters and flow rates are shown in fig 4.

3 RESULTS & DISCUSSIONS

Graph between temperature and tray position is shown in fig 5. It indicates that initially reflux from the condenser is at a very low temperature of -41^0 while the vapors from the bottom of the column are at high temperature. The temperature of the liquid increases due to the heat transfer between vapor-liquid interaction on the tray as the liquid moves from top to bottom tray. So the temperature of liquid increases as it moves to next plate from top to bottom of the column. The graph between pressure (Psia) and tray position is shown in fig 6. It indicates the steady state increase in pressure. As the pressure and temperature are directly proportional to each other, so as temperature in the column increases from top to bottom, pressure also increases from top to bottom.

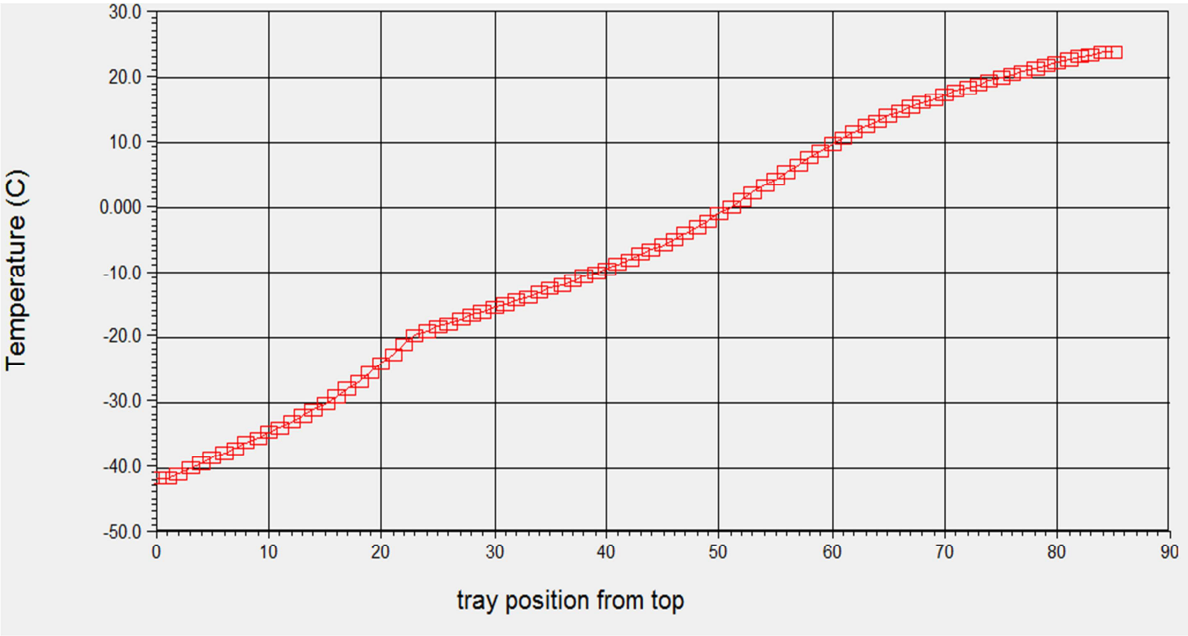

Figure 5: Temperature vs tray position from top

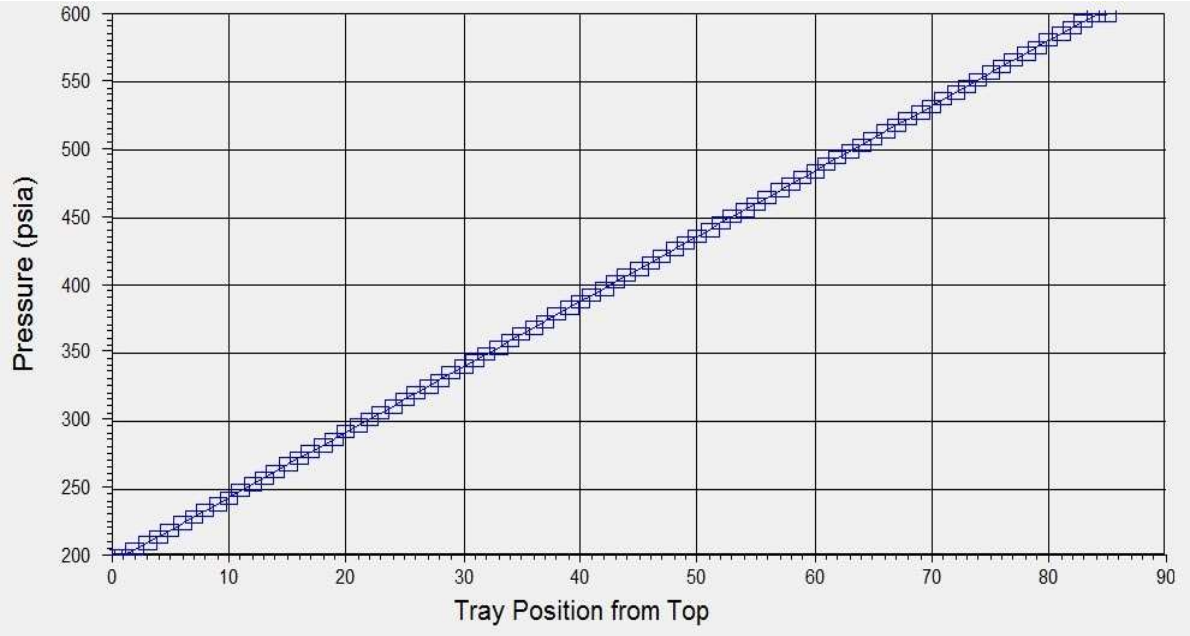

Figure 6: Pressure vs tray position from top

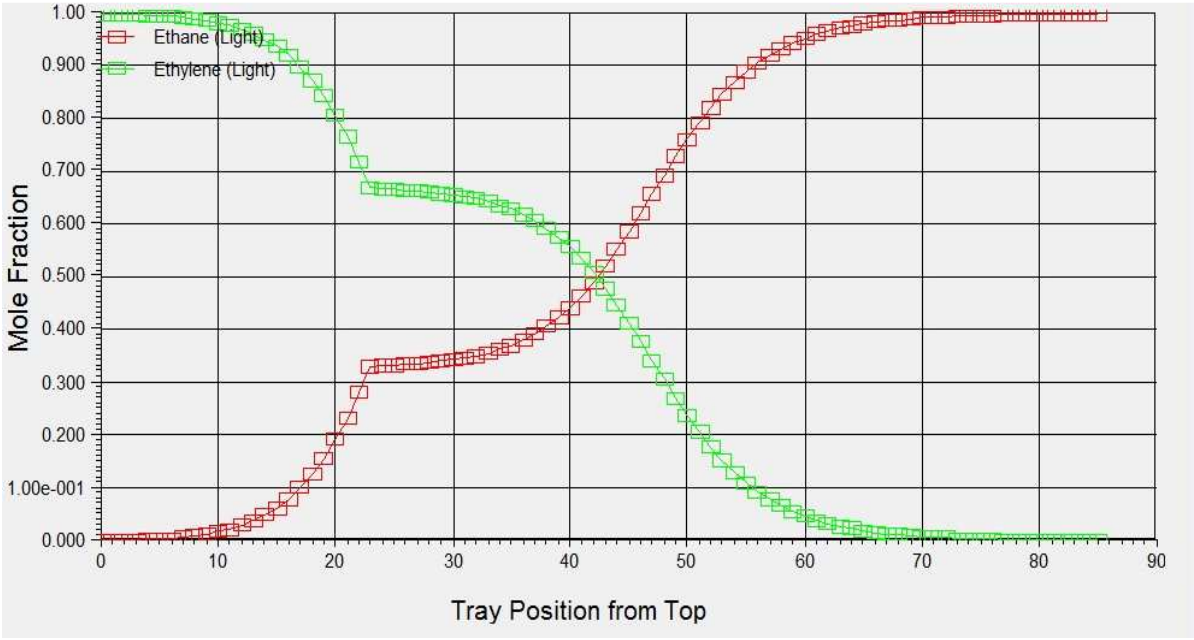

Figure 7: Mole fraction vs tray position from top

The graph composition vs. tray position shown in fig. 7 indicates that at the top of the column, mole fraction of lighter component ethene is close to one while the mole fraction of heavier component ethane is almost zero. The concentration of ethene decreases as it moves from top to bottom while the concentration of ethane increases because ethene is a more volatile component. So its mole fraction should be maximum at the top rather than at the bottom of the column due to its high relative volatility and vapor pressure. Hence the mole fraction of ethane is maximum at the bottom of the column.

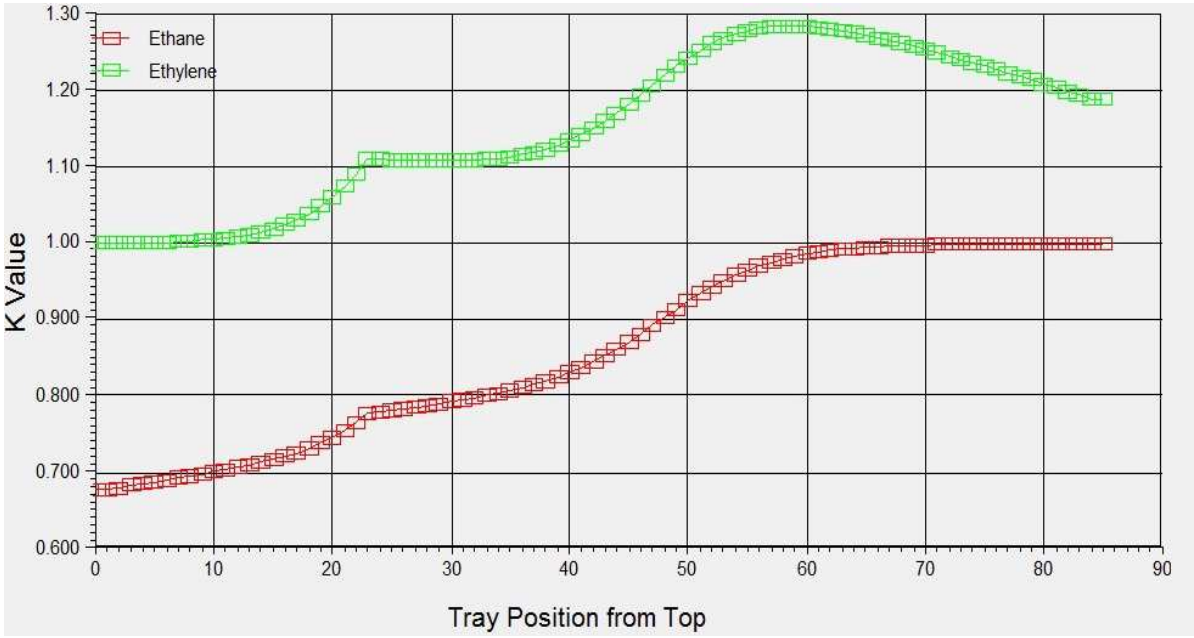

Figure 8: K values vs tray position from top

As more volatile component have higher vapor pressure & lower boiling point than the less volatile component, so k-value is larger for more volatile component than the less volatile components. Fig. 8 indicates that as the feed enters the optimal feed stage where the internal temperature of the liquid traffic is almost similar to the feed entering the column, so there is a negligible temperature difference between vapors and liquid and hence k-value remains same for a specific period.

After that it increases gradually and reaches a point of minimum number of trays or total reflux ratio where it attains the equilibrium. After that it decreases slowly. While the k-value of ethane after the equilibrium point remains constant.

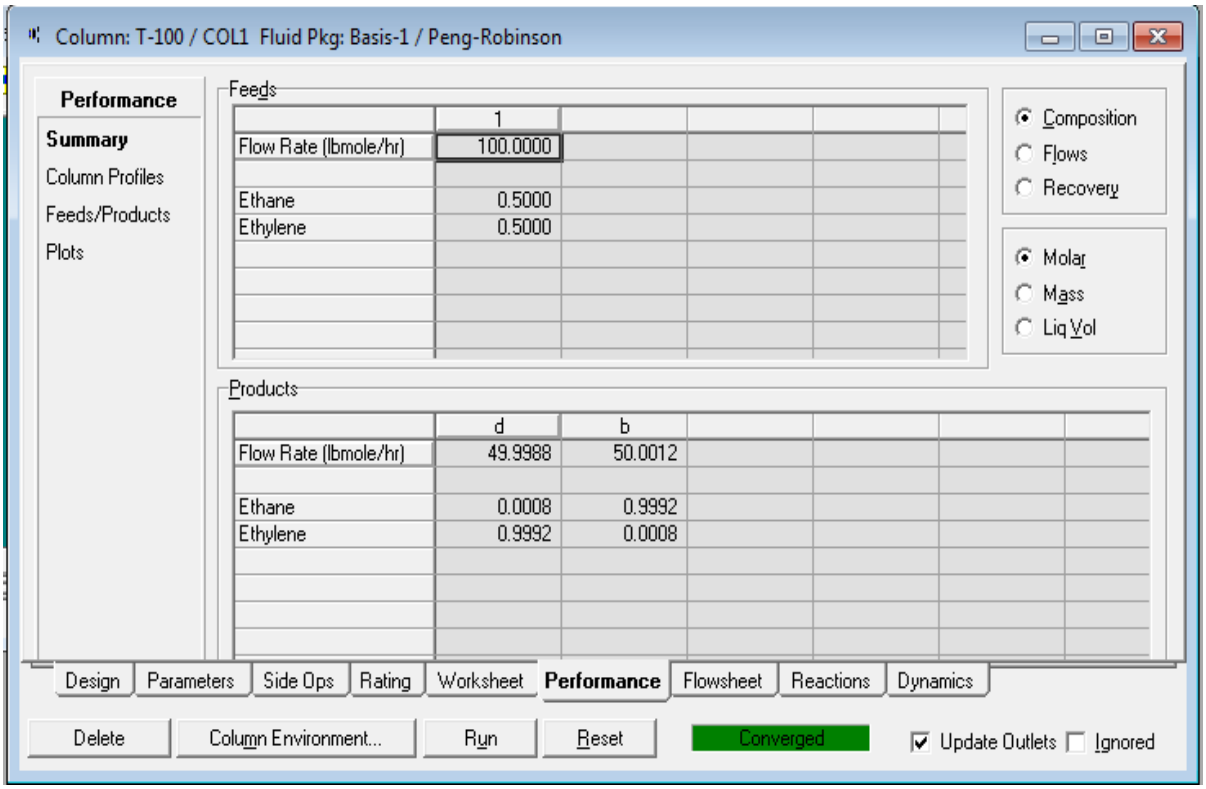

Figure 9: Performance of distillation column

3.1 ANALYSIS OF REFLUX RATIO

In order to obtain higher product purity of about 99.92% with increase in pressure; a higher reflux ratio is required. This is because at lower pressure relative volatility is higher and more liquid is refluxed to maintain higher purity as pressure increases. So by decreasing the pressure, the lighter component becomes more volatile and hence separation becomes easier.

4 NUMBER OF STAGES

In order to maintain the product purity to specific level, number of stages also important for specific higher purity. At specific reflux ratio, a large number of stages are required.

A tray comparison is analyzed in both cases. Table shows that with decreased pressure and increased number of trays, the product purity is increased. This is due to that each additional tray works as an additional equilibrium contractor permitting for extra mass transfer to occur.

Table 1: Tray analysis of distillation column

	Distillate		Bottom	
Trays	Ethene Purity	Ethane purity	Ethane Purity	Ethene Purity
84	99.92	.0008	99.92	.0008
80	99.90	.001	99.90	.001
75	99.87	.0013	99.87	.0013
70	99.82	.0018	99.82	.0018
65	99.78	.0022	99.78	.0022
60	99.67	.0033	99.67	.0033
55	99.55	.0045	99.54	.0046
50	99.36	.0064	99.35	.0065
45	98.98	.0102	98.97	.0103
40	98.47	.0153	98.46	.0154
35	97.73	.0227	97.72	.0228
30	96.33	.0367	96.32	.0368
25	94.15	.0585	94.14	.0586
20	91.34	.0866	91.33	.0867
15	86.45	.1355	86.44	.1356
10	79.21	.2079	79.20	.2080
5	68.47	.3153	68.46	.3154

Table 1 shows the tray analysis of distillation column. It can be seen that a purity of 99.92% purity is achieved by using 84 trays which is better than the results reported in earlier work.

5 CONCLUSIONS

With developed HYSYS process software an analysis is conceded for an ordinary distillation system. Result shows that by changing the reflux ratio, product purity also changes. It also shows that separation becomes difficult as the pressure increase. So at lower pressure relative volatility is higher and more liquid is refluxed to maintain higher purity as pressure increased. So decreasing the pressure makes the lighter component more volatile and hence the separation becomes easier. It also shows that number of trays also plays an important role for specific higher product purity. At specific reflux ratio; a large number of stages are required. With increased number of trays product purity is increased.

This is due to that each additional tray works as an additional equilibrium contractor permitting for extra mass transfer to occur. The extra mass transfer occurs with more number of stages which leads to higher product purity. For moderately low volatility mixture, as is the case with ethane/ethylene basic diffusion membrane system is not economically feasible due to slow transfer rate and low selectively in separation.

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