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Comparative Study of Conventional Distillation Column and Divided Wall Distillation Column By using Simulation

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ABSTRACT:
The Dividing Wall Distillation column system is promising over conventional distillation columns for separating ternary and multicomponent mixtures. In this work efficiency of Dividing Wall Distillation columns over Conventional Distillation columns for ternary mixtures by simulation was studied. The area of work is on energy-saving advances. The Comparative study was carried out by using Aspen Plus. In this study effect of distillate rate, Feed stage, and Side draw stage for separating benzene, toluene, and xylene were investigated for the conventional distillation column as well as the divided wall distillation column. The influences of several variables such as vapor split ratio, liquid split ratio on product composition, reboiler and condenser duty were investigated.

Keywords: Aspen Plus, Aspen Simulation, Divided Wall Distillation Column, Vapor split, Liquid split

I. INTRODUCTION

In petrochemical and other process industries, distillation columns are widely applied as an important separation unit. Adsorption and Extraction need further processing. Distillation is carried out sequentially for the separation of a multicomponent mixtures. Many distillation columns are required in the process industry for the separation of mixtures. Distillation columns have a wide range of flexibility and a wide range of applications. Energy consumption is a major factor in distillation columns. Many people are concentrated on energy-efficient distillation columns. For energy saving, optimization is one of the ways for single distillation column or distillation sequences. At least one distillation column is required during Crude oil to final production. The distillation column operating cost is greater than half of the plant operating cost. More than two components are involved in many distillation columns. For pure separation, we have required at least Z-1 distillation column, where Z is the number of components. Divided wall columns have more benefits than conventional distillation columns. Divided wall distillation column reduces operating as well as fixed costs over the conventional distillation column. Internal and vertical partition walls are present in the distillation column which indicates two conventional distillation columns in one shell. Dividing wall column is a good alternative to conventional distillation column. Divided wall columns can save up to 30% of plant operating cost over the conventional distillation column.

II. MATERIAL AND METHODS

Simulation was carried out by using aspen plus software. The specifications were used for the simulation of conventional distillation column as well as dividing wall column given as follows.

Table 2.1: Specifications for simulation

Components	Mole	Feed conditions
Benzene Toluene Xylene	0.3 0.3 0.4	3600 Kmol/hr., 1.7 atm, 100°C, Saturated liquid.

2.1 Simulation of Conventional Distillation Column:

The DSTWU model was used for the simulation of Conventional Distillation Column (CDC). DSTWU model estimates total number of stages by giving the reflux ratio, the pressure of the condenser and reboiler and adjusting the light key and heavy key recoveries at appropriate product composition. Radfrac model was used for rigorous simulation of the conventional distillation.

2.1.1. Shortcut Simulation of Conventional Distillation Column:

DSTWU model was used for shortcut simulation. Two DSTWU blocks were used in direct sequence for shortcut simulation. Shortcut design calculations are carried out by using Winn-Underwood-Gilliland. Recoveries of light keys and heavy keys were specified. Reflux Ratio, number of theoretical stages, optimum feed stage location and duties of the Condenser and reboiler are estimated by DSTWU.

Fig. 2.1 shows shortcut simulation of conventional distillation column was done by using two DSTWU models.

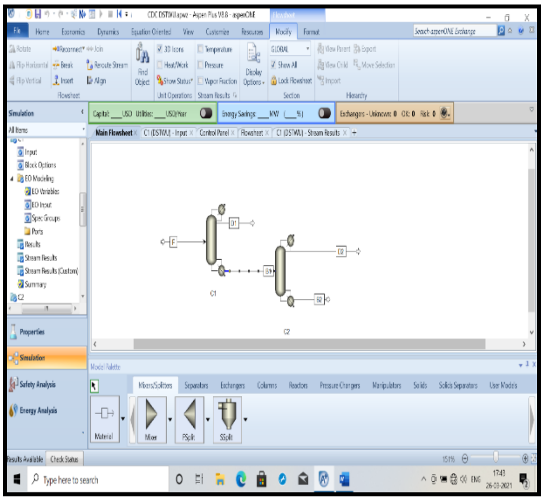


Fig. 2.1: Flowsheet of shortcut simulation CDC

2.1.2 Rigorous Simulation of Conventional Distillation column:

Radfrac model was used for rigorous simulation of the conventional distillation. In the rigorous simulation for the first and second columns by adjusting the reflux ratio and distillate rate, desired product compositions were obtained. Fig. 2.2 shows two Radfrac models used for rigorous simulation of conventional distillation column.

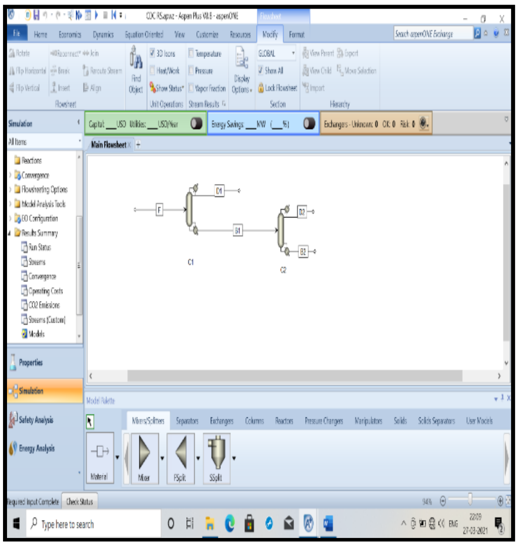


Fig. 2.2: Flowsheet of rigorous simulation CDC

2.2 Simulation of Divided Wall distillation Column:

Simulation of Divided wall distillation column (DWC) requires some parameters, these parameters were obtained from shortcut simulation of DWC.

2.2.1 Shortcut Simulation of Divided Wall Distillation Column:

DSTWU model was used for shortcut simulation. Three DSTWU blocks were used in DWC for shortcut simulation.

Shortcut design calculations were carried out by using Winn-Underwood-Gilliland. Recoveries of light keys and heavy keys were specified. Reflux Ratio, number of theoretical stages, optimum feed stage location, and duties of the Condenser and reboiler were estimated by DSTWU.

Fig. 2.3 shows a shortcut simulation of dividing wall distillation columns done by using three DSTWU models.

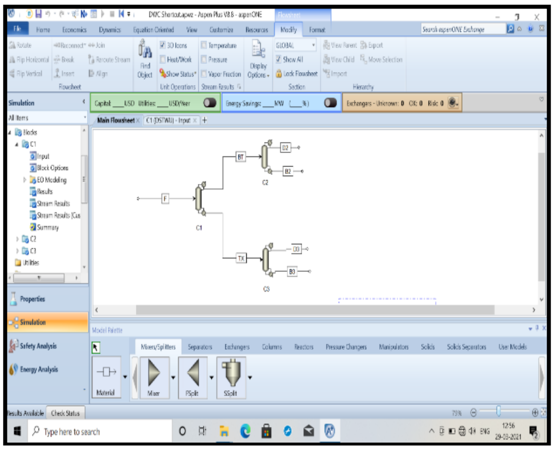


Fig. 2.3: Flowsheet of shortcut simulation of DWC

2.2.2 Rigorous Simulation of Divided Wall Distillation Column:

The stripper, absorbers, and rectifier as shown in Fig. 2.4 consist of a steady-state Radfrac model. The stripper, rectifier, and absorber blocks are named “STRIPPER,” “RECTIFR”, “ABSRBR1”, and “ABSRBR2” respectively. Two splitters were used in the model these are “LIQSPLIT” and “VAPSPLIT” respectively.

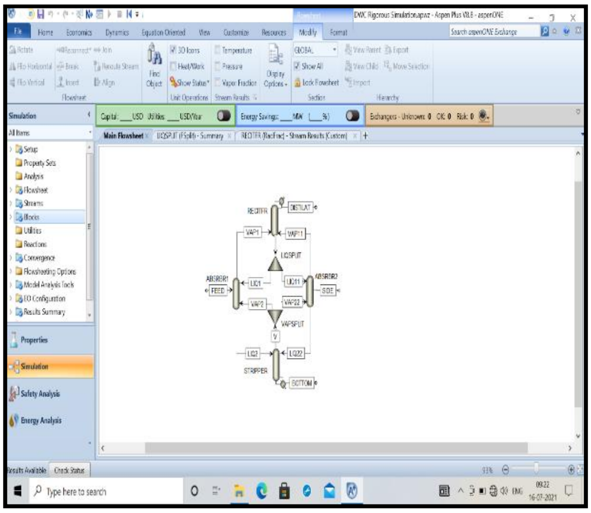


Fig. 2.4 Flowsheet of rigorous simulation DWC

III. RESULT AND DISCUSSION:

3.1 The Steady State Analysis of CDC:

In the steady state simulation of conventional distillation columns (CDC), two Radfrac columns were used in series. We obtain the following results:

Table 3.1: Operating parameters for CDC

	Parameter	Specifications
C1	Number of stages	24
	Feed stage location	11
	Reflux ratio	3.5
	Distillate flow rate	1080 Kmol/hr.
	Reboiler duty	45977.76 Kw
	Condenser duty	41060.93 Kw
C2	Number of stages	38
	Feed stage location	19
	Reflux ratio	3.5
	Distillate flow rate	1080 Kmol/hr.
	Reboiler duty	44561.36 Kw
	Condenser duty	44827.5 Kw
	Product Composition	Benzene: 99.85% Toluene: 99.74% Xylene: 99.84 %
	Total heat duty	176427.55kW

Running the conventional distillation simulator, we obtain 99.85% benzene from the overhead of the first column,99.74 % toluene and 99.84% Xylene from the top and bottom of the second column respectively. The reflux ratio was 3.5 for both columns and the distillate rate for the first and second columns was 1080 Kmol/hr. The feed stages for the first and second columns were 11th and 19th respectively. The duties of the reboiler for the first and second columns were 45977.76 Kw and 44561.36 Kw respectively. The duties of the condenser for the first and second columns were 41060.93 Kw and 44827.5 Kw respectively. In the first and second columns the effect of reflux ratio, distillate rate, feed stage on product composition, reboiler duty and condenser duty was seen by sensitivity analysis, The graphs of sensitivity analysis were given below.

3.1.1 Impact of Reflux Ratio on product composition, reboiler and condenser duty:

The optimum reflux ratio is 3.5. The corresponding reboiler and condenser duties are 45978.01Kw and 41061.24 kW respectively. The effect of the reflux ratio on reboiler, condenser duties and product composition are shown in the following Fig 3.1 and Fig 3.2 respectively. The corresponding benzene composition is 99.85%.

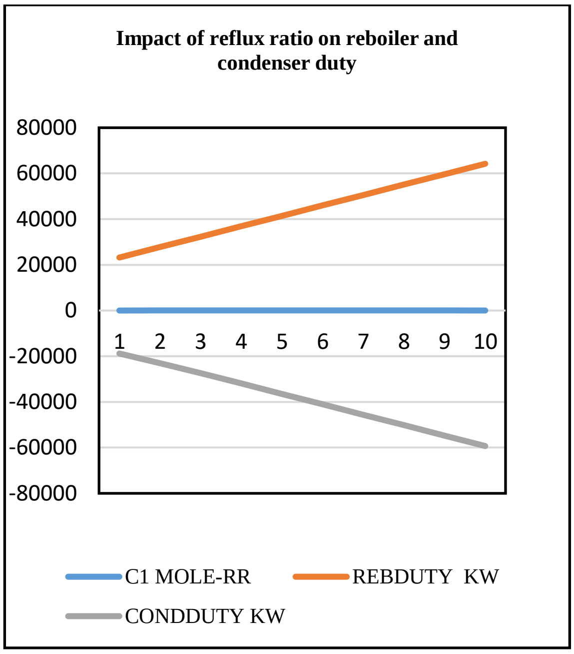


Fig 3.1: Impact of reflux ratio on reboiler and condenser duty

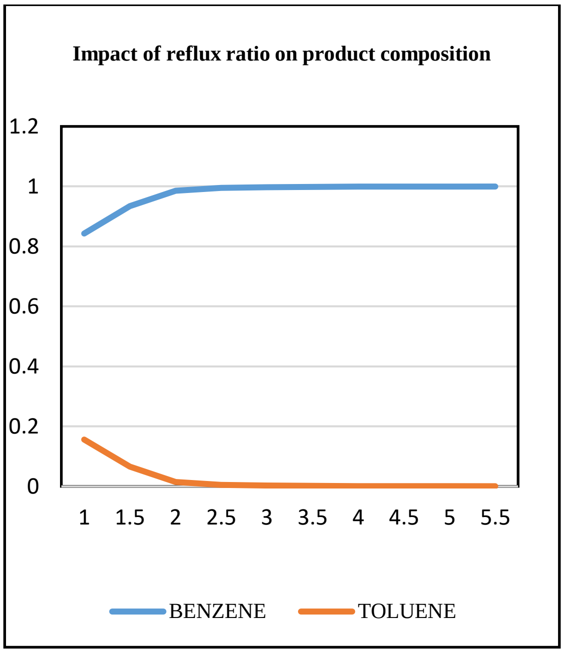


Fig 3.2: Impact of reflux ratio on product composition

3.1.2 Impact of Distillate rate on product composition, reboiler and condenser duty:

The optimum distillate rate is 1080 Kmol/hr. The corresponding reboiler and condenser duties are 45977.93 Kw and 41061.14 Kw respectively. The effect of the distillate rate on reboiler, condenser duties and product composition are shown in the following Fig 3.3 and Fig 3.4 respectively. The corresponding benzene compositionis 99.85%.

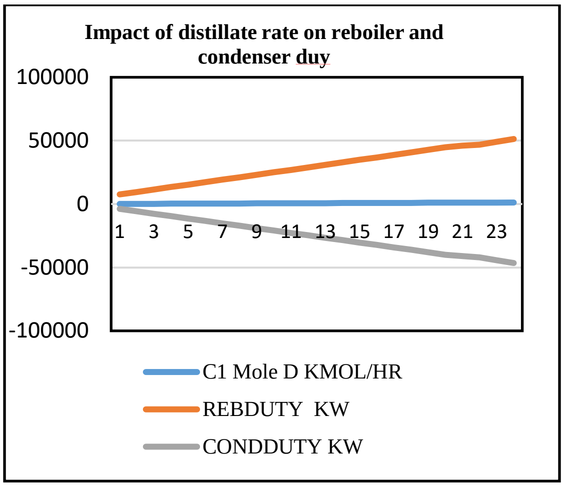


Fig 3.3: Impact of distillate rate on reboiler and condenser duty

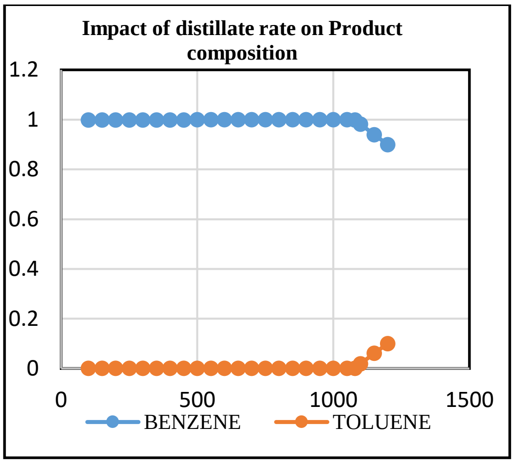


Fig 3.4: Impact of distillate rate on product composition

3.1.3 Impact of Feed stage on product composition, reboiler and condenser duty:

The optimum Feed stage location is 11. The corresponding reboiler and condenser duties are 45977.95Kw and 41061.16 kW respectively. The effect of the feed stage on reboiler, condenser duties and product composition are shown in the following Fig 3.5 and Fig 3.6 respectively. The corresponding benzene composition is 99.85%.

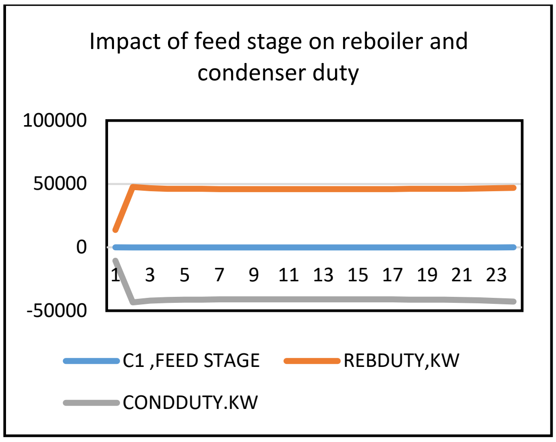


Fig 3.5: Impact of feed stage on reboiler and condenser duty

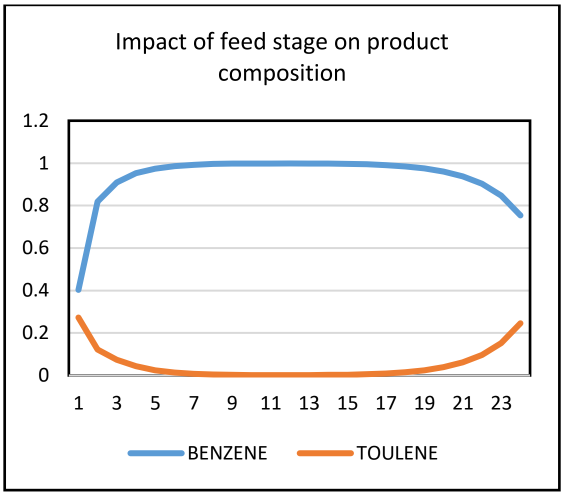


Fig 3.6: Impact of feed stage on product composition

3.1.4 Impact of reflux ratio on product composition, reboiler and condenser duty:

The optimum reflux ratio is 3.5. The corresponding reboiler and condenser duties are 44561.38 Kw and 44826.86 Kw respectively. The effect of the reflux ratio on reboiler, condenser duties and product composition are shown in the following Fig 3.7 and Fig 3.8 respectively. The corresponding toluene composition is 99.74%.

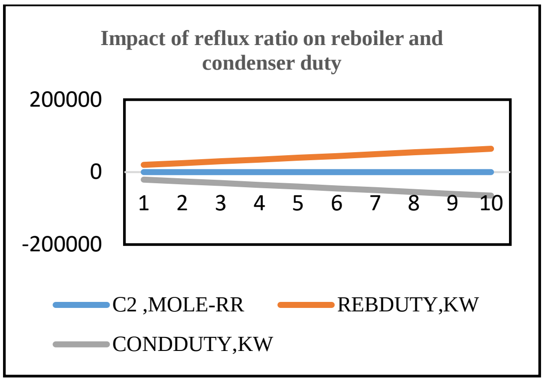


Fig 3.7: Impact of reflux ratio on reboiler and condenser duty

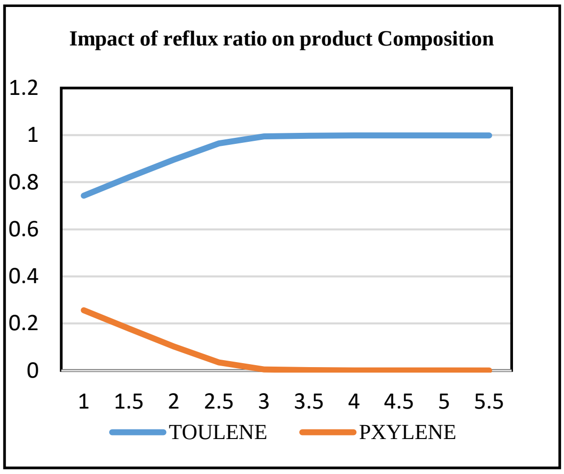


Fig 3.8: Impact of reflux ratio on Product composition

3.1.5 Impact of distillate rate on product composition, reboiler and condenser duty:

The optimum distillate rate is 1080 Kmol/hr. The corresponding reboiler and condenser duties are 44561.44Kw and 44826.94 kW respectively. The effect of the distillate rate on reboiler, condenser duties and product composition are shown in the following Fig 3.9 and Fig 3.10 respectively. The corresponding toluene composition is 99.74%

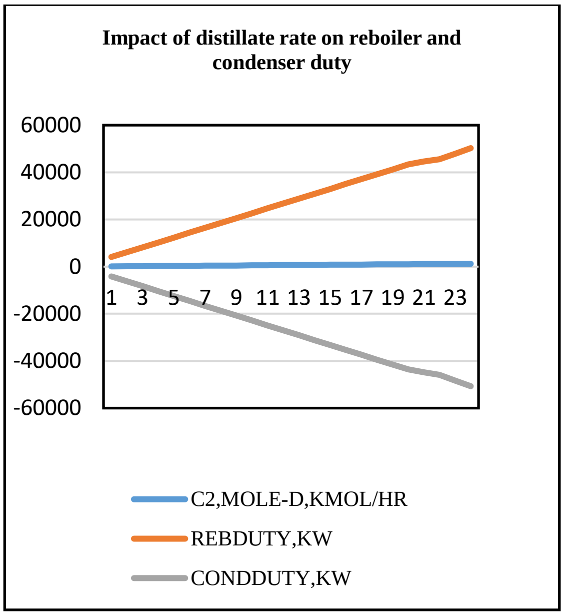


Fig 3.9: Impact of distillate rate on reboiler and condenser duty

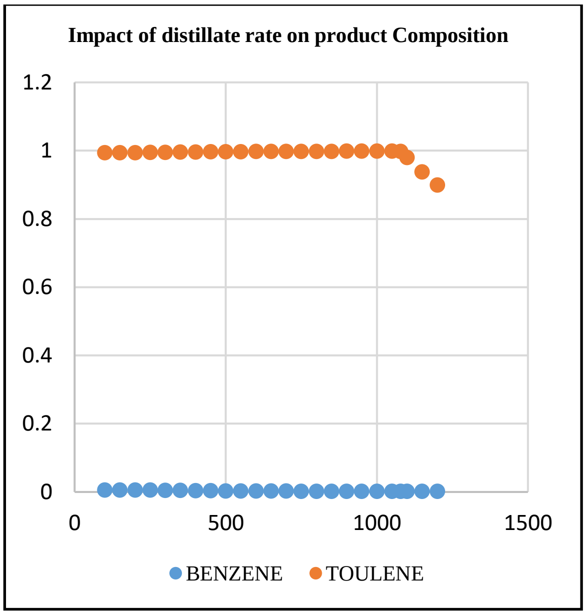
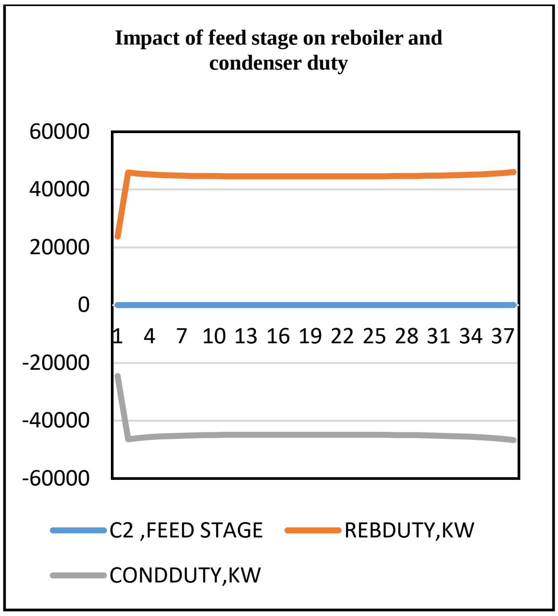


Fig 3.10 Impact of distillate rate on product composition

3.1.6 Impact of feed stage on product composition, reboiler and condenser duty:

The optimum Feed stage location is 19. The corresponding reboiler and condenser duties are 44561.31Kw and 44826.75 kW respectively. The effect of the feed stage on reboiler, condenser duties and product composition are shown in the following Fig 3.11 and Fig 3.12 respectively. The corresponding toluene composition is 99.74%.



3.11: Impact of feed stage on reboiler and condenser duty

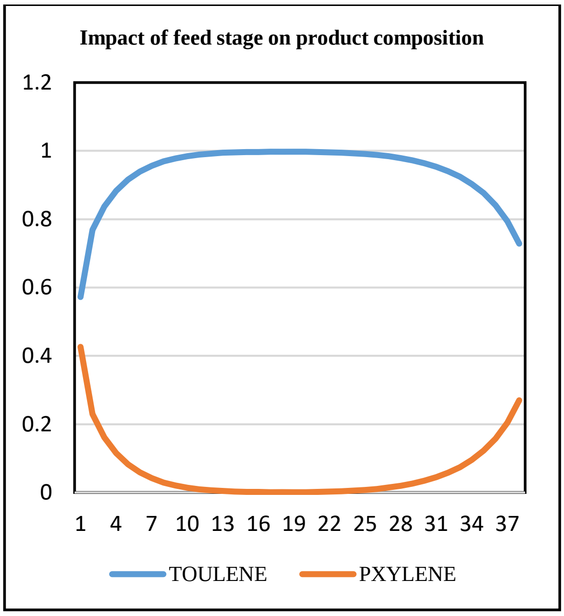


Fig 3.12: Impact of feed stage on Product composition

3.2 The Steady State Analysis of DWC:

Running the dividing wall column simulator, we obtain the following results:

Table 3.2: Operating parameters for DWC

Parameter	Specifications
Number of stages	66
ABSRBR1 Feed stage	17
ABSRBR2 Side draw stage	17
Side draw flow rate	1080 Kmol/hr.
Liquid split	0.6
Reflux ratio	4.61
Bottom rate	1442 Kmol/hr.
Vapor split	0.6
Reboiler duty	55632 Kw
Condenser duty	50985.6 Kw
Product Composition	Benzene: 99.99 % Toluene: 99.43 % Xylene: 99.57 %
Total heat duty	106617.6 kW

We obtain 99.99 % benzene from the top, 99.43% toluene from the middle stream, and 99.57 % xylene from the bottom of the dividing wall column. The reflux ratio and bottom rate are 4.61 and 1442 Kmol/hr. respectively. The values of reboiler and condenser duties are 55632Kw and 50985.6 kW respectively. The feed stage location in ABSRBR1 and the side draw stage location in ABSRBR2 is the 17th stage respectively. The flow of the side stream is 1080 Kmol/hr. The value of liquid split and vapor split is 0.6. The effect of reflux ratio, bottom rate, vapor split, liquid split

on product composition, reboiler duty and condenser duty were studied by using sensitivity analysis. The graphs of sensitivity analysis are given below.

3.2.1 Impact of Reflux Ratio on product composition, reboiler and condenser duty:

The reflux ratio is a very important factor. For a reflux ratio of 3, only benzene composition is more than 90%, and the rest of the two products are less than 90%. On increasing the reflux ratio, the purity of all the components increases up to the reflux ratio of 4.61, beyond which the composition does not improve. Therefore, a reflux ratio of 4.61 is the optimum. The corresponding reboiler and condenser duties are 55632Kw and 50985.6Kw respectively. The effect of the reflux ratio on reboiler, condenser duties and product composition are shown in the following Fig 3.13 and Fig 3.14 respectively.

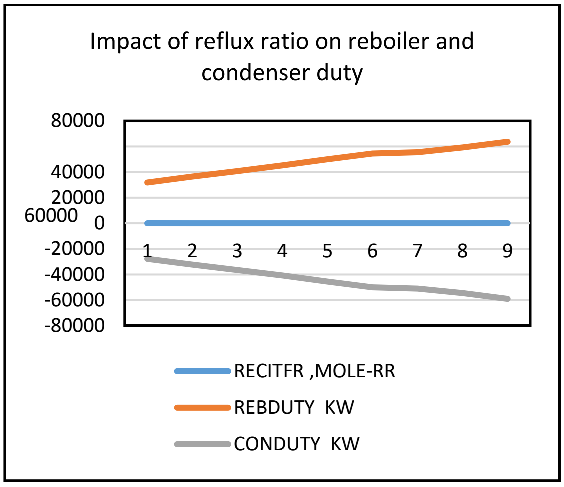


Fig.3.13: Impact of reflux ratio on reboiler and condenser duty

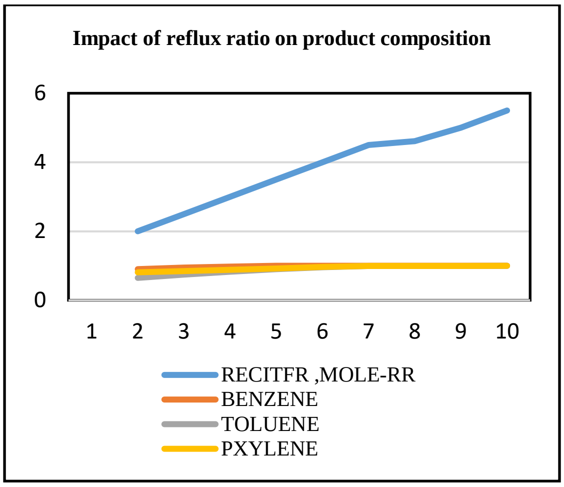


Fig 3.14: Impact of reflux ratio on Product composition

3.2.2 Impact of bottom rate on product composition, reboiler and condenser duty:

The bottom rate directly affects the purity of all the components. As we increase the bottom flow rate, the purity of the bottom product will decrease as other components will also enter the bottom. At 1100 Kmol/hr. of bottom rate, xylene is almost 99.99% and the other two components are below 80%. On continuously increasing the bottom rate up to 1442 Kmol/hr., compositions of benzene and toluene improved, however, xylene remains almost constant. Furthermore, on increasing the bottom rate beyond 1442 Kmol/hr., toluene and xylene purities decrease, however, benzene becomes almost constant. Therefore, the bottom rate of 1442 Kmol/hr. is almost optimum. The corresponding reboiler and condenser duties are 55632 Kw and 50985 Kw respectively. The effect of the bottom rate on reboiler, condenser duties and product composition are shown in Fig 3.15 and Fig 3.16 respectively.

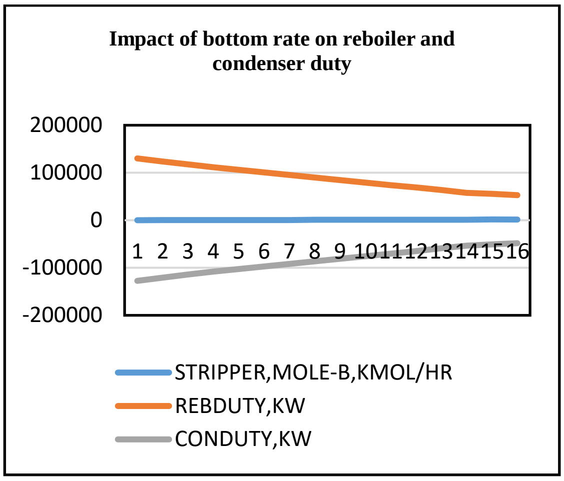


Fig 3.15: Impact of bottom rate on reboiler and condenser duty

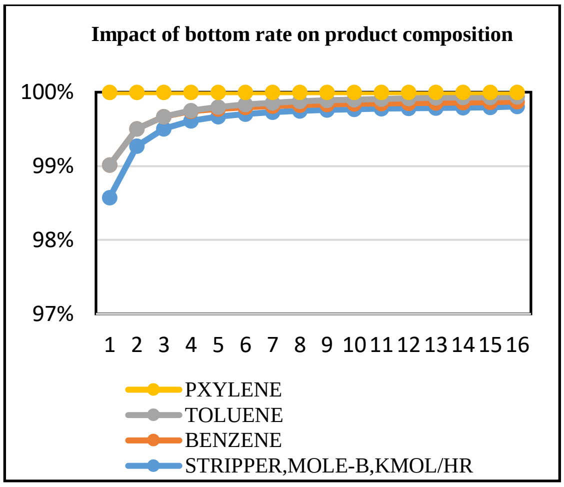


Fig 3.16: Impact of bottom rate on product composition

3.2.3 Impact of vapor split on product composition, reboiler and condenser duty:

Product purity increases by increasing the vapor split ratio from 0.5 to 0.6. however, benzene becomes almost constant at 99.99% after a gradual increase up to a split ratio of 0.6. The corresponding reboiler and condenser duties are 55632.2 Kw and 50985.1 Kw respectively. The effects of the vapor split on reboiler, condenser duties and product composition are shown in the following Fig 3.17 and Fig 3.18

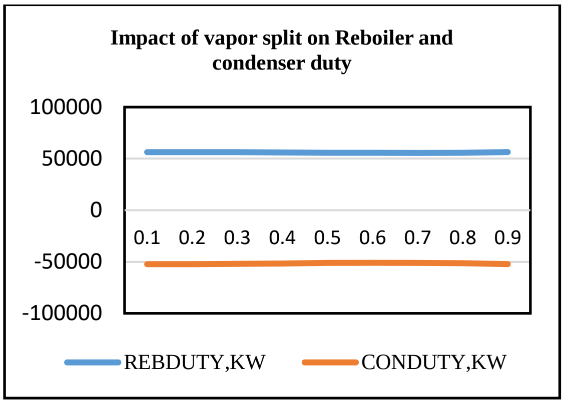


Fig 3.17: Impact of vapor split on reboiler and condenser duty

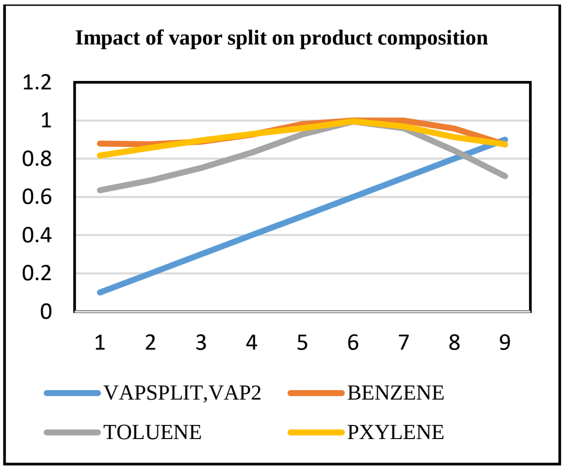


Fig 3.18: Impact of vapor split on product composition

3.2.4 Impact of liquid split on product composition, reboiler and condenser duty:

The purity of toluene and Xylene decreases from 99.43% to 94.95% and 99.57% to 96.21% by liquid split ratio between 0.6 to 0.7, respectively. However, benzene purity is not affected much. Therefore, the optimum liquid split is 0.6. The corresponding reboiler and condenser duties are 55632.2 Kw and 50985.1 Kw respectively. The effects of the liquid split on reboiler, condenser duties and product composition are shown in the following Fig 3.19 and Fig 3.20 respectively.

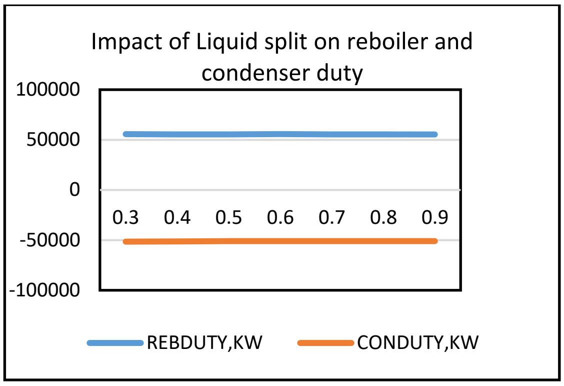


Fig 3.19: Impact of Liquid split on reboiler and condenser duty

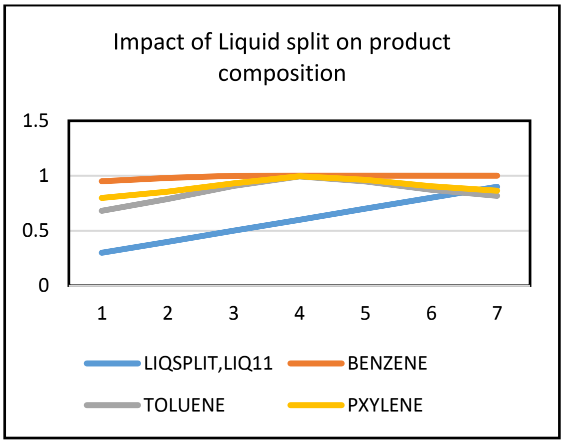


Fig 3.20: Impact of Liquid split on product composition

3.3 Comparison between CDC and DWC:

This BTX separation shows that dividing wall distillation column is best for ternary separation.

Table 3.3: Comparison between CDC and DWC

Parameter	CDC	DWC
Number of Stages	62	66
Product Composition	Benzene:99.85% Toluene:99.74% Xylene:99.84%	Benzene:99.99% Toluene:99.43% Xylene:99.57%
Total Heat duty (Kw)	176427.55	106617.6

3.4 Energy Savings:

The energy saving in the divided wall column over the conventional distillation column is calculated by using the following formula:

$$Energy\ saving\ (\%) = \frac{Q_{CDC} - Q_{DWC}}{Q_{CDC}} * 100$$

$$Energy\ saving = 39.568\ \%$$

The dividing wall column reduced energy consumption up to 39.568%.

IV. CONCLUSION

1.Dividing wall column can save 39.568% operating cost for BTX separation.
2.From this study, dividing wall column is best for Separation.

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