SIMULATION ANALYSIS OF THERMALLY COUPLED DISTILLATION SYSTEMS

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ABSTRACT

Distillation is one of the most common industrial separation processes. The energy requirement of this separation process is very large. Efforts have been made by various researchers to minimize the energy consumption of this process. New complex distillation arrangements have been developed that provide the efficient separation at lower energy consumption. Thermally Coupled Distillation Systems (TCDS) are one of such arrangements that reduce the reboiler duty significantly as compared to the conventional distillation sequences. Petlyuk Column is a fully thermally coupled distillation sequence, which has been reported to provide energy savings of about 30% over the conventional sequences. In this paper, the simulation of Petlyuk configuration for a ternary mixture has been performed and the energy consumption is compared with that of the conventional sequences. The parametric analysis has also been performed.

***Keywords*: Distillation, Energy, Petlyuk, Simulation, Thermally Coupled**

I. INTRODUCTION

Distillation is a separation process in which the liquid or vapour mixture of two or more substances separates into its component fractions of desired purity, by the application of heat. It depends on the distribution of substances between the gas and liquid phase, also known as the relative volatility. Distillation separations are performed for about 95% of all fluid separations in the chemical industry. It requires a huge amount of energy, i.e., about 3% of the total energy consumption of the world is used in distillation units [1]. Distillation finds innovative applications in absorption thermodynamic cycle, SI thermo chemical cycle for hydrogen production in terms of reduction of energy requirement compared to traditional processes [2-5].

The thermally coupled distillation systems (TCDS) were proposed many decades earlier. TCDS, in the form of a divided wall column was patented by R.O. Wright in year 1949 [6]. Later, theoretical studies were performed by Petlyuk et al in 1965 [7]. Thermal couplings are obtained by elimination of a condenser or a reboiler of one of the distillation columns and substituting vapor–liquid interconnections between the two columns.

In conventional distillation sequences, as shown in Fig. 1, the concentration of intermediate component reaches a maximum below the feed stage and then decreases in the bottom of the column. Such an effect is known as remixing. It requires more energy to re-purify the binary mixture in the second column in conventional sequences. The recycle streams in TCDS sequences are capable of significantly reducing the remixing and hence the energy savings for the ternary mixtures is significant [8].

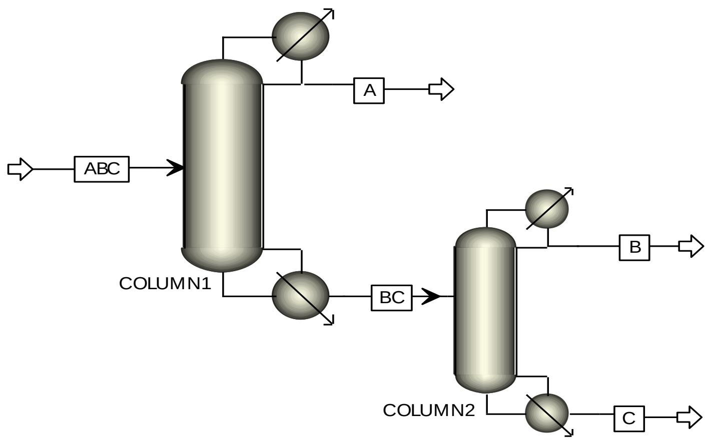


Fig. 1 - Direct Distillation Sequence for Ternary Mixtures

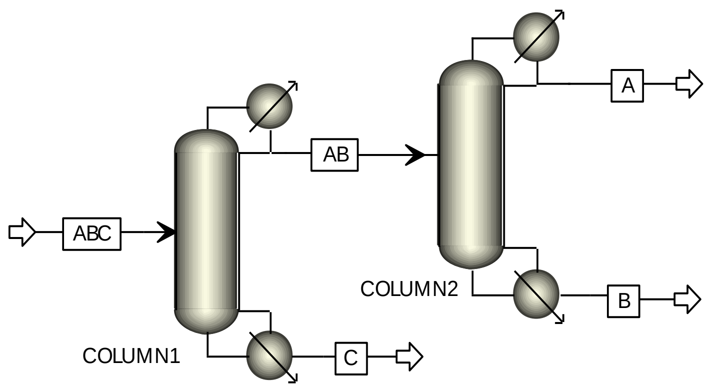


Fig. 2 - Indirect Distillation Sequence for Ternary Mixtures

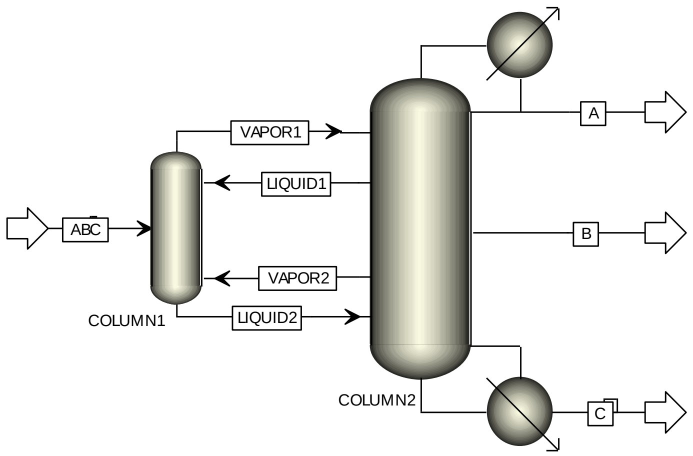


Fig. 3 – Fully Thermally Coupled Distillation System (Petlyuk Column)

The energy consumption in Petlyuk column (Fig.3) is the lowest as compared to the conventional sequences (Fig. 1 and 2) as well as the thermally coupled sequences with side columns for a system of ternary mixtures [9]. It was proved that the total vapor flow in Petlyuk configuration reduces by 10 to 50 % as compared to conventional systems [10]. The low vapor flow is desirable as it would require smaller diameter columns and smaller reboiler and condenser. The conventional distillation sequences require three heat exchangers, while, Petlyuk column requires only two heat exchangers. Hence, Petlyuk Column shows potential to reduce the operating cost as well as the capital cost as compared to the conventional sequences.

In this work, Petlyuk Column has been studied by performing rigorous simulations in RadFrac model of Aspen Plus. The heat duty of Petlyuk Column and conventional direct and indirect sequences has been compared. The parametric study of the Petlyuk Column has also been performed.

II. SIMULATION METHODOLOGY

The basis for this simulation study was taken from the work of Premkumar and Rangaiah (2009) [1]. The feed is a saturated liquid mixture of Benzene, Toluene and p-Xylene, with a flow rate of 100 kmol/hr and at 10 atm pressure. Other specifications for this case study are listed in Table 1. The Aspen Plus flowsheet for Petlyuk Column is shown in Fig. 4.

Table 1: Various Specifications for the Case Study

Component	Feed Composition	Product Specification	Other Conditions
Benzene	0.33	0.995	Column Pressure : 10 atm
Toluene	0.33	0.91	Total Condenser
p-Xylene	0.34	0.92	Peng-Robinson Model

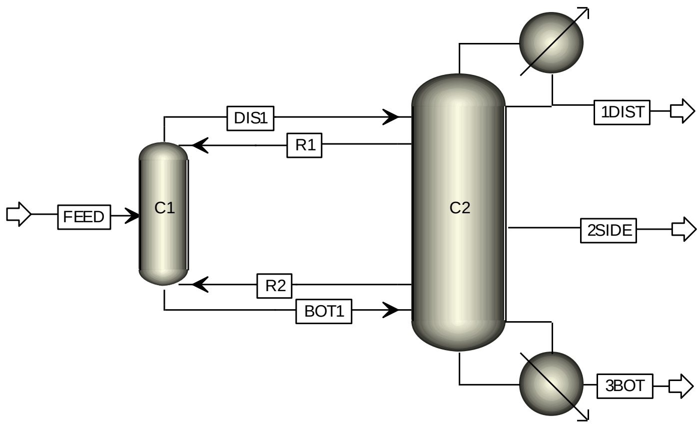
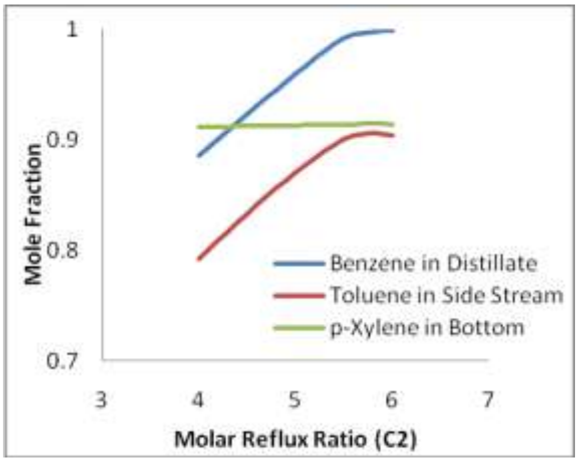
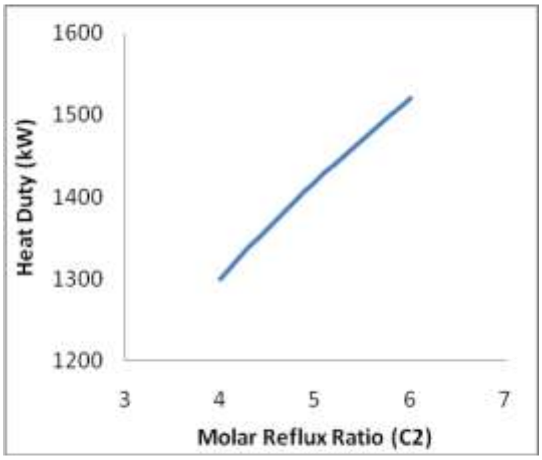


Fig. 4 – Flowsheet for Petlyuk Column in Aspen Plus

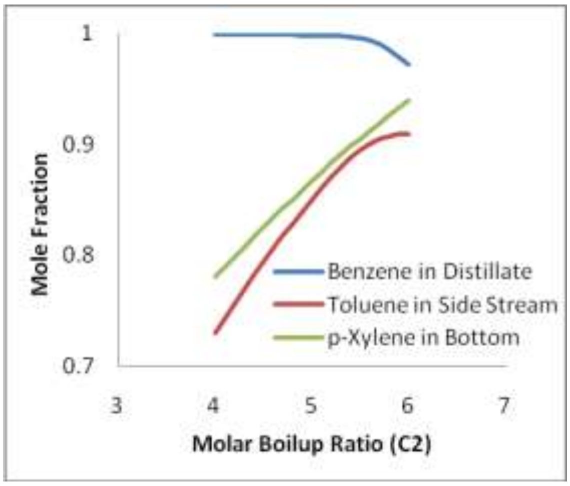
The conventional direct and indirect sequences were simulated and optimized in terms of energy consumption, using the Optimization Block of Aspen Plus. For the Petlyuk Column, parametric study was first performed using Sensitivity Analysis. It gives the region of optimum solution. Energy optimization for this configuration was done by using the Optimization block of Aspen Plus, in the range provided by the Sensitivity Analysis. The results of Sensitivity Analysis are shown in Fig. 5(a-h). Those parameters are selected at which energy consumption is minimum, provided the product purities have reached.


Mole Fraction
1
0.9
0.8
0.7
3 4 5 6 7
Molar Reflux Ratio (C2)
Benzene in Distillate
Toluene in Side Stream
p-Xylene in Bottom

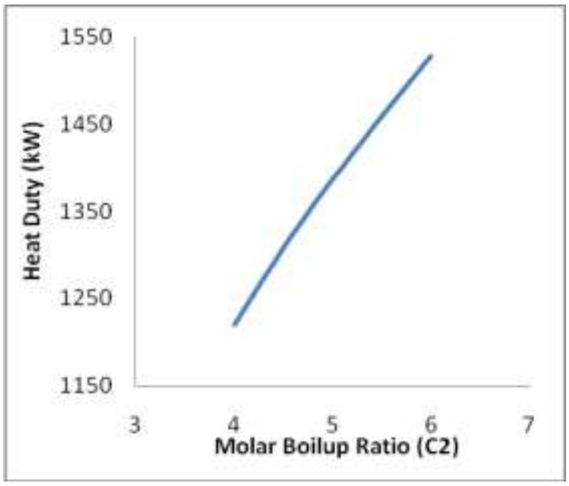
(a)


Heat Duty (kW)
1600
1500
1400
1300
1200
3 4 5 6 7
Molar Reflux Ratio (C2)

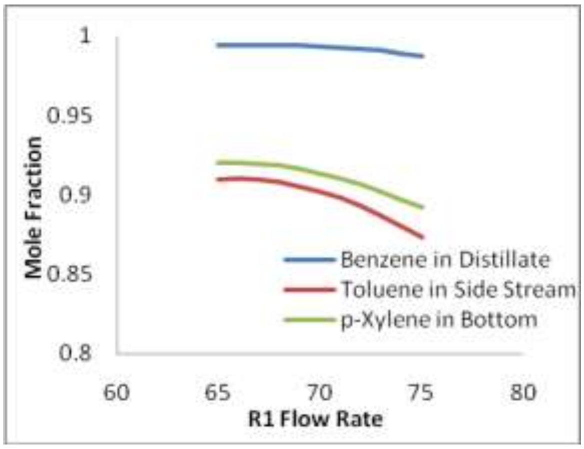
(b)


Mole Fraction
1
0.9
0.8
0.7
3 4 5 6 7
Molar Boilup Ratio (C2)
Benzene in Distillate
Toluene in Side Stream
p-Xylene in Bottom

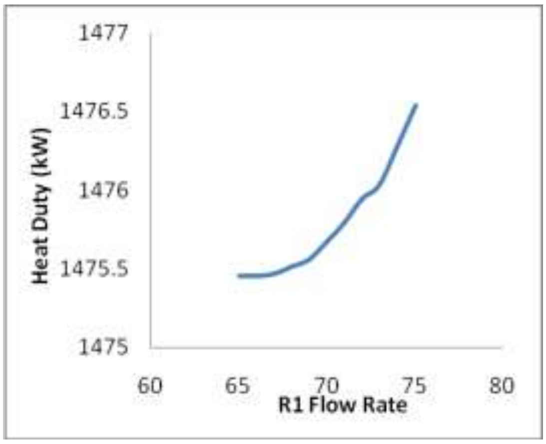
(c)


Heat Duty (kW)
1550
1450
1350
1250
1150
3 4 5 6 7
Molar Boilup Ratio (C2)

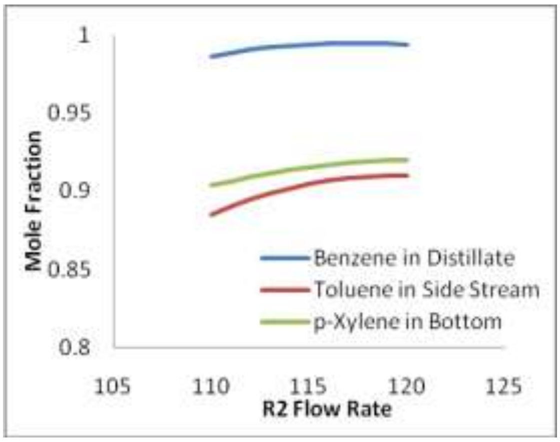
(d)


Mole Fraction
1
0.95
0.9
0.85
0.8
60 65 70 75 80
R1 Flow Rate
Benzene in Distillate
Toluene in Side Stream
p-Xylene in Bottom

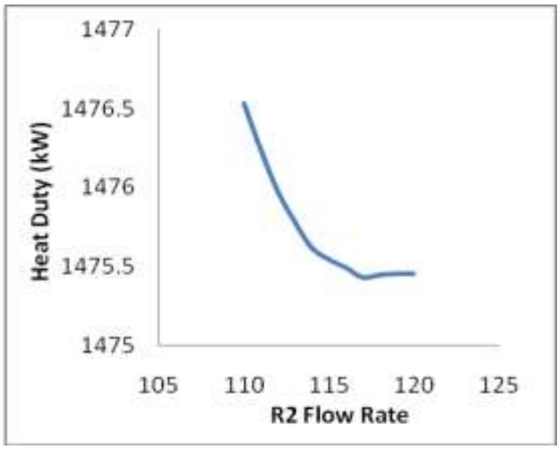
(e)


Heat Duty (kW)
1477
1476.5
1476
1475.5
1475
60 65 70 75 80
R1 Flow Rate

(f)



(g)



(h)

Fig. 5 – Sensitivity Analysis Results for Petlyuk Column

III. RESULTS AND DISCUSSION

The optimized values of parameters obtained by putting the results of Sensitivity Analysis in the Optimization block are shown in Table 2. Optimized parameters for Conventional sequences are shown in Table 3.

Table 2: Optimized Parameters for Petlyuk Column

Parameter	Optimized Value
Molar Reflux Ratio (C2)	5.57
Molar Boilup Ratio (C2)	5.61
R1 Flow Rate (kmol/hr)	66.14
R2 Flow Rate (kmol/hr)	113.61
Distillate Flow Rate (C2)	32
Side Flow Rate (C2)	33
Bottom Flow Rate (C2)	35

Table 3: Optimized Parameters for Conventional Sequences

Parameter	Direct Configuration		Indirect Configuration	
	Column1	Column 2	Column1	Column 2
Distillate Rate (kmol/hr)	32	33.01	65.54	32.48
Molar Boilup Ratio	2.47	5.58	6.52	3.16
Bottoms Rate (kmol/hr)	68.01	35	34.46	33.06
Molar Reflux Ratio	4.61	5.09	2.43	4.52

The optimized energy consumption values for Petlyuk Column and the conventional (direct and indirect) sequences are shown in Table 4. The results show that the indirect distillation sequence is more energy efficient than the direct sequence. The fully thermally coupled sequence, Petlyuk Column, requires least energy.

Table 4: Energy Consumption for all the Sequences

S. No.	Distillation Sequence	Energy Consumption (kW)	% Savings w.r.t. Indirect Configuration
1.	Direct Arrangement	2718	------
2.	Indirect Arrangement	2442.55	------
3.	Petlyuk Column	1477.46	39.51

V. CONCLUSION

In this work, Petlyuk column was studied through simulations performed in the process simulator Aspen Plus. The results of simulations indicate that the energy consumption of direct sequence is higher than that of the indirect distillation sequence. Petlyuk column was found to provide energy savings of about 40%, over the indirect sequence, which is in agreement with the literature. Such a high energy saving will significantly affect the cost of operation. Reduction in the energy consumption of a process does not only affect the economics of the process but also provide environmental benefits by reduction in the emissions associated with the use of the fossil fuels. Hence, this sequence should be explored for industrial applications.

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