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Reduction of Energy Consumption of Distillation Process by Recovering the Heat from Exit Streams

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***Abstract*—**Distillation consumes enormous quantity of energy. This work proposed a process to recover the energy from exit streams during the distillation process of three consecutive columns. There are several novel techniques to recover the heat with the distillation system; however, a complex control system is required. This work proposed a simpler technique by exchanging the heat between streams without interrupting the internal distillation process that might cause a serious control problem. The proposed process is executed by using heat exchanger network with pinch analysis to maximize the process heat recovery. The test model is the distillation of butane, pentane, hexane, and heptanes, which is a common mixture in the petroleum refinery. This proposed process saved the energy consumption for hot and cold utilities of 29 and 27%, which is considered significant. Therefore, the recovery of heat from exit streams from distillation process is proved to be effective for energy saving.

***Keywords*—**Distillation, Heat Exchanger, Network Pinch Analysis.

I. Introduction

DISTILLATION is one of the most extensively used processes in a wide range of industries especially in the energy sector. It is important to reduce the energy consumption of the distillation [1]. A large number of research publications have been targeted the reduction of energy consumption and the improvement of distillation column efficiency. The energy loss in distillation process is derived from the loss in a column itself (adiabatic), a reboiler, a condenser, and a pre-heater [2]. Several research publications show a leap improvement of the energy reduction using internally heat-integrated distillation column [3]-[8]. The basic fundamental is that the heat loss in the column from adiabatic process must be recovered. Therefore, both liquid and vapor flow in each column from particular trays must be transported from that column to exchange the heat with either the liquid of vapor streams of the other column. This process causes a serious control problem as well as a construction problem.

This work proposed the energy reduction process by recovering the energy of the exit stream of each equipment in the distillation network so that the streams inside the column are not transported outside the column to remove the previously stated problems. The test model of this work is an equimolar mixture of n-butane, n-pentane, n-hexane, and n-heptane.

The conventional distillation network is shown in Fig. 1 for separation of n-butane, n-pentane, n-hexane, and n-heptane. Light components are separated from the distillation columns as the distillates shown in Fig. 1. The heat duties in this schematic diagram come from pre-heaters, reboilers, and condensers. The proposed process is to utilize the energy from the exit streams for each unit operation except the column.

Pinch analysis was performed and the heat exchanger network was designed accordingly to recover maximum process energy with minimum utility requirement. In constructing heat exchanger network, the hot streams must be combined in a particular temperature range and as must the cold streams. These combined streams are called "composite stream." According to thermodynamic laws, the temperature of the composite hot stream must be higher than that of the composite cold stream because the heat must be transfer from high to low temperature. The temperature versus the enthalpy of each section is plotted in order to determine the process feasibility. In a certain systems, the temperature of the composite hot stream may be lower than or cross that of the composite cold stream. To make it possible, the composite cold stream must be shifted to the right in order to until all sections in the hot composite stream are above the composite cold stream. The minimum difference between the hot and cold composite streams is called minimum pinch point temperature and this point is called pinch point. Heat cannot be transferred across this point. In other words, heat above pinch must be transferred within the above pinch region and the same manner applies in the below pinch region.

II. Simulation

The process simulations were performed by Aspen Plus program. RADFRAC was used as a model for a distillation column. Thermodynamic model was based on Soave-Redlich-Kwong model. The numbers of stage were 22. Pinch Analysis was performed with the assumed minimum temperature difference of 10 K.

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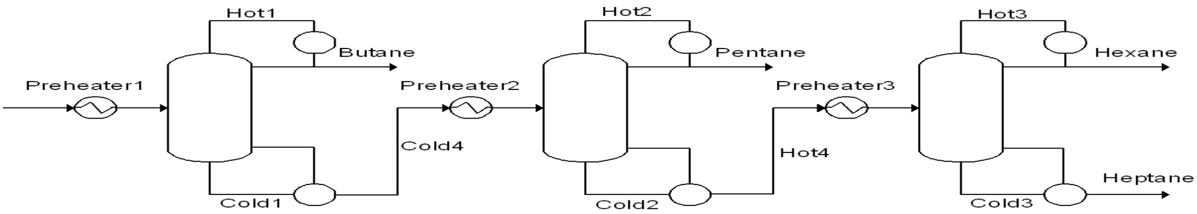

Fig. 1 Schematic diagram of distillations of butane, pentane, hexane, and heptanes

III. Result and Discussion

Table I shows the operating conditions and streams results of each column. According to Table I, the purity of the final products is over 96%. Table II shows the heat requirement of each unit operation and the temperature across it. The streams that need to be heated are marked as "cold" stream while the ones that need to be cooled are marked as "hot." Fig. 2 illustrates the temperature intervals for stream matching in order to generate heat exchanger network. As shown in Fig. 2, there were four sections of hot streams. Only hot streams 1 and 4 shared the temperature intervals. All cold streams do not share the same temperature intervals. From Table II, total heat duties were 249849 and 26907 kW for hot streams and cold streams, respectively. According Fig. 2, the temperature intervals were four for hot streams and three for cold streams. Fig. 3 shows the composite curves of hot streams and cold streams. In Fig. 3, the top line is the composite hot stream while the bottom line is the composite cold stream. The composite cold stream was shifted to the right in order that the composite hot stream is always above the composite cold stream with the minimum temperature difference of 10 K. The pinch point was at 413 and 373 K for composite hot and cold streams, respectively. It was not possible to have only temperature difference at the pinch of 10 K from this process. According to Fig. 3, the recovery heat recovery from hot to cold streams was 7183 kW. The hot utility to heat cold streams and cold utility to cool hot streams and cold streams were 17806 and 19724 kW. In summary, the hot and cold utilities were significantly reduced by 29 and 27 % from the original requirements. The heat exchanger network is shown in Fig. 3. No heat was exchanged across the pinch point. Total number of inserted heat exchanger was four. The required exchanger is shown in Fig. 2.

IV. Conclusion

The heat exchanger network was designed for a set of four three distillation columns of equimolar mixture of n-butane, n-pentane, n-hexane, and n-heptane. The aim was to utilize the heat from the exit streams from each unit operation in the system using pinch analysis so that foreign energy requirement was minimized. Instead of applying complex internally-integrated heat exchanger network, pinch analysis offers much simpler network construction without process control problems. The unit operations that require heat duty include preheater, condenser, and reboiler. The hot utility was reduced by 29% while the cold utility was reduced by 27%.

This reduction was considered significant. Therefore, the construction of heat exchanger network with pinch analysis is an effective method to recover the heat within the distillation network.

TABLE I
Operating Conditions and Stream Results of Each Column

	Tin (K)	Tout (K)	Q (kw)	Name
Condenser1	321.34	320.46	6959	H1
Condenser2	364.87	363.77	11155	H2
Condenser3	408.05	407.15	6551	H3
Reboiler1	371.67	379.28	7920	C1
Reboiler2	414.33	418.19	11732	C2
Reboiler3	438.39	438.9	7117	C3
Preheater2	379.28	381.95	139	C4
Preheater3	418.19	407.17	323	H4
Qh,Total (kw)		24988		
Qc,Total (kw)		26908		

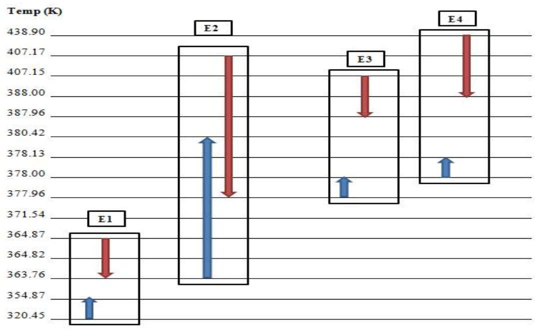

Fig. 2 Temperature interval of each stream and the proposed heat exchangers between streams

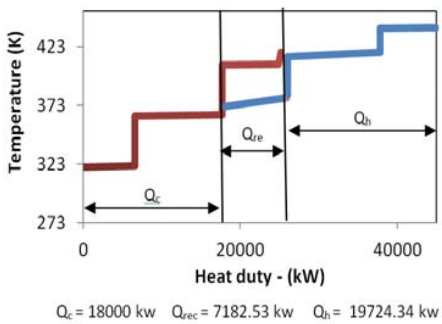

Fig. 3 Composite curve of pinch analysis

TABLE II
HEAT DUTY OF EACH EQUIPMENT AND THE TEMPERATURE ACROSS THE EQUIPMENT

	Column1		Column2		Column3	
light key/heavy key	1.09954874		0.901758386		1.004882332	
Feed rate (mol/s)	347.22		.232.05		110.52	
Condenser Pressure (atm)	4.462		4.85		5.238	
Reboiler Pressure (atm)	4.462		4.85		5.238	
RR	0.327779999		0.244756006		0.20042157	
Feed stage	8		14		12	
	Distillate	Bottom	Distillate	Bottom	Distillate	Bottom
Flow rate (mol/s)	115.17	232.05	121.53	110.52	55.39	55.13
Composition (mole fraction)						
Butane	0.97	0.025	0.02	0.03	Trace	Trace
Pentane	0.02	0.488	0.97	Trace	Trace	Trace
Hexane	Trace	0.243	Trace	0.48	0.96	0.03
Heptane	Trace	0.243	Trace	0.48	0.03	0.97

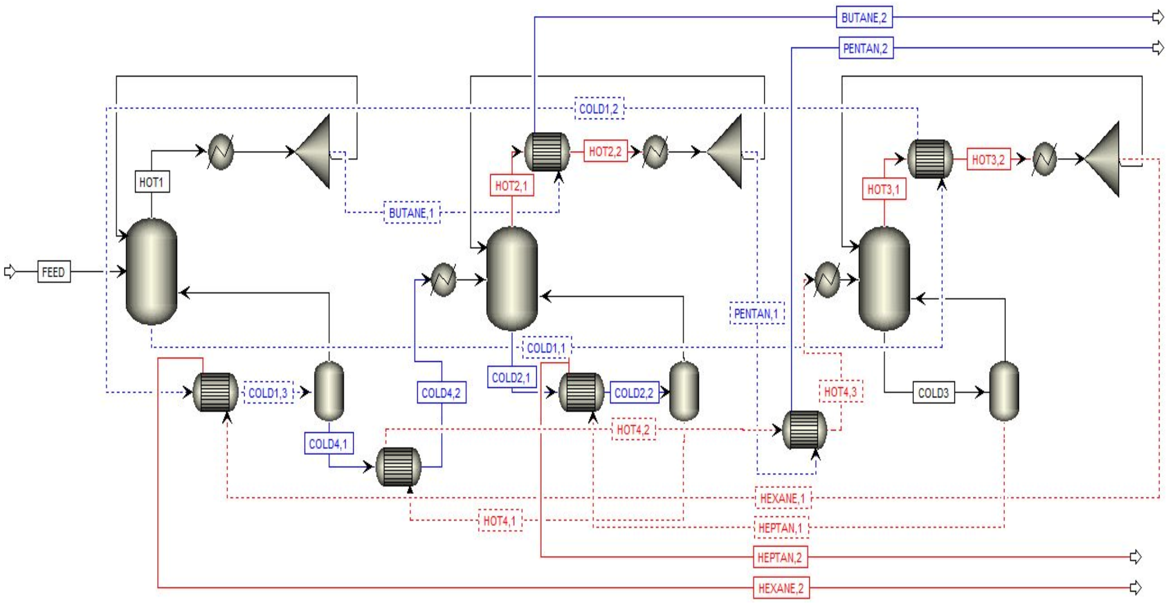

Fig. 4 The full schematic diagram of the heat exchanger network

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