Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

Efficiency Improvement of Distillation Column

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***Abstract*- Methanol-water system was chosen to study heat pump assisted distillation system along with conventional distillation. Conventional process along with mechanical vapour recompression and vapour compression was simulated using UniSim software platform in order to find energy savings as well as economically best alternative. Mechanical vapour recompression and vapour compression for this system shows energy savings of 82% and 78% respectively with payback period of less than year.**

Keywords: Distillation, Energy savings, Heat pump, Process Simulation

1. INTRODUCTION

Distillation being a war-horse of separation in wide range of process industries, it has continuously elicited interest from researchers in finding ways to optimize its energy requirements. Mix et al. [12] found that 60% of energy used by chemical industry was for distillation. Heat pump utilizes the energy of the cold stream to heat the bottom hot mixture thus saving large utility consumption. Anton et al [6] proposes a novel selection scheme of energy efficient distillation technologies, with a special focus on heat pumps. Methanol-water separation by distillation is widely reported for methanol production in literature [3,4]. Juntao Zhang [8] mainly focuses on heat integration used for methanol production.. Feng and Berntsson [9] has derived expression for critical COP which is a function of price ratio between input energy and heating, the price ratio between equipment, energy and the payback period. Quadri [13] used heat pumps for propane-propene separation and suggested single compressor scheme and double compressor schemes. Later Annakou and Mizsey [14] found that vapour recompression gives 37% savings on total annual cost when compared to conventional column for C3 separation. Fonyo et al. [15] has shown 29% saving on utilities for butane-isobutane separation and Eduardo [8] has reported energy saving of 33% by vapour recompression.

The objective of this work is to simulate methanol-water distillation process and to compare the energy and cost of the conventional distillation with heat pump assisted distillation system. Two different configurations are considered (MVR, VC) to determine best alternative to the conventional distillation. All the simulations were undertaken with UniSim Design R430 build 18522 under license from Honeywell Process Solutions [11].

2. UniSim SIMULATION OF THE DISTILLATION COLUMN SYSTEMS

2.1 Conventional Column

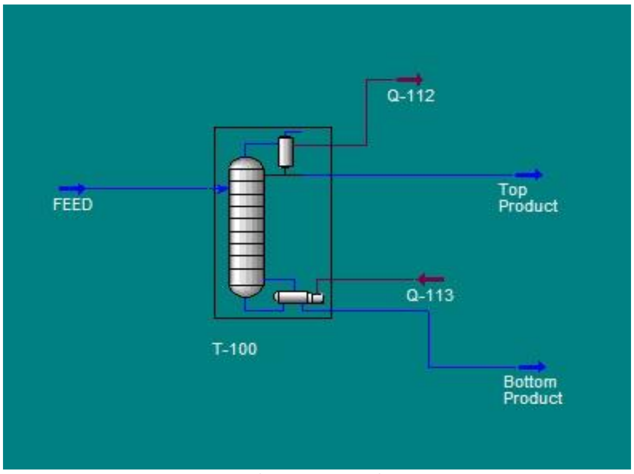

Figure 1: UniSim process flow diagram for the conventional column

To compare conventional column (CC) with heat pump assisted distillation systems, NRTL-ideal property package

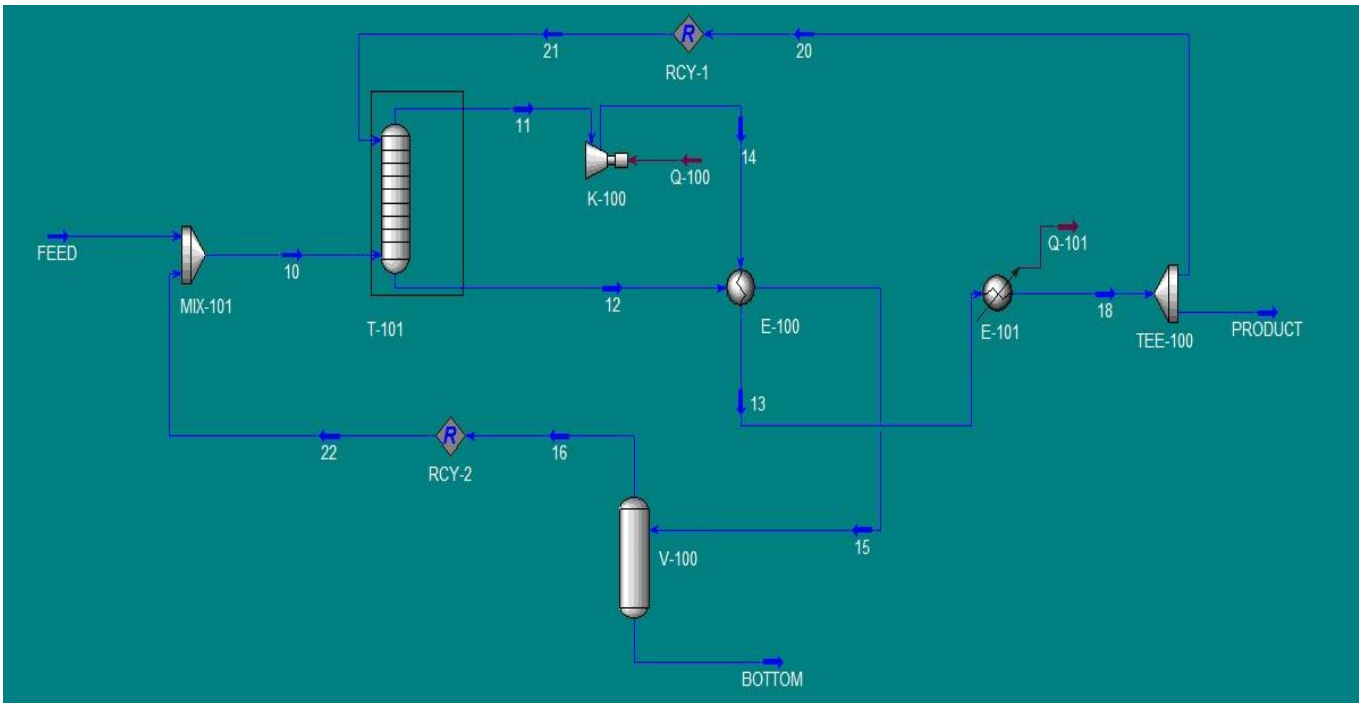

Figure 2: UniSim process flow diagram for mechanical vapour recompression heat pump

is selected for methanol water separation [1,8]. The base data is taken from industrial pharmaceutical firm, this is an actual system with all the design/operating data. 6000 litre per hour of 25% (by weight) methanol (M) and 75% (by weight) water (W) was fed to the column at ambient conditions namely 35^{0}C and atmospheric pressure (101.325 kPa). The separation is carried out at one atmospheric pressure; distillate purity of 99% (by weight) methanol is the final product requirement keeping reflux ratio as 6. Figure 1 show UniSim flow diagram for Conventional column with top product pressure and temperature of 101.325kPa and 64.73 ^{0}C and bottom column temperature and pressure is 97.77 ^{0}C and 103 kPa.

In all simulations, the feed is supplied at the same conditions, the product is recovered as saturated liquid at 101.325kPa and pressure drop across column is kept constant. Cooling is provided by water cooled heat exchangers. Assuming water inlet temperature of 30 ^{0}C and outlet temperature as 45 ^{0}C. No energy losses are assumed in this system.

2.2 Distillation column with mechanical vapour recompression heat pump

The flow diagram of MVR scheme is shown in figure 2. The top column outlet stream is compressed with compressor (K-101) to raise its temperature so that required boil-up can be created. The temperature is increased from 64.49 ^{0}C to 237 ^{0}C and also the pressure is increased from 101.325 kPa to 807 kPa. A minimum approach of 5 ^{0}C is used to calculate the outlet compressor pressure. After the compressor, the heat exchanger E-100 allows transfer of the energy of this stream followed by E-101. This stream is then divided in two streams in TEE-100. One outlet stream is the final top product and the other one is recycled back to the column.

Note that the following heat balance applies:

$$Q_C \approx Q_R \approx Q_{E\text{-}100} \qquad (1)$$

$$Q_{K\text{-}100} \approx Q_{E\text{-}101} \qquad (2)$$

Where Q_C is conventional column condenser energy, Q_R is conventional column reboiler energy.

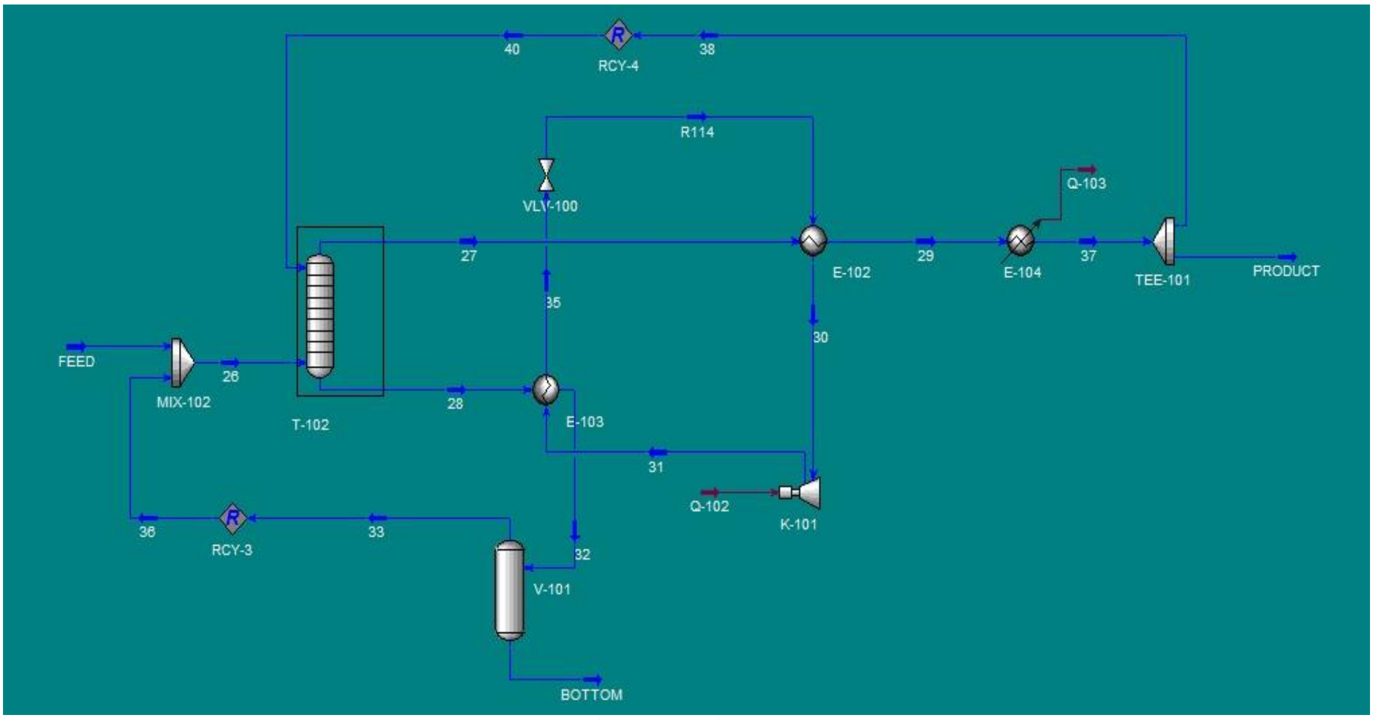

Figure 3: UniSim process flow diagram for vapour compression heat pump

2.3 Distillation column with vapour compression heat pump

The flow diagram of VC scheme is shown in figure 3. G Venkatarathnam, S Murthy [10, 2] provides various refrigerants for vapour compression and provides refrigerants from different chemical groups. R-114 is chosen as working fluid for this separation. R-114 is heated in E-102 at a pressure of 562 kPa, enters compressor K-101 where it is compressed to a pressure of 1520 kPa and temperature of 103.4 ^{0}C so that a required boil up can be provided to column. After E-103, the bottom column outlet stream is divided in V-101 flash drum. The vapour outlet stream is recycled back to the column, and the liquid outlet is the final bottom product stream.

2.4 Feed Preheating

Thermal condition of the feed is one of the important schemes for energy-efficient design of a distillation column. By exchanging heat with the bottom product or with any other available low-grade heat sources, thermal condition of the feed may be altered to reduce the reboiler duty. Column bottom stream is at a temperature about 97 ^{0}C and is cooled to a temperature of 65.5^{0}C utilising this energy to heat feed from ambient condition (35^{0}C) to 60^{0}C.

3. ECONOMIC EVALUATION OF ALL ALTERNATIVES

The economic evaluation of each system was carried out by estimating the simple payback period (PBP), in terms of combination of capital and operational cost and of time required to recover the cost of an investment. Calculated as

$$\text{Payback period} = \text{Annual Cost} / \text{Annual cash Savings} \qquad (3)$$

Total annual cost consists of basically two factors. First is depreciated capital cost per year (compressor, heat exchanger) and secondly operating cost per year (utilities). Annual cash savings are price saved from utility consumption. Difference between reboiler and compressor duty is the amount of heating utility saved. Similarly, difference between condenser and trim cooler duty is the amount of cooling utility saved.

MVR shows maximum energy saving of 82% followed by VC (78%) and feed preheating shows net energy saving of 2.32% as can be seen from table 1.The primary energy savings for methanol-water separation for MVR is reported as 69% and for VC as 46% as per anton et. al. [6].Appendix A shows the detailed calculation procedure for Compressor equipment used in MVR technique.

Table 1: Energy requirement (10^6) for three techniques (All energy units are in KJ/hr)

	CC	MVR	VC	Feed Preheat
Qr	11.4	2.63	3.05	10.8
Qc	10.1	1.35	1.77	10.2
% Avg Saving		82%	78%	2.32%

Table 2: Payback time (year) for three techniques (10^6 Rupees/year)

	MVR	VC	Feed Preheat
Total Annual Cost	83.4	167	0.039
Net Savings	175	206	3.66
PBT (years)	0.48	0.81	0.01

4. CONCLUSION

Methanol-water mixture is selected to analyse heat pump assisted distillation when compared to conventional distillation. MVR features slightly higher efficiency and lower investment cost than VC. Hence, MVR is indeed a better option in terms of both, energy and payback time when compared to VC. One major drawback of heat pump assisted distillation technique is compressor which is very expensive and hard-to-maintain equipment.

ACKNOWLEDGEMENT

The author is thankful to Prof. Prajakta Angre, HOD.Dr. Kolhe, Dept. of Chemical Engineering , Mahatma Gandhi Mission's College Of Engineering And Technology, Navi Mumbai ,for all their support and help.

I would like to extend my sincere thanks to Equinox Software & services pvt. Ltd., Pune for providing the opportunity to work on industrial project and gratitude to Shri Alok Pandit for his valuable guidance.

APPENDIX A: CALCULATION FOR EQUIPMENT COST

Compressor Cost

STEP 1: Compressor Duty= 730.05 KW = 978.63 hP

STEP 2: Compressor Cost:

From Six-tenth rule [5], $C_B = C_A (S_B/S_A)^{N}$, $C_B = 190000* (978.63/600)^{0.32} = 222199.4$ \$ Using Cost Index to calculate price of Compressor in different year, Cost of compressor = 410474.89 \$ = Rupees 2, 46, 28,493.63 /-

STEP 3: Installation Cost: For a compressor, installation cost is 30-60% of purchased cost.

STEP 4: Operational Cost: For compressor, electricity is used as utility. Electricity cost = 6.08 Rupees / unit. Electricity requirement annually=6.08* 730.05=4438.75 rupees/ hour = 4438.75 * 8000 = 35509977.70 rupees/ year

APPENDIX B: CALCULATION FOR ENERGY SAVINGS

MVR on an average saves 82% energy both from heating utility and cooling utility.

STEP 1: Mass of steam saved, $Q = m. \lambda = 3.26*10^7$ kg / year

STEP 2: Price saved on steam = $3.26*10^7 * 0.75 = 2.44*10^7$ Rupees / year

STEP 3: Mass of cooling water saved, $Q = m*C_p*\Delta T = 1.12*10^9$ kg / year

STEP 4: Price saved on cooling water = $1.12*10^9 * 0.18 = 2.01*10^8$ Rupees / year

NET PRICE saved from MVR = $2.44*10^7 + 2.01*10^8$ = Rupees $2.26 *10^8$ /-

APPENDIX C: NOMENCLATURE

MVR	Mechanical Vapour Recompression
VC	Vapour Compression
NRTL	Non Random Two Liquid
PBT	Payback time
Qc	Conventional column condenser energy
Qr	Conventional column reboiler energy

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