DISTILLATION COLUMN DESIGN AND ANALYSIS

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ABSTRACT

This research investigates the utilization of a heat pump-assisted distillation system for separating a methanol-water mixture. By integrating conventional distillation with advanced simulations using AspenPlus software, the study aims to assess the energy efficiency and economic viability of the proposed method. The simulation results demonstrate significant energy savings, with the vapor recompression method achieving an impressive 82% reduction in energy consumption compared to traditional distillation techniques. This substantial decrease in energy use underscores the potential of heat pump-assisted distillation systems to enhance the sustainability of chemical processes. Furthermore, the economic analysis indicates a payback period of less than one year for the vapor recompression method. This rapid return on investment highlights the economic feasibility of implementing this technology on an industrial scale. The findings suggest that heat pump-assisted distillation systems are not only effective in reducing energy consumption but also present a cost-effective solution for the separation of methanol-water mixtures. The study concludes that the integration of heat pumps in distillation processes can significantly contribute to both energy efficiency and economic benefits, making it a promising alternative to conventional distillation methods. Overall, the research provides valuable insights into the practical application of heat pump-assisted distillation systems, emphasizing their potential to revolutionize industrial distillation by offering substantial energy savings and a swift payback period.

Keyword: *Distillation, Energy savings, vapor recompression, Process Simulation, Aspen plus*

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1. INTRODUCTION

In the realm of distillation column design, the efficient separation of methanol and water hinges on the integration of energy-saving strategies, particularly the incorporation of vapor recompression techniques. This project is dedicated to exploring and optimizing the simulation and calculation aspects of the distillation process using Aspen Plus, with a primary focus on enhancing energy efficiency.

Traditional distillation columns grapple with challenges such as heightened energy consumption and escalating operational costs. By embracing vapor recompression technology, the objective is to augment energy efficiency without compromising the efficacy of methanol-water separation. The simulation endeavors involve leveraging Aspen Plus, a robust process simulation tool, to meticulously model and analyze the intricacies of the distillation process. Rigorous calculations and simulations are employed to evaluate the column's performance under diverse conditions, enabling the optimization of parameters for energy savings

1.1 BACKGROUND

In the realm of distillation column design, the efficient separation of methanol and water hinges on the integration of energy-saving strategies, particularly the incorporation of vapor recompression techniques. Traditional distillation columns grapple with challenges such as heightened energy consumption and escalating operational costs. Vapor recompression technology offers a promising solution by recycling energy within the system, thus enhancing overall efficiency. This project is dedicated to exploring and optimizing the simulation and calculation aspects of the distillation process using Aspen Plus, a robust process simulation tool. By leveraging Aspen Plus, the study meticulously models and analyzes the intricacies of the distillation process, allowing for a comprehensive evaluation of the column's performance under diverse conditions. Rigorous simulations and calculations are employed to optimize parameters and achieve significant energy savings, all while maintaining the efficacy of methanol-water separation. This approach aims to address the dual challenge of reducing energy consumption and operational costs, making the distillation process more sustainable and economically viable.

1.2 OBJECTIVES OF THE RESEARCH

The primary objective of this research is to investigate and optimize the integration of vapor recompression techniques within the distillation process for separating methanol and water. By utilizing Aspen Plus for detailed simulations and calculations, the study aims to enhance energy efficiency and reduce operational costs without compromising the effectiveness of the separation process. Specifically, the research seeks to:

1. Model the methanol-water distillation process using Aspen Plus to accurately represent real-world operations.
2. Evaluate the energy consumption and performance of traditional distillation methods.
3. Implement and analyze the vapor recompression technique within the distillation model.
4. Compare the energy efficiency and economic feasibility of the vapor recompression method against conventional distillation.
5. Optimize the operational parameters to achieve maximum energy savings and minimal payback period.

The ultimate goal is to demonstrate that vapor recompression can significantly improve the sustainability and cost-effectiveness of industrial distillation processes.

2. LITERATURE SURVEY

Heat pumps offer a promising solution by harnessing the energy from colder streams to heat the hotter mixture, thereby reducing utility consumption. Anton et al. [2] propose a new method for selecting energy-efficient distillation technologies, with particular attention to heat pumps. Fonyo et al. [9] demonstrated a 29% reduction in utility costs for butane-isobutane separation, while Eduardo [5] reported a 33% energy saving through vapor recompression.

The separation of methanol and water through distillation is commonly discussed in literature for methanol production [3,4]. Juntao Zhang [5] concentrates on heat integration techniques used in methanol production. Feng and Berntsson [6] have developed a formula for the critical coefficient of performance (COP), which depends on the ratio between energy and heating prices, equipment costs, and the payback period. Distillation, a crucial process in various industries, has long been a focus for researchers aiming to optimize energy usage. According to T.J Mix et al. [1], a significant portion (60%) of the chemical industry's energy consumption is attributed to distillation. Quadri [7] employed heat pumps for propane-propene separation, suggesting both single and double compressor schemes. Annakou and Mizsey [8] discovered that vapor recompression resulted in a 37% reduction in total annual costs compared to conventional methods for C3 separation.

The goal of this study is to model the methanol-water distillation process and evaluate the energy and cost implications of traditional distillation versus a vapour recompression-assisted system. The base data which is feed conditions of the methanol water mixture for this project is take from the research paper published by pratibha singh and prajakta angre. [10] We're exploring two configurations, Conventional Column and Vapour Recompression, to identify the most efficient alternative to traditional distillation. All simulations were conducted using Aspenplus V10.

3. DESIGN CALCULATION BY GRAPHICAL METHOD

Step 1: fix the feed parameters and product specification:
We have taken the feed conditions from reference [10]

parameter	value	unit
Feed rate	6000	Liter/hour
temperature	35	℃
pressure	101.325	kpa
Composition of feed	25% 75%	Wt%
Distillate composition	97%	Wt%

***Table no 1**: feed and product specification*

Step 2: determine the process operation variables

$$\mathbf{F=D+B} \quad (1)$$

$$\mathbf{F*zf = D*xd + F*xb} \quad (2)$$

By solving above material balance equation, we get the values of the required process variables like distillate rate, bottom rate etc.

Step 3: Determine the minimum reflux ratio:
The McCabe-Thiele method is widely used for the determination of the minimum reflux ratio in case of the binary mixture distillation operation.
The formula for calculating the minimum reflux ratio is given as

$$R_{min} = \left(\frac{XD}{Yintercept}\right) - 1$$

Step 4: choose the actual reflux ratio:
Most columns are designed to operate between 1.2 and 1.5 times the minimum refluxratio because this is approximately the region of minimum operating cost. Therefore, based on first estimates, the operating reflux ratio is equated so that (Douglas, 1988)

$$R_{actual} = R_{min} * 1.2$$

Step 5: determine the theorotical number of trays:
For finding the theorotical number of trays we need to draw the top operating line and bottom operating line and then by using x-y diagram we find the number of stages.

Step 6: determine the actual number of trays:
This is determined by taking the quotient of the number of theoretical trays to the trayefficiency. Typical values for tray used, as well as the internal liquid and vapor flow rates. efficiency range from 0.5 to 0.7.
These values depend on the type of trays being

$$N_{actual} = \frac{N(theorotical)}{\epsilon}$$

Since we want to simulate vapour recompression distillation column along with conventional distillatation column we need the input which are calculated by above steps. Or we can also use the DSTUW model in aspen plus to calculate the above parameters.
The dimensions of distillation column are also clculated but since the objective of this research paper is to do the comperative study of the energy efficiency of the two configuration we limit the calculation till actual number of stages.

	value	
parameter	**McCabe-Thiele method**	**Shortcut Method**
Minumum number of trays	**6**	**5.58**
Minimum reflux ratio	**1.66**	**2.5**
Actual reflux ratio	**2**	**2**
Optimum feed tray location	**8**	**7.68**

Table no 2: calculation of number of trays

4. ASPEN PLUS SIMULATION ANALYSYS FOR CONVENTIONAL AND VAPOUR RECOMPRESSION

Aspen Plus is a powerful process simulation software used extensively in chemical engineering for modeling, designing, and optimizing processes, including distillation columns. It offers advanced features for rigorous modeling of complex processes, thermodynamic property calculations, and process optimization. Aspen Plus enables researchers to simulate the performance of distillation columns, analyze energy efficiency, and explore various design configurations to achieve optimal separation. Its robust capabilities make it an essential tool for process optimization and innovation in the chemical industry

4.1 Conventional Column

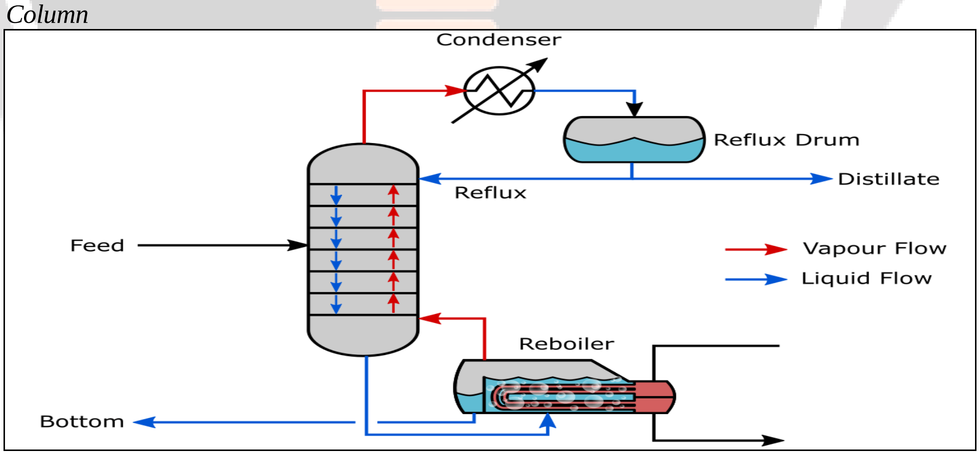

Fig2: conventional distillation column configuration

To compare conventional column (CC) with vapour recompression distillation systems, NRTL-ideal property package
NRTL property package is generaly used for the binary mixture of the two non random polar liquids like methanol-water, ethanol-water.for the selection of the proper property package we can use method assistant.such as the reboiler, condenser, trays, and feed input, each playing a crucial role in the separation process. Simulating a conventional distillation column using Aspen Plus provides detailed insights and optimization results that are

essential for efficient design and operation. Aspen Plus enables the simulation of these components to analyze and enhance the performance of the distillation process.

Key results obtained from Aspen Plus simulations include the optimum reflux ratio, which balances the trade-off between energy consumption and separation efficiency. Determining the optimum number of trays is another critical outcome, as it directly impacts the column's height and cost. Additionally, the simulation provides the condenser duty, indicating the amount of heat removed to condense the vapor at the top of the column, and the reboiler duty, which shows the heat input required to vaporize the liquid at the bottom.

By adjusting various parameters within Aspen Plus, researchers can explore different scenarios and configurations to achieve optimal performance. This includes evaluating the effects of feed composition, feed stage location, and column pressure on the overall separation efficiency. The software's ability to model real-world behavior accurately and provide detailed thermodynamic data makes it an invaluable tool for designing and optimizing distillation column

Simulation in Aspen Plus: Key Results

When simulating a conventional distillation column in Aspen Plus, we gain valuable insights into its performance. Here are some critical results:

1.Optimum Reflux Ratio: The reflux ratio (the ratio of condensed liquid returned to the column to the distillate) significantly impacts separation efficiency. Aspen Plus helps determine the optimal reflux ratio for maximum purity of the desired product.

2.Optimum Number of Trays: The number of trays affects both capital costs and energy consumption. By simulating different tray configurations, Aspen Plus identifies the ideal tray count for efficient separation.

3.Condenser Duty: Aspen Plus calculates the heat duty required by the condenser to cool the vapor. This information guides equipment sizing and energy optimization.

4.Reboiler Duty: The reboiler duty corresponds to the heat input needed to vaporize the liquid feed. Aspen Plus provides insights into the optimal reboiler duty for efficient operation.

Economic Considerations:

Beyond these technical aspects, Aspen Plus allows us to evaluate the economic feasibility of the distillation process. By considering capital costs, operating expenses, and utilities costs, we can make informed decisions about design modifications. In summary, Aspen Plus empowers engineers to rigorously model conventional distillation columns, optimize their performance, and achieve cost-effective designs. Whether you're fine-tuning an existing process or designing a new one, this powerful tool plays a crucial role in chemical engineering

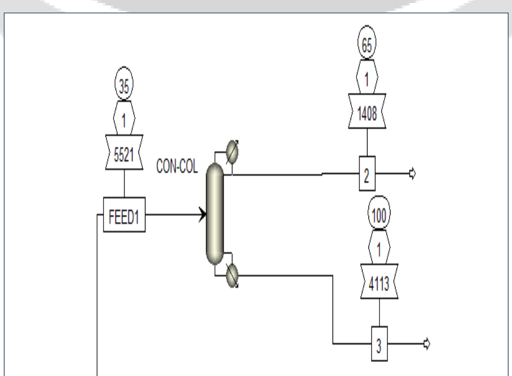

Fig 3: Conventional distillation column in aspen plus

Minimum reflux ratio	1.33
Actual reflux ratio	2
Feed tray location	8.06
Optimum number of trays	11.24
Reboiler type	kettle
Reboiler duty	1.73 MW
Condencer duty	1.34 MW

Table no 3: Conventional column results in aspen plus

4.2 vapour recompression distillation column

vapour recompression is the technique in which the top product of the distillation column is compressed by using the compressor in order to increase its temperature and use this stream as the hot utility to reboil the bottom product in order to reduce the heat duty of the steam operated reboiler. One part is also important to note that when we compress the vapour stream of methanol in high pressure it gets liquified and this also reduces the condencer duty on the water operated condencer.

In vapour recompressor technique following are the main components of the configuration is aspen plus

A) secondary compressed steam opeated reboiler

B) compressor

C) trim cooler (flash drum2 water operated vapour condencer)

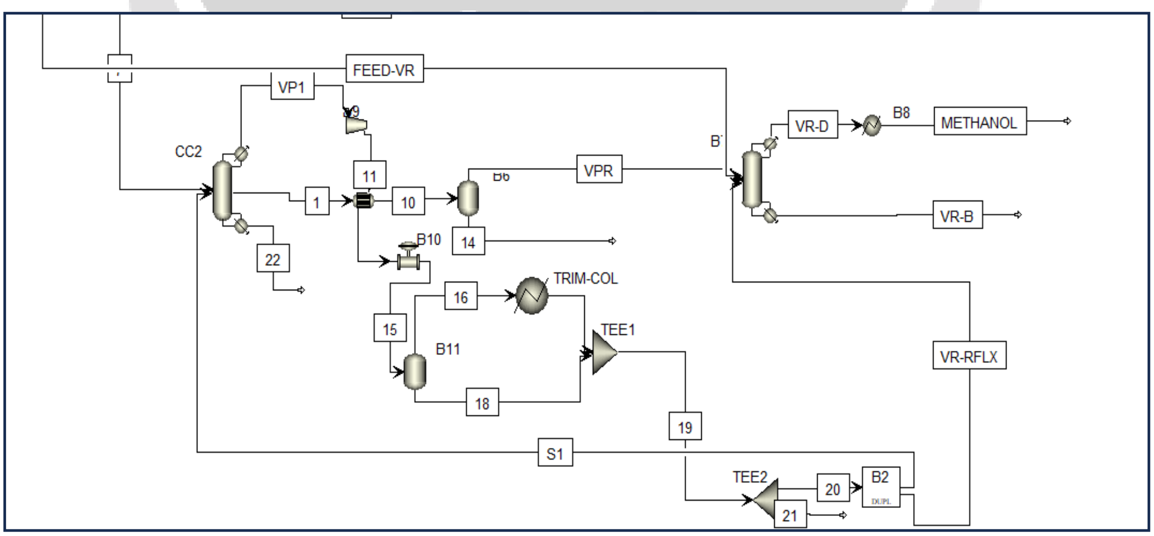

Fig 4: Vapour recompression distillation column configuration in aspen plus

Distillation column with mechanical vapour recompression heat pump:
The flow diagram of vapour recompression scheme is shown in figure 2. The top column outlet stream is compressed with compressor 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 allows transfer of the energy of this stream followed by This stream is then divided in two streams in. One outlet stream is the final top product and the other one is recycled back to the column.

A. COMPRESSED STEAM OPERTED REBOILER

in the conventionla distillation column the reboiler uses the steam as the hot utility but in vapour recompression distillation column we are going to use the compressed. vapour of the distillation column for the purpose of the heating the bottom product of the distillation column this technique saves the large amount of energy by utilizing the latent heat of condensation of the top vapour of the distillation column for the purpose of the vapourization of the bottom stream of the distillation column.

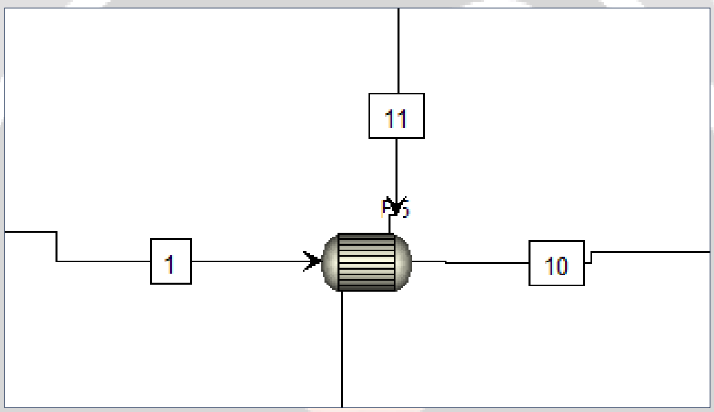

Fig 5: Compressed vapour operated reboiler

Hot stream inlet/outlet	11/12
Cold stream inlet/outlet	1/10
Heat duty	1.72626
Hot stream inlet temperature	331 ℃
Hot stream outlet temperature	102 ℃

Table no 4: Results of compressed vapour operated

B. COMPRESSOR

In vapor recompression distillation, the compressor is a vital component that enhances the system's efficiency by increasing the pressure and temperature of the vapor produced during boiling. This heated vapor is then used as a heat source for the reboiler, effectively recycling energy within the distillation process. By compressing and reusing the vapor, the system significantly reduces the need for external heating, leading to substantial energy savings. This method is particularly advantageous in industrial applications where energy efficiency and cost reduction are critical. The compressor's ability to improve the thermal efficiency of the distillation process makes vapor recompression a sustainable and economically attractive technique, aligning with modern goals for greener and more efficient industrial operations.

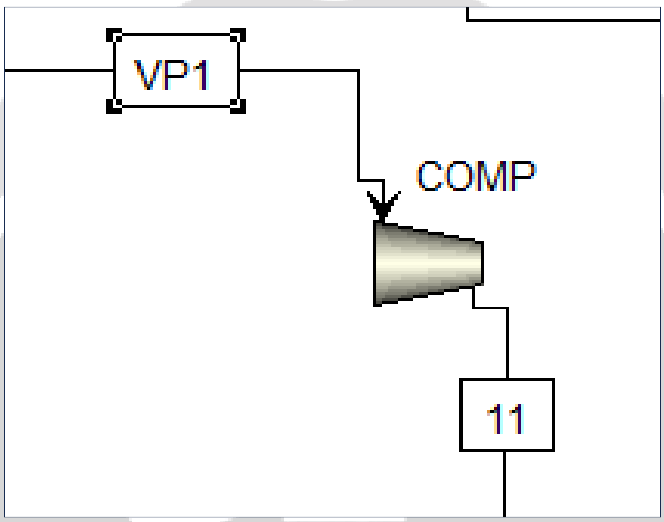

Fig 6: Vapour compressor

Compressor model	Isentropic compressor
Utility	Electricity
Efficiency	0.72
Inlet pressure	1.013 bar
Outlet pressure	19.5557 bar
Compressor duty	0.559 MW

Table no 5: Vapour compressor results

C. TRIM COOLAR

In vapor recompression techniques, a water-operated trim cooler is an essential component used to fine-tune the temperature of the recompressed vapor before it re-enters the distillation column. The trim cooler operates by using water to absorb excess heat from the vapor, ensuring it reaches the optimal temperature for effective distillation. This cooling process is crucial for maintaining the efficiency and balance of the system, as it prevents overheating and ensures that the vapor provides the correct amount of thermal energy to the reboiler. By precisely controlling the vapor temperature the water-operated trim cooler enhances the overall energy efficiency and stability of the vapor recompression distillation process, contributing to more consistent and reliable industrial operations.

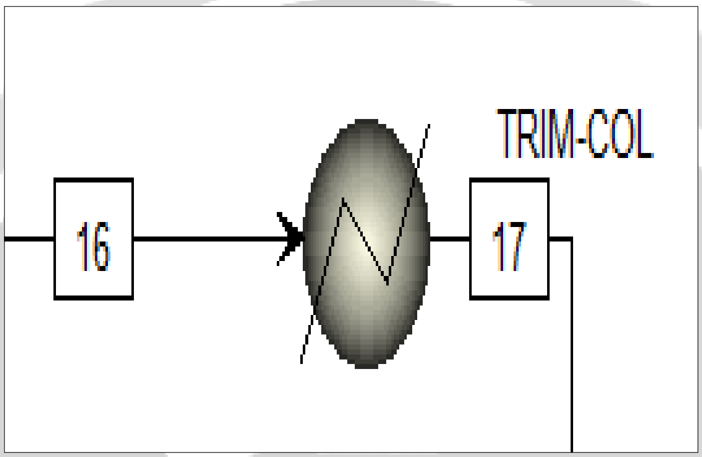

Fig 7: Trim cooler

Utility	Cooling water 30℃
Hot Inlet vapour fraction	1
Hot outlet vapour fraction	0
Hot inlet temperature	65.3265℃
Hot outlet temperature	64.85℃
Heat duty	0.1682 MW

Table no 6: Trim coolar results

ENERGY REQUIREMENT COMPERISION OF CONVENTIONAL COLUMN AND VAPOUR RECOMPRESSION COLUMN:

Parameter	Conventional column	Vapour recompression column
Condenser duty (MW)	1.33653	0
Reboiler duty (MW)	1.72664	0.00193
Trim coolar duty (MW)	0	0.1682
Compressor work (MW)	0	0.559

Table no 7: Energy required comperision

4. CONCLUSIONS

When comparing vapour recompression distillation to conventional distillation using a methanol-water mixture, Vapor Recompression (VR) shows slightly higher efficiency and lower investment costs for utility than conventional column . Therefore, VR is a better option for both energy savings and quicker payback time. However, a major drawback of heat pump-assisted distillation is the compressor, which is very expensive and difficult to maintain. Despite this, the overall benefits of VR make it a more attractive choice for efficient and cost-effective distillation.

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