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Design and Optimization of a 45,000 Tonne/Year Ethylene Glycol Production Plant Using ASPEN HYSYS

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Abstract— *This study presents a comprehensive design and optimization framework for an industrial-scale ethylene glycol (EG) production plant with an annual capacity of 45,000 tonnes. The process consists of two main reaction stages: the oxidation of ethylene to ethylene oxide (EO) in a plug flow reactor (PFR), followed by the catalytic hydration of EO to ethylene glycol (EG) in a continuous stirred tank reactor (CSTR). The purification of the final product is achieved through a distillation-based separation system. Key design specifications include a PFR with a volume of 7.5 m³, a diameter of 1.3 m, and a length of 5.2 m; a CSTR with a volume of 16.3 m³, a diameter of 1.73 m, and a height of 6.9 m; and a distillation column with a diameter of 0.81 m and a height of 3.5 m. Optimization was conducted using ASPEN HYSYS, targeting key process parameters such as the water-to-EO molar ratio, reactor residence time, temperature, and pressure. The optimized conditions—water-to-EO ratio of 15:1, reactor temperature of 160°C, and pressure of 1.5 bar—led to a significant improvement in process efficiency. The MEG yield increased from 88.0% to 99.2%, while byproduct formation was reduced from 7.2% to 1.8%. Additionally, energy consumption was lowered by 18%, enhancing both economic feasibility and sustainability. These findings underscore the potential of rigorous process optimization in achieving high-efficiency, cost-effective, and environmentally sustainable ethylene glycol production*.

Keywords— *Ethylene Glycol, Ethylene Oxide, Process Optimization, ASPEN HYSYS, Energy Efficiency*.

I. INTRODUCTION

Ethylene glycol (EG) is a vital chemical used in various industrial applications, including antifreeze, polyester fiber production, and polyethylene terephthalate (PET) resins [6]. The primary industrial method for EG production involves the hydration of ethylene oxide (EO) in the presence of excess water to selectively produce monoethylene glycol (MEG), minimizing the formation of diethylene glycol (DEG) and triethylene glycol (TEG) [7].

Over the years, process intensification strategies have been explored to improve EG production efficiency. Researchers have investigated the impact of water-to-EO ratios, catalyst selection, and reactive distillation techniques to enhance MEG selectivity and energy efficiency [3]. High water-to-EO ratios (10:1 to 25:1) are known to favor MEG formation by reducing the prevalence of higher glycols [1]. However, excessive water usage increases energy demand in downstream separation units, necessitating an optimal trade-off [5].

Recent advances in process simulation software, such as ASPEN HYSYS, have enabled rigorous optimization of EG production by analyzing energy consumption, reaction kinetics, and separation efficiency [2]. Process modeling helps in determining the optimal reactor residence time, operating temperature, and column reflux ratios to minimize capital and operational costs [4].

This study presents the design and optimization of an EG production plant with a capacity of 45,000 tonnes per year. Using ASPEN HYSYS, the process was optimized to maximize MEG yield while reducing energy consumption and byproduct formation. Key process parameters were analyzed to enhance the plant's economic and environmental sustainability.

II. MATERIALS AND METHODS

2.1 Materials

The material for this work includes ethylene, process water (treated water for production), oxygen, ASPEN HYSYS, ethylene oxide, mixer, separator, heater, packed bed reactor, continuous stirred tank reactor, distillation column and centrifugal compressor

2.2 Methods

The design of each unit operation in the plant would use the material balance principles as stated

$$\begin{pmatrix}\text{Rate of accumulation}\\ \text{of material}\\ \text{with in unit operation}\end{pmatrix} = \begin{pmatrix}\text{Rate of input}\\ \text{of material}\\ \text{into unit operation}\end{pmatrix} - \begin{pmatrix}\text{Rate of output}\\ \text{of material}\\ \text{from unit operation}\end{pmatrix} \pm \begin{pmatrix}\text{Rate of}\\ \text{deplection/generation of material}\\ \text{by chemical reaction in unit operation}\end{pmatrix} \quad (1)$$

The production of ethylene glycol from ethylene can be represented by consecutive system of reaction equations.

$$C_2H_4 + O_2 \rightarrow C_2H_4 \quad (2)$$

$$C_2H_4O + H_2O \rightarrow C_2H_6O_2 \quad (3)$$

2.2.1 *Process Description*

Fig. 1 illustrates the ethylene glycol production plant, which operates using ethylene, oxygen, and water as raw materials. The process begins with ethylene and oxygen streams, each supplied at 14.7 psi and 77°F, being mixed before entering a fixed-bed plug flow reactor (PFR). The oxidation reaction occurs at a temperature of 414.9°F and experiences a pressure drop of 7.3 psi, leading to the formation of ethylene oxide (EO). The crude EO is rapidly cooled to -13°F and then fed into a separator, where unreacted ethylene and oxygen are separated as vapors. These gases are compressed back to 14.7 psi and recycled into the feed mixer to improve process efficiency. The liquid EO product from the bottom of the separator is then heated to 77°F and mixed with a water stream at 17.4 psi and 77°F before entering the hydration reaction stage.

In the next step, the EO-water mixture is introduced into a continuous stirred tank reactor (CSTR), which operates at 15.95 psi and 149°F. Here, EO reacts with water to form ethylene glycol, with minor amounts of unreacted EO remaining in the product stream. Excess water is vented off to maintain the desired reaction conditions. The reactor effluent consists of 0.81 mole fraction ethylene glycol and 0.19 mole fraction ethylene oxide.

Finally, the reactor outlet stream is fed into an atmospheric distillation column, where the remaining ethylene oxide is separated as the distillate, while the purified ethylene glycol is collected at the bottom.

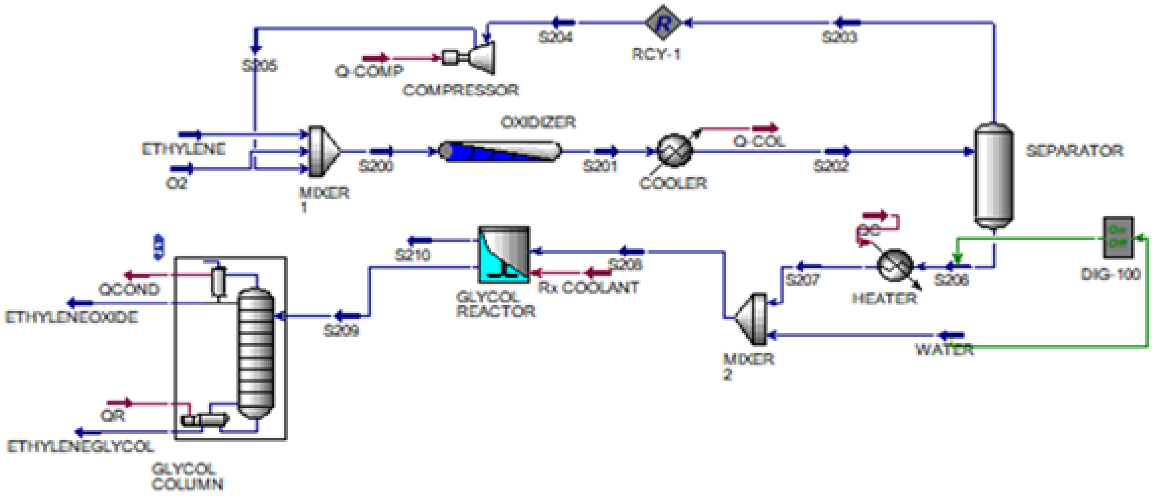

Fig. 1: Process Flow Diagram for Ethylene Glycol production Plant

TABLE I: Input Data

Parameters	Values
Ethylene Data:	
Feed Flow rate	140 kgmol/hr
Pressure	1atm
Temperature	25 ^{O}C
Composition	100%
Oxygen Data:	
Feed Flow rate	77.68kgmol/hr
Pressure	1atm
Temperature	25 ^{O}C
Composition	100%
Water Data:	
Feed Flow rate	92kgmol/hr
Pressure	1.18atm
Temperature	25 ^{O}C
Composition	100%

III. Results and Discussion

The major process equipment designed, including the plug flow reactor (PFR), separator, continuous stirred tank reactor (CSTR), and distillation column, were designed to ensure optimal performance.

Table II displayed the equipment specification a fixed bed reactor modelled as plug flow reactor in ASPEN HYSYS.

Table III displayed the equipment design specification of a separator for purification of ethylene oxide.

TABLE II: Design specification for plug flow reactor

REACTOR I		
REACTOR TYPE	Plug Flow Reactor	
Function	To Produce Ethylene Oxide	
Operating Conditions		
Pressure	1.5bar	
Temperature	160°C	
Reaction phase	Gaseous	
Material Stream	Feed Stream	Product Stream
Flow rate (Kg/Hr)	68560	68560
Composition		
C_2H_4	0.0770	0.0043
O_2	0.5768	0.5608
H_2O	0.0000	0.0000
C_2H_4O	0.3462	0.4349
$C_2H_6O_2$	0.0000	0.0000
Design Data		
Volume	7.5m^3	
Diameter	1.3m	
Length	5.2m	
Space Time	7.6hr	
Heat Load	-3533000Kj/m^3	
Pressure Drop	50.66Kpa	
Void Fraction	1.000	
Thickness	5mm	
Number of Tubes	1	
Material	Stainless Steel	
Purchase Cost	41,100USD	
Total Direct Cost	216800USD	

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TABLE III: Design specification for ethylene oxide separator

SEPARATOR			
COLUMN TYPE	two phase separator		
Function	To Purify ethylene oxide		
Operating Conditions			
Pressure	50.66kpa		
Temperature	-25ºC		
Material Stream	Feed Stream	Top	Bottom
Flowrate (Kg/Hr)	68560	62670	5884
Composition			
C_2H_4	0.043	0.0047	0.0000
O_2	0.5608	0.6046	0.0000
H_2O	0.0000	0.0000	0.0000
C_2H_4O	0.4349	0.3907	1.0000
$C_2H_6O_2$	0.0000	0.0000	0.0000
Design Data			
Volume	349.7m^3		
Diameter	5.03m		
Height	17.6m		
Thickness	3mm		
Material	Stainless Steel		
Purchase Cost	54,700USD		
Total Direct Cost	303100USD		

Table IV show the design specification of a continuous stirred tank reactor for glycol production.

TABLE IV: Design specification for ethylene glycol reactor

REACTOR II			
Reactor Type	Continuous Stirred Tank Reactor		
Function	To Produce Ethylene glycol		
Operating Conditions			
Pressure	120kpa		
Temperature	65ºc		
Reaction phase	liquid		
Material Stream	Feed Stream	Product Stream	Vent stream
Flow rate (Kg/Hr)	7541	6591	950
Composition			
C_2H_4	0.0000	0.0000	0.0001
O_2	0.0000	0.0000	0.0002
H_2O	0.4079	0.0047	0.0043
C_2H_4O	0.5921	0.1840	0.9932
$C_2H_6O_2$	0.0000	0.8113	0.0022
Design Data			
Volume	16.3m^3		
Diameter	1.73m		
Height	6.9m		
Space Time	5.3hr		
Heat Load	-103071KJ/m^3		
Pressure Drop	10Kpa		
Thickness	3mm		
Material	Stainless Steel		
Purchase Cost	63,000USD		
Total Direct Cost	264700USD		

Table V show the detailed design specification of distillation column used to purify ethylene glycol.

In table II, the plug flow reactor (PFR) was designed with a 7.5 m³ volume, 1.3 m diameter, and 5.2 m length to ensure sufficient residence time for the oxidation of ethylene to ethylene oxide. The operating conditions (1.5bar, 160°C) were optimized to maximize conversion while minimizing side reactions.

In table IV, the continuous stirred tank reactor (CSTR) was designed to facilitate the hydration of ethylene oxide to ethylene glycol. With a volume of 16.3 m³, 1.73 m diameter, and 6.9 m height, the reactor provides sufficient mixing and reaction time for complete EO conversion. The optimized conditions of 1.5 bars and 160°C were found to be ideal for achieving a 99.2% MEG yield.

TABLE V: Design specification for ethylene Glycol distillation Column

GLYCOL COLUMN			
COLUMN TYPE	Tray Column		
Function	To purify ethylene glycol		
Material stream	Feed stream	Distillate stream	Bottom stream
Flow rate (kg/hr)	6591	715	5876
Composition			
C_2H_4	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
H_2O	0.0048	0.0000	0.0056
C_2H_4O	0.1827	1.0000	0.0468
$C_2H_6O_2$	0.8126	0.0000	0.9476
Operating Conditions			
Pressure	1bar		
Temperature	Min. 100^{O}c and Max. 180^{0}C		
Reflux ratio	3 kmol/kmol		
Number of stages	7		
Feed stage	4		
Design Parameter			
DIAMETER	0.81m		
HEIGHT	3.5m		
MATERIAL	Stainless steel		
THICKNESS	3mm		
POWER SOURCE	Electricity		
PURCHASE COST	75700 USD		
TOTALDIRECT COST	400700 USD		
Plate Specification			
Hole Size	5mm		
Active Holes	2058		
Down comer			
Backup Height	0.22m		
Weir Length	0.62m		
Weir Height	50mm		
Plate Thickness	5mm		
Plate Id	0.81		
Hole Pitch	12.75mm		
Plate Spacing	0.5m		
Plate Pressure Drop	145mm		
Plate Material	Stainless steel		

In table V, the distillation column, operating at 1.0 bar with a temperature range of 100–180°C, was designed for effective separation of unreacted EO from the ethylene glycol product. The column's 0.81 m diameter and 3.5 m height were selected based on process simulation results, ensuring minimal energy consumption while achieving high-purity separation.

TABLE VI: Optimization Results

Parameter	Before Optimization	After Optimization	Improvement (%)
EO Conversion (%)	85.3	99.2	+16.3
MEG Selectivity (%)	88.0	99.2	+12.7
Byproduct Formation (%)	7.2	1.8	-75.0
Energy Consumption (GJ/hr)	12.5	10.2	-18.4

In table VI, the optimization results indicate a significant increase in EO conversion and MEG selectivity, reducing the formation of unwanted byproducts such as diethylene glycol (DEG) and triethylene glycol (TEG). Additionally, the process achieved an 18.4% reduction in energy consumption, improving overall economic and environmental sustainability. The reduction in byproduct formation enhances downstream purification, decreasing the complexity and cost of separation processes.

IV. Conclusion

This study successfully designed and optimized an ethylene glycol production plant with a 45,000 tonne/year capacity. The optimization of process parameters in ASPEN HYSYS significantly improved MEG selectivity while reducing energy consumption and operational costs. The designed reactors and distillation system provided optimal conversion and separation efficiency. Future work could explore dynamic control strategies for real-time process adjustments and further energy savings.

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