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(Research Article)

Design of an industrial fan-powered cooler unit at the TEG inlet of a conventional natural gas dehydration plant

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Abstract

The natural gas industry faces significant challenges due to water vapor that is associated with natural gas, which results to issues like hydrate formation, blockages, corrosion of processing facilities and flow assurance related issues. To address this, the triethylene glycol (TEG) dehydration process is crucial for efficient water removal. A critical component of this process plant is the fan-powered cooler which regulates the temperature of lean TEG for optimum dehydration. This research integrates the conservation principle of mass and energy balance in the development of the fan-powered cooler design models and HYSYS simulation of the conventional dehydration plant in order to analyze the performance of the fan-powered cooler in terms of mass and energy balance during the dehydration process. Analysis of the results showed that the fan-powered cooler as a single input and single output unit gave the same value of 0.14221kg/s for mass flow rate at inlet and exit streams, but in terms of energy balance, the inlet and outlet temperature was 60.1437^0C and 48.8889^0C respectively, the temperature difference (reduction) showed that the lean temperature was reduced by the cooler before it was feed to the contactor in order to prevent loss of TEG during the dehydration process. This clearly showed why a cooler is configured at the TEG inlet to the contactor in a dehydration plant and improves the efficiency of dehydration process.

Keywords: Water Vapor; Heat transfer; Fan-Powered Cooler Design; Dehydration; Aspen HYSYS

1. Introduction

The performance of process plant such as the natural gas triethylene glycol (TEG) dehydration plant greatly depends on the efficiency of heat transfer for effective dehydration. The TEG contactor unit is designed for natural gas dehydration where TEG absorbs water vapor from natural gas streams (Wosu *et al*, 2023a). The contactor's performance relies heavily on the temperature and flow rate of TEG entering the system (Wosu & Ikenyiri, 2025; Wosu, 2024). This article focuses on design and performance analysis of the fan-powered cooler at the TEG inlet to the contactor in dehydration plant that regulates the heat or temperature of TEG before it enters the contactor. The goal is to provide insights into how various design parameters and operating conditions affect heat transfer and the overall performance of the dehydration process.

Natural gas is a clean and environmentally friendly energy source that is utilized for industrial applications (Zhang, 2009; Wosu *et al*., 2023b), and Nigeria's significant gas reserves have contributed substantially to the nations growth. However, natural gas contains contaminants like water, which can cause problems such as hydrate formation, corrosion and flow issues during processing, storage and transmission. In a bid to prevent the above mentioned problems, dehydration by TEG becomes highly imperative in gas processing industries (NCDB, 2004; Wosu *et al*., 2024). The use of TEG to dehydrate natural gas is widely recognized as the most effective method, as it can reduce the water content of gas to less than 0.0113kg H_2O/m^3s of NG, meeting pipeline transmission standards (Foss, 2004).

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The fan-powered cooler at the TEG inlet to the contactor is a critical component of the TEG dehydration plant. To achieve efficient dehydration, it plays an essential role to maintain the lean TEG temperature below 80^0C (Kidnay & William, 2006) and the sales gas temperature between 20-35^0C (Christensen, 2009). This research focuses on designing and simulating a TEG dehydration plant using Aspen HYSYS, as well as developing the fan-powered cooler performance models based on material and energy balance principles.

Previous researches have highlighted the importance of removing water and other contaminants from natural gas to meet pipeline transmission standard. Triethylene glycol (TEG) is widely used as a dehydration agent due to its ease of regeneration, low vaporization temperature and high boiling point (Mohammed *et al.*, 2014) . Natural gas is a vital energy source, but it contains impurities that must be removed to meet pipeline specifications. The fan-powered cooler design as a unit in natural gas dehydration plant plays significant role as a heat control device for successful dehydration (Bahman, 2017).

In 2005, Nivargi *et al* stated that to meet the pipeline specification for gas transmission, contaminants such as water, oil, condensate, sulfur and carbon dioxide must be sufficiently removed. Triethylene glycol (TEG) have demonstrated a better performance characteristics for natural gas dehydration process over ethylene glycol (EG), diethylene glycol (DEG), and tetraethylene glycol (TREG), because of its ability to regenerate to a concentration of 98–99.99% in an atmospheric stripper, low vapourization temperature, high boiling point, and decomposition temperature, as well as low capital and operating costs. They designed the TEG dehydration plant using the advanced process simulation software HYSYS.

According to Undiandeye *et al.*, 2015, natural gas is a fossil fuel that is formed from the dead, decomposing remains of plants and animals that are buried beneath the earth's crust under conditions of extreme heat, pressure, and the absence of air. They stated that natural gas is the third most widely utilized energy source in the world that is applied domestically and industrially in areas of heating, cooking, producing electricity, and as fuel for vehicles (Zimmerman & Zimmerman, 1995). Their research considered Shell Gbaran as a case study and compared various natural gas dehydration processes.

Heat exchangers and coolers are widely employed in process industries (Omoyi *et al.*, 2024; Ojong *et al.*, 2023) like those involved in the processing of natural gas, according to Arturo *et al.*, (2011) definition, they enable the transfer of heat between two fluids that are at different temperatures. The design and optimization of heat exchangers and coolers are crucial because they increase their competitiveness and enable process energy savings. Their study concentrated on the design or sizing of several exchanger types to ascertain the correlation between heat transfer and energy loss for a turbulent flow.

The design and performance analysis of a fan-powered cooler just like reactors and other process equipment basically integrates the application of the conservation law of mass and energy for the specification of equipment size (heat duty) as in the case of fan-powered cooler (Wordu & Wosu, 2019; Wosu & Ekokoje, 2025; Wosu & Okoro, 2025; Wosu & Uhuwangho, 2024)

2. Material and methods

The materials needed in this research are the feed materials such as the characterized natural gas, TEG, data obtained from plant, HYSYS simulation as well as the calculated or derived data.

The research methodology is both quantitative and qualitative or analytical. The procedures involved in the research are;

- Presentation of the characterized natural gas composition and HYSYS simulation operating condition
- Development of the TEG natural gas dehydration plant from HYSYS simulation
- Presentation of the various units and streams of the dehydration plant
- Development of the fan-powered cooler design models from the conservation principle of mass and energy balance.

2.1. Natural Gas Composition and HYSYS Simulation Operating Condition

The characterized natural gas composition and TEG dehydration process simulation data are presented in table 1

Table 1 Natural Gas Properties (Wosu *et al*, 2023 ;Wosu & Ezeh, 2024)

Components	Composition	Molar Mass (g/mol)
C_1	0.8939	16.00
C_2	0.0310	30.00
C_3	0.0148	44.10
i-C_4	0.0059	58.12
n-C_4	0.0030	58.12
n-C_5	0.0005	72.15
i-C_5	0.0010	72.15
H_2O	0.0050	18.00
N_2	0.0010	14.00
H_2S	0.0155	34.10
CO_2	0.0284	44.00
TEG	0.0000	150.154
Total	1.0000	610.894
Operating Condition		
Pressure(kPa)	6205.2832	
Temperature (^{0}C)	29.4444	
Flow rate (kg/s)	768.6343	

2.2. TEG Natural Gas Dehydration Plant

The process flow diagram of the TEG natural gas dehydration plant obtained from HYSYS simulation is presented in figure 1.

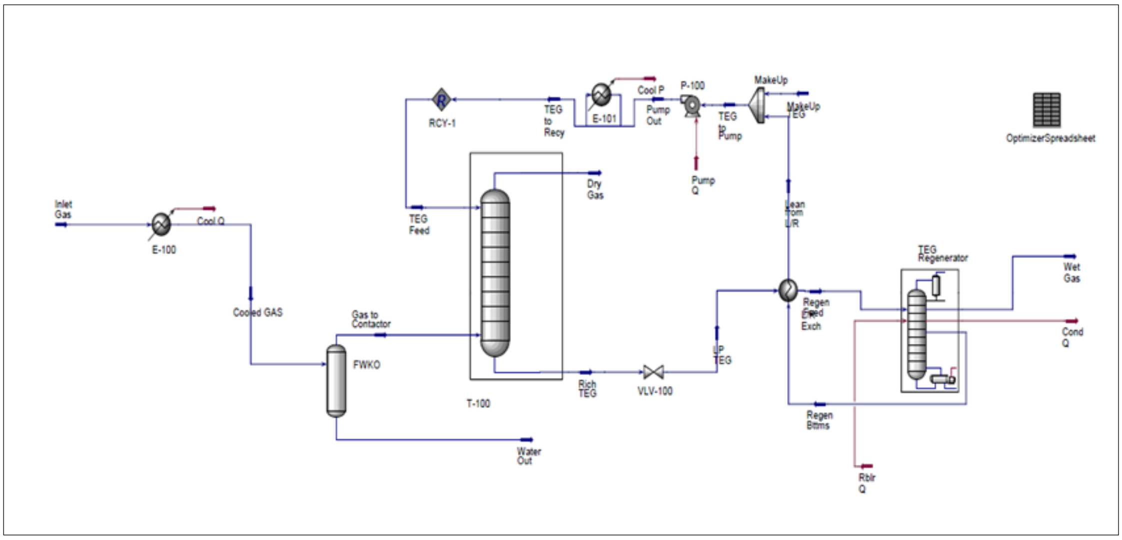

Figure 1 Process Flow Diagram of Natural Gas Dehydration Plant

2.3. Dehydration Plant Units and Process Streams

The TEG natural gas dehydration plant units and process streams are presented in table 2 and 3.

Table 2 Equipment and the Units of Proposed/Modified Plant Design

Design Equipment	Designation/Unit
Cooler 1	U.01
Scrubber/Separator	U.02
Absorber/Contactor	U.03
Heat exchanger 1	U.04
Regenerator/Distillation column	U.05
Mixer	U.06
Pump	U.07
Cooler 2	U.08

Table 3 Streams Associated with Developed TEG Dehydration Plant

Streams	Name
S_1	Inlet gas
S_2	Cooled gas
S_3	Water out
S_4	Gas to contactor
S_5	TEG feed
S_6	Dry gas
S_7	Rich TEG
S_8	Low pressure rich TEG
S_9	Regeneration feed
S_{10}	Wet gas
S_{11}	Regeneration bottom
S_{12}	Lean TEG from L/R
S_{13}	Make-up TEG
S_{14}	TEG to pump
S_{15}	Pump out
S_{16}	TEG to recycle

2.4. Development of the Fan-Powered Cooler Performance Models

Consider the schematic of the fan-powered cooler unit [E101] of a TEG dehydration plant with input and output streams.

2.5. UO8 (Cooler 2) Material Balance

Consider the schematic representation of cooler 2 unit at the TEG inlet to the contactor of the conventional dehydration system indicating mass balance with input and output streams

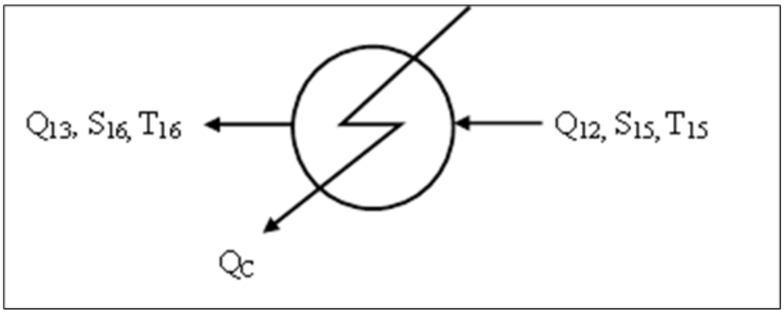

Figure 2 Material and Energy Balance of Cooler 2

The mass balance models of the shell and tube heat exchanger can be developed as follows:

$$\begin{bmatrix} Rate\ of\ input\ of mass/ \\ material\ to\ the\ system \end{bmatrix} = \begin{bmatrix} Rate of output\ of mass/ \\ material from\ the\ system \end{bmatrix} \text{.........(1)}$$

$$S_{15} = S_{16} \text{............(2)}$$

where S_{16} is the TEG to recycle stream (Kg/s)

2.6. UO8 Cooler 2 Energy Balance

Consider the schematic representation of cooler 2 unit at the TEG inlet to the contactor of a dehydration system indicating inflow and outflow of energy or heat in Figure 1.

$$Q_{12} = Q_{13} + Q_C \text{........................} \qquad (3)$$

But

$$Q_C = S_{14} C_{P_{TEG}} T \text{........................} \qquad (4)$$

Therefore,

$$Q_{13} = Q_{12} - Q_C \text{........................} \qquad (5)$$

Where

$\dot{Q}_{13}$ is the lean TEG recycled heat (Kw), $\dot{Q}_C$is the heat of condenser (Kw)
T_{16} is the lean TEG temperature (K) and T_{15} is the Pump out temperature (K)

2.7 Fan-Powered Cooler Design

Consider the schematic representation of a fan powered cooler as shown below:

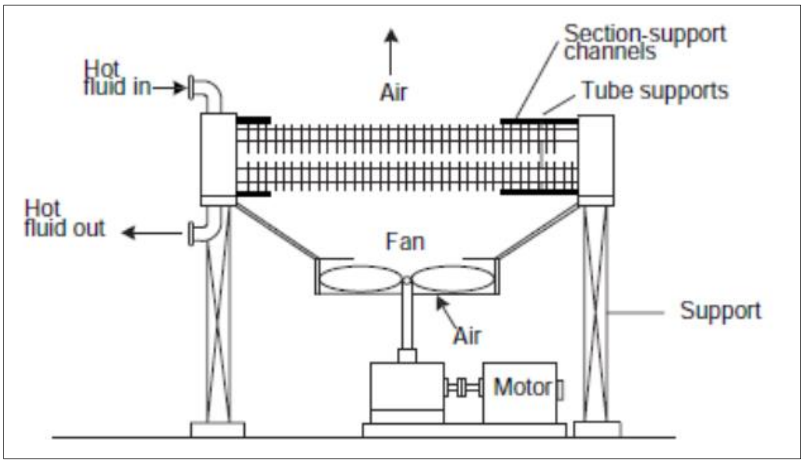

Figure 3 Fan Powered Cooler Design (Sinnott & Towler, 2009)

The following equations can be considered in designing a fan powered cooler

Prandtl Number Determination ($\boldsymbol{P_r}$)

$$P_{r,c} = \frac{C_P \mu_L}{K_L} \text{.......................} \qquad (6)$$

where,C_P is the specific heat capacity of condensate kg/kgk, μ_L is the condensate mass flow rate NS/m^2 and K_L is the condensate thermal conductivity.

Vertical Loading Determination ($\boldsymbol{\Gamma_V}$)

$$\Gamma_V = \frac{\dot{m}}{\pi d_o} \text{.......................} \qquad (7)$$

Where $\dot{m}$ is the condensate mass flow rate

Reynold's Number Determination ($\mathbf{R}_{\boldsymbol{e,C}}$)

$$\mathrm{R}_{e,C} = \frac{4\Gamma_V}{\mu_L} \text{.......................} \qquad (8)$$

Mean Condensate Film Coefficient Determination ($\boldsymbol{h_{C_i}}$) for Shell Side

$$h_{C_i} = 0.5 K_L \left[\frac{{\mu_L}^2}{\rho_L(\rho_L - \rho_g)g}\right]^{-1/3} \text{.......................} \qquad (9)$$

Condensate inside the Tube ($\boldsymbol{\Gamma_{V_i}}$)

$$\Gamma_{V_i} = \frac{\dot{m}}{\pi d_i} \text{.......................} \qquad (10)$$

Tube Side Reynold's NumberDetermination $\left(\boldsymbol{R_{e,t}}\right)$

$$\mathrm{R}_{e,t} = \frac{4\Gamma_V}{\mu_{TEG}} \text{.......................} \qquad (11)$$

Mean Condensate Film Coefficient Determination ($\mathbf{h}_{\boldsymbol{c,t}}$) for Tube Side

$$h_{C,t} = 0.6K_{TEG}\left[\frac{\mu_{TEG}{}^{2}}{\rho_L(\rho_L-\rho_g)g}\right]^{-1/3} \dots\dots\dots\dots(12)$$

Cross-Sectional Area of the Tube Determination ($\boldsymbol{A_C}$)

$$A_C = \frac{\pi d_i^2}{4}\dots\dots\dots\dots \qquad (13)$$

Tube-Side Velocity Determination ($\boldsymbol{U_t}$)

$$U_t = \frac{\dot{m}}{\rho_L A_C}\dots\dots\dots\dots \qquad (14)$$

Reynold’s Number Determination ($\boldsymbol{R_e}$)

$$R_e = \frac{\rho U_t d_i}{\mu_{TEG}}\dots\dots\dots\dots \qquad (15)$$

Applying the correlation used by Boyko and Kruzhilim

$$h_t^1 = \frac{d_i K_L}{\mu_L}(R_e)^{0.8}\left(P_{r,C}\right)^{0.43}\dots\dots\dots\dots \qquad (16)$$

$$h_{C,t} = h_t^1\left[\frac{1+\sqrt{\rho_L/\rho_g}}{2}\right]\dots\dots\dots\dots \qquad (17)$$

Overall heat Transfer Coefficient Determination ($\boldsymbol{U_0^1}$)

$$U_0^1 = \frac{1}{\frac{1}{h_{C_i}}+\frac{1}{h_{C,t}^1}+\frac{1}{h_C}}\dots\dots\dots\dots \qquad (18)$$

Area of Exchange ($\boldsymbol{A_C}$)

$$A_C = \frac{Q_C}{U_C \Delta T_m}\dots\dots\dots\dots \qquad (19)$$

Bundle Area Determination ($\boldsymbol{A_b}$)

$$A_b = LP_t N_{bk}\dots\dots\dots\dots \qquad (20)$$

where,L is the effective tube length, P_t is the tube pitch and N_{bk} is the boundle group number

Fan Power Consumption Determination ($\boldsymbol{W_f}$)

$$\frac{W_f=\mu_f A_b \Delta P_b}{\gamma_f}\dots\dots\dots\dots \qquad (21)$$

where,μ_f is the face velocity, ΔP_b is the pressure drop across the bundleandγ_f is the fan efficiency typically about 0.6

3. Results and Discussion

The results of the fan-powered cooler unit at the TEG inlet to the contactor for mass, energy and composition are presented and discussed in Tables 4, 5 and 6 below:

Table 4 Material Balance Results for Cooler 2 in the Conventional Design

Cooler 2 Streams	Inflow Pump Out (S_{15})	Outflow TEG to Recycle (S_{16})	Difference
Molar Flow (Kgmol/S)	0.00101	0.00101	0.0000
Mass Flow (Kg/S)	0.14221	0.14221	0.0000
Volume Flow (m^3/S)	0.00013	0.00013	0.0000

Table 4 is the material balance of cooler 2 unit in the conventional design of a natural gas TEGdehydration plant configuration. This unit is a single input, single output system and where inflow equals outflow ($S_{15} = S_{16}$). In this unit, no changes in material balance occur. The cooler 2 unit is configured basically to maintain the temperature of lean TEG that is suitable for dehydration in the absorber or contactor unit.

Table 5 Energy Balance Results of Cooler 2 in the Conventional Plant Design Configuration

Cooler 2 Streams	Inflow Pump Out	Outflow TEG to Recycle	Difference
Temperature (^{0}C)	60.1437	48.8889	11.2548
Pressure (kPa)	6274.2308	6274.2308	0.0000
Heat Flow (KJ/S)	-7.83×10^2	-7.81×10^2	-2.4444

From Table 5, the cooler 2 unit in the conventional design is a single input and single output system. The temperature decrease in the TEG to recycle is as a result of the loss of heat in the cooler to keep the lean TEG in a higher temperature suitable for absorption to take place in the absorber thereby preventing TEG loss due to high temperature. Hence, the maximum temperature difference between inflow and outflow streams is 11.2548^{0}C while the heat flow difference between the inflow and outflow streams is 2.4444kJ/S. No pressure difference is observed in this unit. The heat loss to the atmosphere as a result of the fan powered cooler is vital to keep the lean TEG temperature with the temperature limit for efficient dehydration.

Table 6 Composition Balance Results of Natural Gas Component in Cooler 2 (Unit 08)

Composition (Mole Fraction)		
Components	**Inlet Stream (S_{15}) Pump Out**	**Outlet Stream (S_{16}) TEG to Recycle**
N_2	0.0000	0.0000
CO_2	0.0000	0.0000
H_2S	0.0000	0.0000
C_1	0.0000	0.0000
C_2	0.0000	0.0000
C_3	0.0000	0.0000
i – C_4	0.0000	0.0000
n – C_4	0.0000	0.0000
i – C_5	0.0000	0.0000
n – C_5	0.0000	0.0000
TEG	0.9249	0.9249
H_2O	0.0751	0.0751

From Table 6, the cooler 2 unit demonstrates a single input and single output-system. The role of this unit is to ensure that the temperature of the recycled Lean TEG is cooled and suitable enough for further dehydration of natural gas feed in the absorber. Hence, no changes in composition occurs in this unit and by implication, $S_{15} = S_{16}$.

4. Conclusion

The design of the natural gas TEG dehydration plant was performed using the advanced process simulation tool HYSYS and the performance model of the fan-powered cooler unit at the TEG inlet to the contactor was developed from the first principle of mass and energy balance. The results of the fan-powered cooler mass balance, energy balance and composition balance are summarized in Tables 4 to 6. The discussions of the results were in agreement with the objectives of this article. Furthermore, the design and performance analysis of the fan-powered cooler at the TEG inlet to the contactor is critical to the success of a TEG dehydration process plant. A well-designed fan-powered cooler can maintain optimal performance by regulating the heat of the lean TEG before it enters the contactor column where the TEG natural gas absorption takes place.The lean TEG temperature within the standard specification plays an important role for effective dehydration by preventing loss of TEG as well as the dried natural gas. The performance analysis of the heat exchanger indicated that optimizing design parameters such as the lean TEG temperature, can significantly improve heat transfer rates. Such improvements will lead to an overall increase in TEG dehydration process efficiency, reducing energy consumption, loss of process materials and cost of production

Compliance with ethical standerds

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Authors Contribution

W. C. O and A. E: Conceptualization, Methodology, Original draft preparation, Performed simulation work writing.

Competing Interest

The authors declares that they have no known competing financial interests or personal that could have appeared to influence the work reported in this paper.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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