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Application of Compact Mixer Technique for Khalda Gas Dehydration Plant

Abeer M. Shoaib, Ahmed A. Bhran, Moamen F. Hamed

***Abstract*— The present work aims to investigate the applicability of the compact mixer dehydration technique for Khalda Petroleum Company (KPC) gas plant instead of conventional dehydration process. The effective parameters studied in this work are absorbent flowrate, stripping gas flowrate, and heat requirement during the regeneration process. Simulation results reveal that lower hydrocarbons emissions and heat duties as well as lower absorbent losses are obtained with the proposed compact mixer dehydration process. However, the adverse effect of the compact mixer technique is the higher water content of the dehydrated gas. Three different types of absorbents were studied to select the appropriate absorbent for the compact mixer dehydration process. Results showed that diethylene glycol (DEG) is the most preferable absorbent. This is due to lower heat duty and hydrocarbons emissions of the dehydration plant when using DEG as an absorbent. According to the aforementioned advantages, the compact mixer process could be applied for KPC gas dehydration plant especially when DEG is used as an absorbent. Furthermore, compact mixer technique has other benefits compared to the conventional dehydration method such as unit compact size, higher turn-down ratio, and easier operation and maintenance.**

***Index Terms*—Gas dehydration; absorption process; compact mixer process.**

I. INTRODUCTION

Natural gas is an important source of energy in human life and is a naturally occurring fuel found in oil fields. Natural gas, either from natural production or storage reservoirs, usually contains water or is fully saturated during production operation, which results in many problems. Water may condense and form solid gas hydrates or freeze, at low temperature and high pressure, which plug pipeline flow and especially control systems. Gas hydrate could be defined as clathrate physical compounds, in which the molecules of gas are occluded in crystalline cells, consisting of water molecules retained by the energy of hydrogen bond [1]. Additionally, it may damage pipelines due to the corrosive effect of water (especially in the presence of H_2S and CO_2) and reduce the combustion efficiency [2]. Moreover, it results in a reduction in line capacity due to collection of free water in lines [3]. Thus, effective removal of water from natural gas to a controlled water content (dehydration) becomes an essential target to avoid hydrate formation as well as to minimize corrosion and other related problems. This process is one of the most important operations in gas processing and conditioning [4].

Several methods for gas dehydration have been introduced over years. These include: Absorption, Adsorption, Gas refrigeration and Gas permeation. Among these methods absorption has been used on an industrial scale for many years [5]. Dehydrating absorbents as mono-ethylene glycol (MEG), diethylene glycol (DEG), and triethylene glycol (TEG) are used for absorption process [6,7,8].

For traditional gas dehydration technique as absorption which using absorber tower has many disadvantages such as foaming and flooding. It also needs large stripping section to recover large volume of the reagent. Additionally, the high solvency power of the absorbent increases the corrosivity of the gas that led to material with special demands that increasing the capital, operating and maintenance costs [9]. All these disadvantages lead to the search for a more beneficial technique for gas dehydration.

The injection and mixing of TEG with the feed gas could be considered as an alternative dehydration concept [10]. Several commercial mixing concepts are available in literature, but this work is focusing on the ProPure compact mixer [11]. It is one of the newest and most promising compact mixing units for use in the natural gas industry available today [10]. It depends on providing liquid as the periphery of the pipe, gas flowing through the pipe drawing the liquid into a film, moving this film along inner surface to a sharp edge. Liquid breaks off the surface at the sharp edge end and mixing these droplets with gases flowing.

The flow in this method will be a continuous process and the gas and liquid flowing co-currently. Foaming or flooding problems could be eliminated by the co-current flow since separation can easily be effected downstream of the mixer [11].

Additionally, due to environmental limitation of BTEX (benzene, toluene, ethyl benzene, xylene) and VOCs (volatile organic compounds) emissions, it is important to reduce these emissions to an acceptable values. This can be achieved by applying the proposed compact mixer process new technique investigated in this study instead of conventional absorber tower for the natural gas dehydration plant in Khalda Petroleum Company. The compact mixer process under

Ass. Prof. Abeer M Shoaib, Department of Petroleum Refining and Petrochemical Engineering, Faculty of Petroleum and Mining Engineering, Suez University, Egypt., Mobile no. (02-01004554076)

Ass. Prof. Ahmed Bhran, Department of Petroleum Refining and Petrochemical Engineering, Faculty of Petroleum and Mining Engineering, Suez University, Egypt., Mobile no. (02-01096438600)

Eng. Moamen Fawzy, Faculty of Petroleum and Mining Engineering, Suez University, Egypt., Mobile No. (01000146553)

consideration is investigated to show its effectiveness compared to the conventional absorption process.

It is expected that the compact mixer process of TEG can lower the absorbents losses and hydrocarbons emissions. Furthermore, the proposed technique may participate to solve dehydration tower problems such as flooding and foaming. HYSYS simulation software version 8.0 was used to simulate the compact mixer process as a mixing unit with three theoretical stages.

II. Khalda Natural Gas Dehydration Plant Description

Fig. 1 shows the gas dehydration plant of KPC which uses triethylene glycol (TEG) as an absorbent for water removal. The TEG-dehydration process can be divided into two major parts, gas dehydration and solvent regeneration. In dehydration, water is removed from the gas using TEG and in the regeneration, water is removed from the solvent (TEG). The inlet wet gas stream of 6190 kgmole/hr which contains water mole percentage of 0.2356% is cooled in the inlet cooler to a temperature of 50 °C to condense some vapours such as water and heavy hydrocarbons.

Then, the cooled stream enters inlet scrubber at pressure of 67.39 barg to remove free liquid and liquid droplets in the gas, both water and hydrocarbons. Removing liquids in the scrubber decrease the amount of water that has to be removed in the absorption column and this also decrease the size of the column and therefore decrease the TEG needed in process. Lean TEG is fed to the top of the contactor and absorbs water from the gas while flowing downward through the column [12, 13, 14].

The dried gas leaves from the top of the absorber with water mole percentage of 0.004% (dew point of -9 °C). Rich glycol from the bottom of the absorber contains 23% of water passed through pressure reducing valve as the regeneration process will be operated with low pressure to remove the water to very low concentration. The rich glycol is used to provide cooling and condense water vapour at the top of the regenerator acting as reflux led to raise the temperature of the rich glycol due to heat exchange.

Then partially heated rich TEG entered a reduced pressure flash tank where dissolved hydrocarbon gases are released and used for fuel or other purposes. The partially heated rich glycol is then heated by heat exchange with hot lean glycol from the regenerator in tube shell heat exchanger [8]. The rich glycol passed through a filtration system and finally entered the regenerator column tray section. Water vapour from reboiler entered the regenerator and heat exchanged with the rich glycol that increases its temperature and removes some of water before moving to reboiler so reduce the duty required from the reboiler and consequently minimizes fuel consumption in the reboiler.

Concentration of TEG after regeneration reached 97.47% as mole percentage. At the end of the process cycle, the regenerated TEG will be cooled in the third step of heat exchanger and will back to the dehydration column for reuse.

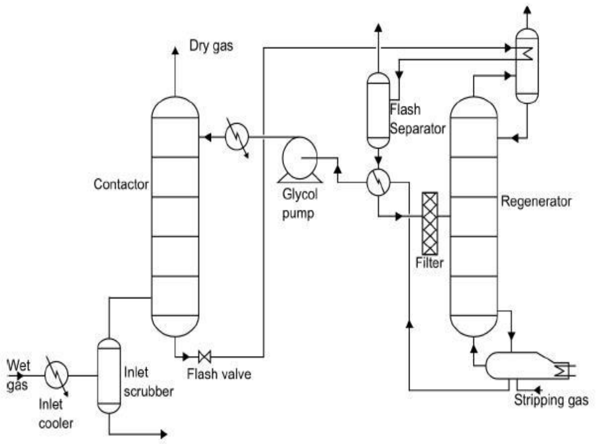


Fig. 1: Khalda Petroleum Company natural gas dehydration process [8]

III. Description of the Dehydration New Technique

The injection and mixing of TEG with the feed gas is an alternative dehydration concept. To minimize the circulation of TEG and enhance the overall unit efficiency, it is very important that the mixer creates as near equilibrium mix as possible, at the same time conserving most of the pressure.

There are several commercial mixing concepts available. However, this study consider the mixing unit from ProPure, as it is one of the newest and most promising compact mixing units for use in the natural gas industry available today [10].

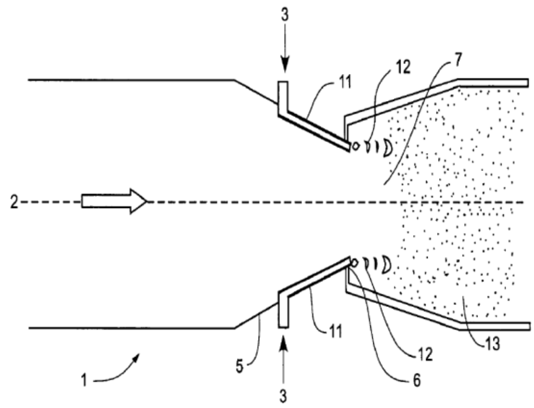


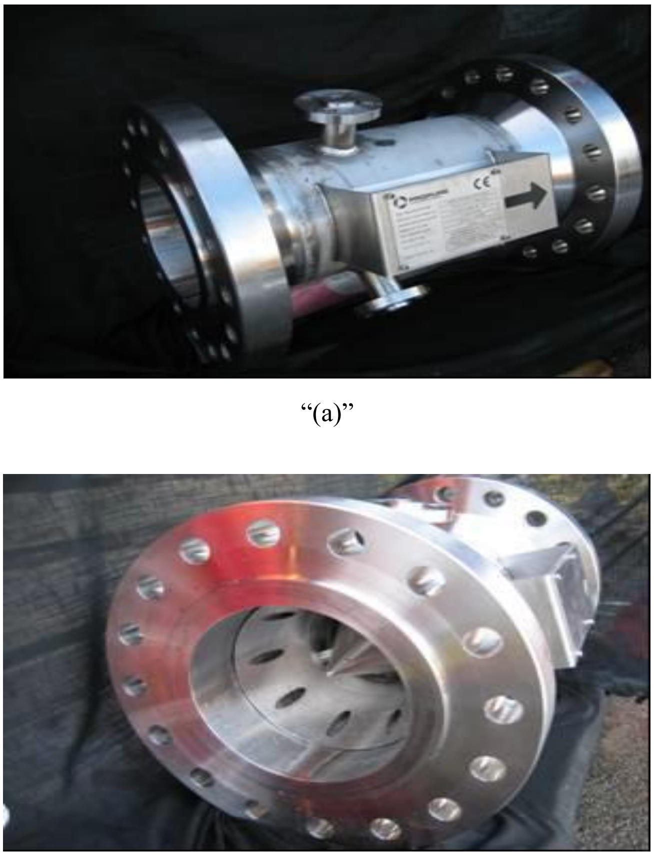
Fig. 2: compact mixer description

Fig. 2 shows the ProPure compact mixer. The contactor (point1) comprises a gas stream inlet (point 2), a liquid stream inlet (point 3) and an outlet (point 4). The gas stream is supplied to the gas stream inlet which leads to a converging pipe section (point 5).

The converging pipe section (point 5) accelerates the gas stream as it passes the liquid stream inlet to the end of the pipe section (point 5) where there is a sharp edge (point 6). Downstream of this sharp edge is a reaction zone (point 7) where the gas and liquid are preferably formed into a homogeneous mixture [15].

The liquid annulus presented to the inner surface of the pipe is drawn along the inner surface of the pipe in the form of a film (point 11) by the gas stream. The liquid film (point11) closely adheres to the side of the pipe section until the sharp edge is reached. At this point, the liquid film breaks up to form filaments (point 12).

The generation of the filaments, and their subsequent velocity vector, is determined by the relative velocity between the gas and the liquid phases, the gas-liquid surface tension and the sharp edge [16]. Due to the extremely turbulent conditions in the reaction zone, the filaments are further broken up into very small droplets (point 13) which provide a very high surface area to volume ration thereby making extremely efficient use of the liquid provided. This allows the use of considerably smaller volumes of liquid than are required by the conventional prior art processes. The ProPure C100W (ProDry) co-current compact mixer, as seen in Fig. 3, corresponds to one theoretical stage in a conventional counter current process [17]. A conventional absorber represents typically 2–4 theoretical stages. The dried gas leaving ProDry, is in equilibrium with the rich glycol. The ProDry has a high interfacial area between the gas and liquid phase.



“(a)”

“(b)”

Fig. 3(a&b): The ProPure compact mixer [17].

The compact mixer was modeled using a mixing unit in HYSYS. This unit assumes perfect mixing of the different streams, which is impossible to achieve in practice. So even though the compact mixer from ProPure has shown to be more efficient than other mixing units available, this still will introduce an error in the simulation model. To model the pressure drop of 0.3 bar across the mixer, a valve is placed after the mixing unit [8].

IV. Results and Discussion

The aim of the present study is to show the effectiveness of the compact mixer technique for dehydrating the natural gas produced from KPC compared to the existing traditional absorption process. The gas plant dehydrated by the two investigated techniques was simulated using HYSYS simulation software version 8.0 with Penq-Robinson as equation of state. The comparison between the two dehydration techniques considered the following parameters:

a) Absorbent flowrate.
b) Effect of stripping gas on the regeneration process and gas dryness.
c) Reboiler Energy consumption with and without stripping gas.
d) Absorbent losses and HCS emissions.

A. *Dehydration performance*

The simulation results of the two dehydration processes without stripping gas are shown in Fig. 5. These results reveal that the traditional dehydration process requires less circulated TEG flowrates compared to the compact mixer process to obtain a given dryness.

It is clear that, for both dehydration techniques, the increasing of regeneration temperature reduces the water content in the dehydrated gas at all the investigated TEG flowrates (20-120 Kmole/hr). This is logic because increasing the regeneration temperature increases the purity of the TEG which consequently increases its activity in dehydration process. However, there are limits on the regeneration temperature of the glycol. The applied regeneration temperature of TEG is from 193 to 200 °C [18]. The maximum limit of TEG regeneration temperature is a few degrees below the glycol decomposition temperature and it is about 204 °C. Below 193 °C, the regenerated lean glycol is obtained with low purity and this consequently leads to higher dew point for sales gas. Thus, this study was applied at regeneration temperatures of 204, 200, and 196 ^{o}C which are accepted as allowable temperatures for TEG regeneration.

The results showed that the increasing of TEG flowrate from 20 to 50 Kmole/hr in both dehydration techniques reduces the water content in the outlet gas. For TEG flowrates higher than 50 Kmole/hr, there is no significant effect of TEG flowrate on reducing the outlet dehydrated gas water content. So, the operating flowrate of TEG was chosen to be 47.74 Kmole/hr. The present dehydration technique shows lower water contents in the dehydrated gas at all TEG flowrates and all regeneration temperatures compared to the proposed new technique. The maximum difference between the water contents of the two investigated techniques for the outlet sales gas appeared at lower TEG flowrate (20 Kmol/hr) and it is lower than 30 ppm of water considering all tested regeneration temperatures.

However, at the operational TEG flowrate of 47.74 Kmole/hr, this difference is less than 20 ppm. Although, the water content in the dehydrated gas of the compact mixer is slightly higher than that of the original dehydration technique, the compact mixer is favoured due to its benefits which include lower operational problems, lower maintenance cost and mixer compactness.

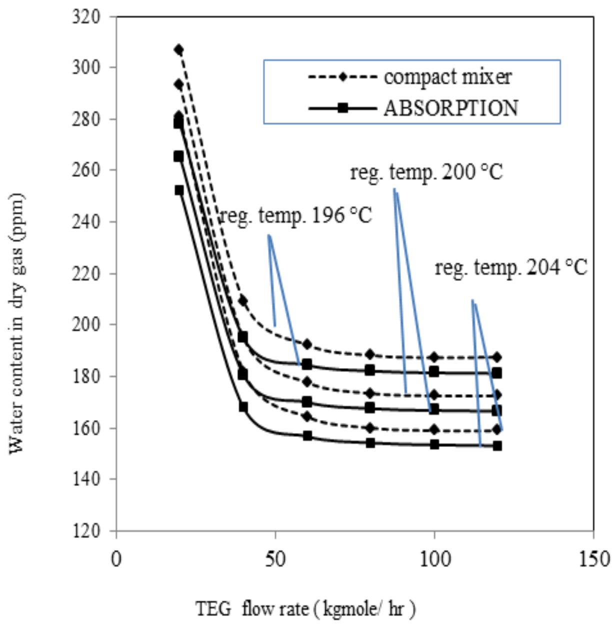


Fig. 4: Water content of dehydrated gas at regeneration temperature of 204, 200 and 196°C

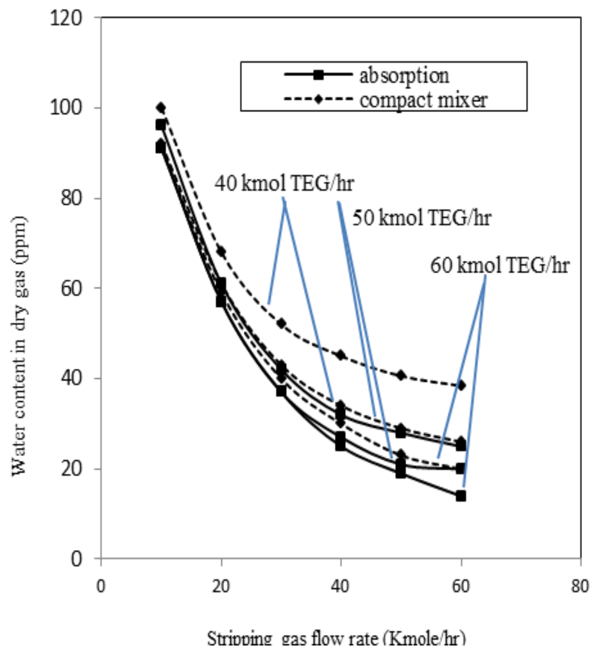


Fig. 5: Water content of dehydrated gas at 40, 50 and 60 kgmole TEG/hr.

The effect of stripping gas on the dehydration process was studied at 40, 50 and 60 kmole/hr of TEG, regeneration temperature of 204°C and a pressure of 110 Kpa for both dehydration techniques. The water content of the dehydrated gas decreases with increasing the stripping gas flowrate for both dehydration techniques as shown in Fig. 5. The old absorption method shows lower water content in the outlet dry gas compared to the proposed new technique. Nevertheless, the maximum difference in the water content between the two different methods is lower than 15 ppm. In addition, at the operating conditions (20 Kmole/hr of stripping gas and about 50 Kmole/hr of TEG) this difference is only about 4 ppm. So, it is clear that both dehydration techniques give nearly the same water content of the dehydrated gas at the operational conditions. However, according to the other benefits of the proposed compact mixer as mentioned earlier, it is preferred for the gas dehydration.

B. Hydrocarbons emissions

Stripping gas in the regeneration process has an effect on the amount of hydrocarbons emissions from the system. Fig. 6 shows the relation between the amount of HCS emissions and the TEG flowrate at the regeneration temperature maximum limit of 204 °C and without using a stripping gas. The results reveal that the compact mixer regeneration process has lower HCs emissions compared to that of the old technique. Moreover, the difference in the amount of HCs emissions estimated for the old and compact mixer dehydration processes is increased with increasing the TEG flowrate. The effect of the stripping gas on the regeneration process HCs emissions was studied at TEG flowrate of 50 Kmole/hr and regeneration temperature of 204 °C as presented in Fig. 7. With stripping gas, compact mixer technique still shows lower HCs emissions in comparison to the conventional technique.

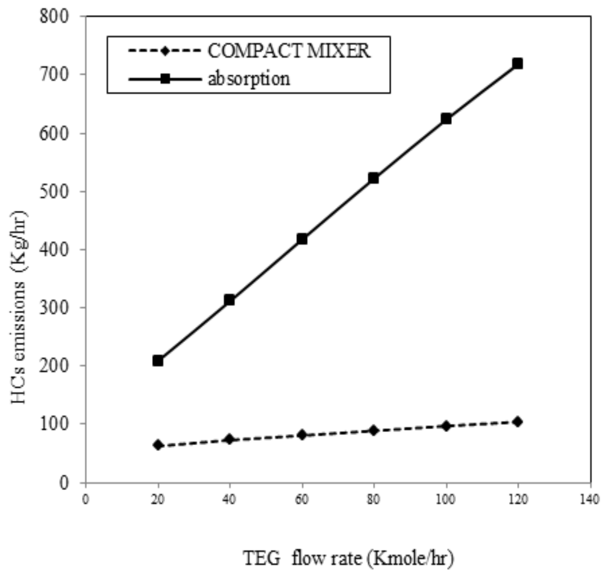


Fig. 6: Hydrocarbons emissions (without stripping gas) at regeneration temperature of 204°C

It is noticed that with increasing the stripping gas flowrate, the HCs emissions increases in both techniques but the difference between them decreases. These results are logic because the original absorption process required high pressure in the absorber tower, so more hydrocarbons are absorbed in rich glycol. During regeneration, more hydrocarbons are vented from the regeneration tower. This could be attributed also to the higher temperature and lower pressure in the regeneration process. However, the optimum flowrate of the stripping gas should be calculated to achieve the optimum condition for operating each of the two investigated dehydration technique. This can be done in our future research work.

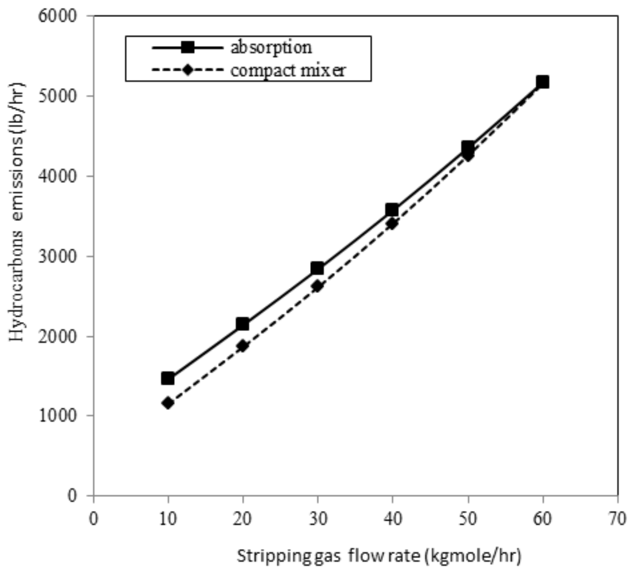


Fig. 7: HCS emissions using stripping gas at 50 kgmole/hr of TEG and at regeneration temperature of 204 °C.

C. Heat duty requirement for the reboiler

The energy required in the reboiler is affected by the type of dehydration technique used as shown in Fig. 8. The energy requirement was estimated for both investigated techniques at various TEG flowrates, at regeneration temperature of 204 °C, and without using a stripping gas. It is obvious that the energy requirement for the reboiler is lower in case of compact mixer and the difference between the two considered techniques is increased as the TEG flowrates is increased.

It is also noticed that the heat duty of the reboiler is increased as the TEG flowrate is increased for the both considered techniques. The lower heat duty requirement in case of compact mixer process could be attributed to the lower amount of absorbed hydrocarbons that need lower heat duty to be removed in the regenerator.

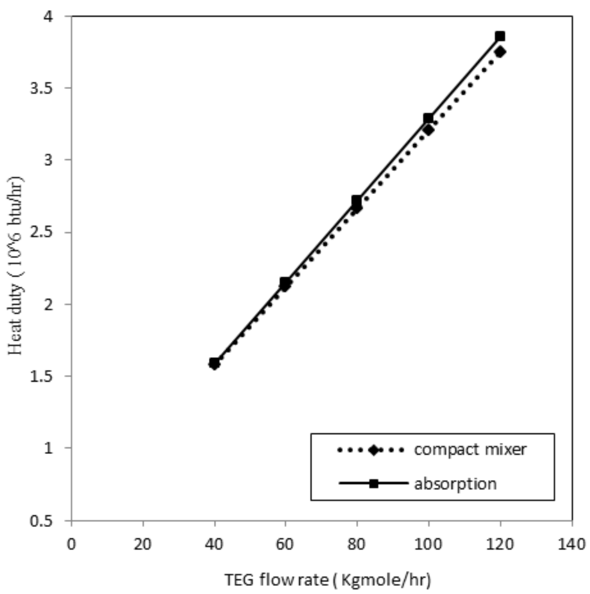


Fig. 8: Reboiler heat duty without using stripping gas and at regeneration temperature of 204°C.

The influence of stripping gas on the heat requirement for the reboiler was studied at various TEG flowrates and at regeneration temperature of 204 °C as addressed in Fig. 9. The results indicated that the heat requirement for the reboiler is increased with increasing the stripping gas flowrate and the influence is duplicated at higher flowrate of TEG. Also, it is clear that the difference in heat duty required for the reboiler according to the both techniques is higher by using the stripping gas.

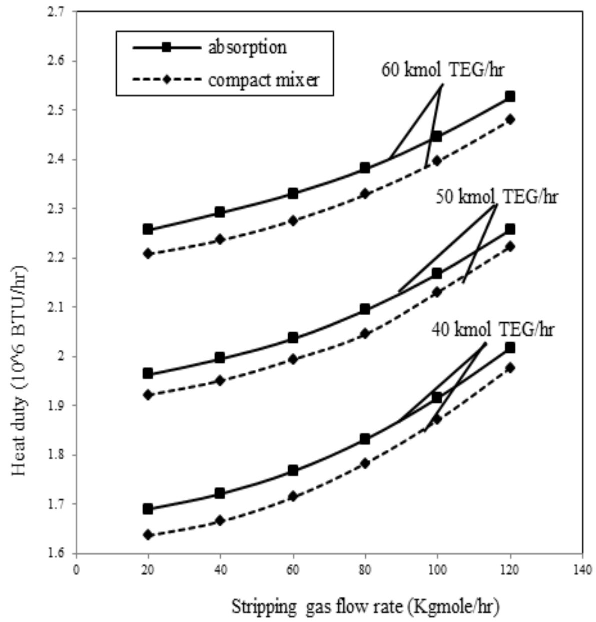


Fig. 9: Reboiler heat duty requirement with using stripping gas and at TEG flowrates of 40,50 and 60 Kgmole/hr

D. Absorbent Losses

It is important to study the influence of the compact mixer dehydration technique on the amount of the TEG losses during the regeneration process. The results shown in Fig. 10 were obtained without using stripping gas in the regenerator for the two considered techniques at different flowrates of TEG, and at regeneration temperature and pressure of 204°C and 10 KPa respectively. These results reveal that the TEG losses are high in the case of old regeneration technique at all studied TEG flowrates. The regeneration process with stripping gas was investigated at the operational conditions; 50 Kmole/hr of TEG, regeneration temperature and pressure of 204°C and 10 KPa respectively. From the simulation results for the both dehydration techniques presented in Fig. 11, it is clear that the amount of TEG losses during regeneration process is more in the case the conventional dehydration technique at all studied stripping gas flowrates.

In addition, it is noticed that the stripping gas flowrate has a minor effect on the TEG losses for both investigated techniques. The higher amount of TEG losses in the traditional dehydration technique could be attributed to the higher amounts of HCs absorbed with the rich glycol in the absorber tower as seen from the higher amount of HCs emissions during regeneration (see Fig. 6 and 7). During regeneration process, the removal of these HCS is accompanied with more losses of TEG.

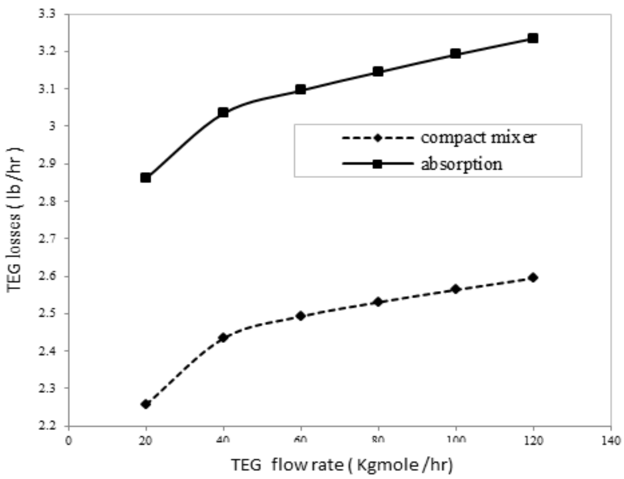


Fig. 10: TEG losses during regeneration without using stripping gas and at regeneration temperature of 204°C

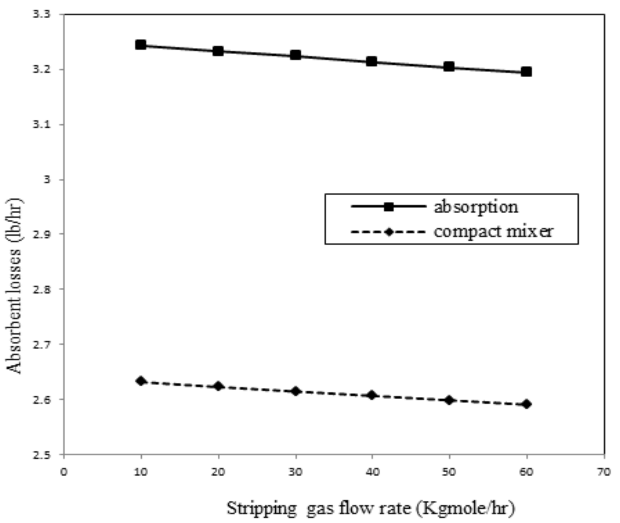


Fig. 11: TEG losses during regeneration with stripping gas at 50 kgmole /hr of TEG and regeneration temperature of 204 °C

E. Selection of the appropriate dehydration technique

A water content of 165 ppm was chosen for a comparison of the TEG injection process (compact mixer) to conventional absorber dehydration without using stripping gas as shown in Table 1. The results reveal that the required circulated amount of lean TEG is lower in case of the existent dehydration process; e.g. 40 and 60 Kgmole/hr for conventional absorber and TEG injection processes respectively. In addition, the energy requirement in the regeneration process is lower in case of the conventional dehydration technique. Thus, the current dehydration process is preferred over the compact mixer in the viewpoint of economics. However, the TEG injection process vents more than threefold of hydrocarbons emissions compared to the existent dehydration unit for obtaining a dehydrated gas with 165 ppm of water. Furthermore, the TEG losses from the regenerator are higher in case of the regular absorber dehydration process. Also, if the requirements for water concentration are less stringent, the compact mixer process becomes more competitive and is almost as good as the traditional dehydration method [8].

Table 1: Comparison between compact mixer and conventional absorber dehydration processes without using stripping gas.

Technique	Water content ppm	TEG flowrate (kgmole/hr)	Required energy (10^6 btu/hr)	HCS emissions (Kg/hr)	TEG Losses (lb/hr)
Compact mixer	165	60	2.121	80.75	2.493
Absorber	165	42	1.589	330	3.04

Introducing stripping gas in the regeneration process gives different results. Table 2 presents a comparison of compact mixer to absorber dehydration techniques (provided stripping gas is used) at lean TEG flowrate of 50 kgmole/hr and a water content of 40 ppm in the dehydrated gas. It is observed that the TEG compact mixer technique required more stripping gas flowrate; 33 and 28 kgmol/hr for the TEG injection and absorber methods respectively. Also, it is noticed that the hydrocarbons emissions are higher for the TEG injection process due to the higher flowrate of stripping gas in this case. Nevertheless, TEG compact mixer process has lower TEG losses and to somewhat lower heat duty requirements for the regeneration of the rich absorbent.

Table 2: Comparison between compact mixer and conventional absorber dehydration processes when using stripping gas.

Technique	Water content (ppm)	Stripping gas (kgmole/hr)	Required Energy (10^6 BTU/hr)	HCS emissions (lb/hr)	TEG Losses (lb/hr)
Compact mixer	40	33	1.94	2750	2.61
Absorber	40	28	1.97	2500	3.22

Table 3: Performance of different absorbents for the compact mixer dehydration process

Abs.	Abs. flowrate, Kg/hr	Stripping gas, Kgmol/hr	Water content , ppm	HCS emissions, Kg/hr	Req. Energy, MJ/hr	Abs. losses, Kg/hr
MEG	7000	30	60	2.9	0.998	15.34
DEG	7000	28	60	7.1	1.12	7.4
TEG	7000	21	60	60.2	1.95	2.55

The effect of different absorbents on the two dehydration techniques was studied. The investigated absorbents are mono ethylene glycol (MEG), diethylene glycol (DEG), and triethylene glycol (TEG). These absorbents were applied at a flowrate of 7000 kg/kr to achieve dehydrated gas with water content of 60 ppm and the results are presented in Table 3. From these results it is clear that:

- ✓ Due to the higher losses of MEG which are twice that of DEG and six times that of TEG, MEG is not used for compact mixer dehydration process, even though it has the best dehydration performance in view of lower hydrocarbon emissions and energy requirement. Moreover, it is noticed that MEG requires high amount of stripping gas compared to that of DEG and TEG.

- ✓ TEG requires the lowest stripping gas flowrate with the lowest absorbent losses compared to the two other types of absorbent to obtain the same degree of dryness. However, TEG requires the highest heat duty and the dehydration process is accomplished with the highest amount of HCs emissions vented to the atmosphere. This consequently increases the pollution problems which may be not accepted in some cases according to the environmental regulations.

- ✓ DEG requires higher stripping gas flowrate and DEG losses are higher than that of TEG. However, DEG may be preferred over TEG due to its influence on lowering heat duty and HCs emissions.

V. Conclusion

The applicability of the compact mixer as an alternative method to dehydrate the natural gas of the KPC was studied in this work. The results reveal that the traditional dehydration process has advantages of lower water content in the dehydrated gas compared to the proposed new technique at all tested TEG flowrates. However, at the existing plant operational conditions, the difference in dehydrated gas water content calculated for the both techniques is less than 20 ppm without using stripping gas and 4 ppm when using stripping gas in the regeneration process. Furthermore, the compact mixer technique has lower absorbent losses and heat requirement as well as lower HCs emissions. The effect of stripping gas appears in decreasing the water content of the dehydrated gas for both dehydration techniques. However, the heat requirement and HCs emissions were increased when stripping gas is used in the regeneration process. The effect of stripping gas is increased with increasing its flowrate. So, it is important to calculate the stripping gas optimum flowrate based on the plant economic study.

The effect of different absorbents (MEG, DEG, and TEG) on the compact mixer dehydration technique was studied. The MEG losses are twice that of DEG and six times that of TEG. This is why MEG is not preferred as an absorbent for the compact mixer dehydration process, although it has the lowest hydrocarbon emissions and energy requirement. Moreover, it is noticed that MEG requires high amount of stripping gas compared to that of DEG and TEG. Considering dehydration with DEG, it requires higher stripping gas flowrate and DEG losses are higher compared to the dehydration process using TEG. However, DEG may be preferred over TEG as an absorbent due to lower heat duty and lower HCs emissions in case of dehydration process using DEG. In addition, the dehydration process using TEG is accomplished with the highest amount of HCs emissions vented to the atmosphere. This consequently increases the pollution problems which may be not accepted in some cases according to the environmental regulations.

Although, the water content of the dehydrated gas of the compact mixer technique are higher than that of the original dehydration technique, the compact mixer may be favored over the traditional process due to its considerable benefits which include lower reboiler heat duty, lower absorbent losses, lower HCs emissions, lower operational problems, lower maintenance cost as well as the plant compactness. In addition, if the required water content in the dehydrated gas is less stringent, the compact mixer process becomes more competitive and is almost as good as the traditional dehydration method specially when using DEG as an absorbent.

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Ass. Prof. Abeer M. Shoaib; Vice Dean of Higher Graduate Studies in the Faculty of Petroleum and Mining Engineering, Suez University- Post Doctor Fellowship in Process Integration Centre, The University of Manchester, UK. She is an editor of the Petroleum and Mining Engineering Journal (PMEJ). She is a reviewer in Resources, Conservation & Recycling Journal- Elsevier. Her research interests focus on the area of Optimization and Process integration; hydrogen networks, heat exchanger networks, water networks, bio refinery integration. Additionally, she is interested in biofuel manufacturing and reclamation of used lubricating oils.


Ass. Prof. Ahmed A. Bhran, is an assistant professor at the Department of Petroleum Refining and Petrochemical Engineering, Faculty of Petroleum and Mining Engineering, Suez University, Egypt. His PhD degree was taken from Lorraine University, France in the field of photochromic polymers. Her research interest is in the area of Natural gas processing, optimization in the field of petroleum industry, polymer technology, Biofuel manufacturing, and water treatment by composite material or RO membrane. He is an excellent trainer and gives many advanced courses in the field of natural gas processing and petroleum refining besides the petrochemical industries. He is a reviewer in the Journal of Natural Gas Science and Engineering.


Eng. Moamen F. Fawzy, Gas and oil process and production engineer. He is responsible for monitoring production of the wells, and preparing production daily report for all western desert wells. He participates in preparing production workshops about sucker rod pumping units. He is also responsible for monitoring and detecting the production of wells by telemetry project (remote controlling system) which is the first one applied on shore in Egypt and it is handling for wells production because the process is easier for production. He had his B.S. in Petroleum refining & petrochemical engineering department (Sep. 2008), Faculty of Petroleum and Mining Engineering, Suez University, Egypt. Mobile No. 01000146553,