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A Systemic Optimization Approach for the Design of Natural Gas Dehydration Plant

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ABSTRACT
In designing dehydration units for natural gas, several critical parameters exist which can be varied to achieve a specified dew point depression. This paper studies the effects of varying number of trays in the contactor, glycol circulation rate through the contactor, temperature of the reboiler in the regenerator, amount of stripping gas used and operating pressure of the regenerator on the water content of the gas in a glycol dehydration unit. The effect of incorporating free water knock out (FWKO) tank before the absorber is also presented. An offshore platform in the Arctic region was chosen as the base case of this simulation and was modeled by using ASPEN HYSYS. Results show that the incorporation of FWKOT does not affect the TEG circulation rate required to approach equilibrium.

I. INTRODUCTION

Nowadays, natural gas is the most valuable source in the world because it is a very important source to generate the energy that is widely used in commercial, industrial and transportation. However, under normal production condition, the natural gas is saturated with water vapor. Water is an impurity found in all natural gas reservoirs to various extents all across the world [1]. However, as long as the water is in vapor phase it presents no danger, but as soon as liquid water is formed several problems arise. High pressure hydrocarbons together with liquid water are able to form an ice like structure called hydrates at ambient temperatures, which can plug the entire pipe or channels in process equipment if allowed to develop. Sour gases, another common impurity of natural gas, mixed with liquid water are corrosive, and of course if the temperature gets low enough, regular ice can form [2] The solution is to reduce the water concentration enough, so that the water present is in vapor form for all conditions encountered throughout the process. For hydrate inhibition use of chemicals is also possible, as is most often employed for pipeline transport from the wellhead to the platform or land based processing facility.

The most commonly used processes for dehydration is absorption into a liquid or adsorption into a solid, but cooling and compression of the gas can also be used [3,4]. Absorption is used for dehydration when the requirement for water content is moderate, typically for dehydration before sending the gas through long distance pipelines. Adsorption can produce extreme dryness in the gas, and is used before low temperature processes (e.g. liquefaction or heavy hydrocarbon extraction). The focus of this paper is on absorption.

Today most absorption processes uses glycol, more specifically tri ethylene glycol (TEG), in an absorption column where lean TEG (lean in water) is introduced from the top while wet gas flows in through the bottom [5]. As the TEG flows down the column over trays or packing, water is absorbed from the rising gas, letting dehydrated gas flow from the top of the column, while rich TEG (rich in water) exits from the bottom. The rich TEG is regenerated by reducing the pressure and increasing the temperature, before it is re-injected into the absorption column again. This equipment is very large and heavy, two major cons on offshore platforms.

This paper presents the simulation software used in design and optimization of dehydration units. The results provide an analysis of the dehydration effectiveness at a variety of common operating variables for a typical dehydration facility.

II. Process Simulation

Glycol dehydration is a continuous liquid desiccant process in which water or water vapour is removed from hydrocarbon streams by selective absorption and the glycol is regenerated or reconcentrated by thermal desorption. The most common application of this process is the dehydration of natural gas streams. The use of triethylene glycol (TEG) is standard for dehydration of natural gas.

The absorption occurs in a trayed vessel called the contactor or absorber column. The lean dry glycol liquor enters the top of the column and the wet gas enters the bottom of the column. As the lean glycol flows down through the trays, it contacts the up flow wet gas. The lean glycol absorbs the water from the wet gas and exits through the bottom of the column as rich glycol. The gas exits the top of the column as a dry product with an acceptable residual moisture content range of 4 to 7 lb/MMscf of gas.

The rich glycol is passed through a heat exchange to preheat the rich glycol with the bottom product of the regenerator. The rich glycol then flows to a regenerator. In the regenerator, the wet glycol flows down to the reboiler while contacting hot gases (mostly water vapour and glycol) rising up from the reboiler. The mixing of these two streams helps to further preheat the wet glycol and to condense and recover any glycol vapours before the gases are vented from the top of the regenerator.

In the reboiler the glycol is heated to approximately 350^oF to 400^oF to remove enough water vapour to reconcentrate it to 99.5 percent or more. Sometimes a small amount of natural gas is injected into the bottom of the reboiler to strip water vapour from the glycol. The water vapour rises through the stripping still and the lean glycol flows to the surge tank where it is cooled down by preheating the rich glycol from the flash separator.

Finally, the glycol is pumped back to the top of the absorber column to repeat this circuit. The required circulation rate is determined by the actual purity of the glycol at the inlet to the contactor, the number of trays or packing height in the contactor, and the desired dew point depression [6,7]. Typical values for plant applications are 17 to 50 L TEG/kg H_2O removed, and for field applications are 20 to 35 L TEG/kg H_2O.

An offshore platform in the Arctic region was chosen as the base case of this simulation. It was simulated with the aid of ASPEN HYSYS Process Simulator.ASPEN HYSYS is a process simulation environment designed to serve many processing industries especially Oil & Gas and Refining. With HYSYS you can create rigorous steady state and dynamic models for plant design, performance monitoring, troubleshooting, operational improvement, business planning, and asset management. Through the completely interactive HYSYS interface, you can easily manipulate process variables and unit operation topology, as well as fully customize your simulation using its customization and extensibility capabilities.The base set of operating parameters are presented below

Table1: Operating parameters and composition of the inlet gas

Name	Gas
Temperature	29.23^0C (84.61^0F)
Pressure	6200 kPa
Volumetric flow	27.70 m^3/h
Component	Mole Fraction
Methane	0.8979
Ethane	0.0310
Propane	0.0148
i-Butane	0.0059
n-Butane	0.0030
i-pentane	0.0010
n-Pentane	0.0005
H_2S	0.0155
CO_2	0.0284
Nitrogen	0.0010
H2O	0.0010

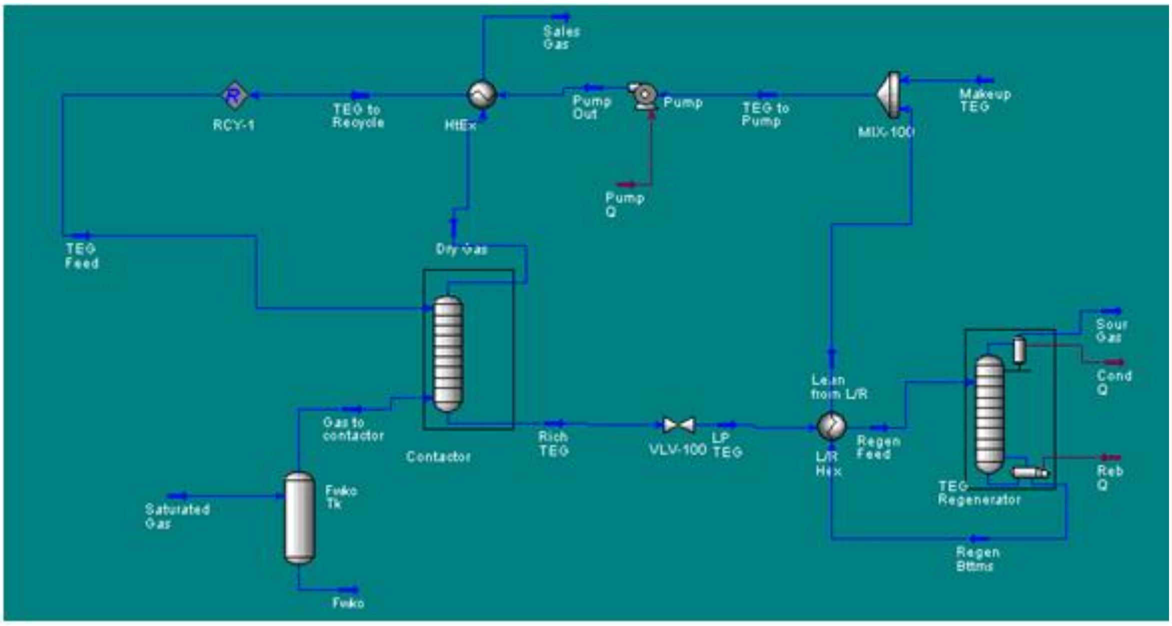

Fig 1: The Base case of the Gas dehydration Plant

Table 2: The operating parameters and composition of the TEG feed

Name	TEG FEED
Temperature	50^0C (120^0F)
Pressure	6200 kPa
Volumetric flow	0.5m^3/h
Component	Mass Fraction
TEG	0.98
H_2O	0.02

Table 3: The Gas Dehydration plant operation parameters

NAME	CONTACTOR
No of Stages	8
Pressures	Value
Top	6190kPa
Bottom	6200kPa
NAME	REGENERATOR
No of Stages	1
Regen Feed	
Temperature	105^0C
Pressure	110kPa
Condenser	
Temperature	102^0C
Pressure	101kPa
Reboiler	
Temperature	205^0C (400^0F)
Pressure	103kPa

III. Process Optimization

When optimizing the design of dehydration facilities, the impact of the following parameters should normally be considered:

- ϖ Number of trays in the contactor
- ϖ Glycol circulation rate through the contactor
- ϖ Temperature of the reboiler in the regenerator
- ϖ Amount of stripping gas used, if any

ϖ Operating pressure of the regenerator

Of the above parameters, only the first four are normally considered as variable parameters. The last parameter affects the lean glycol purity in a manner similar to reboiler temperature. However, the vast majority of units are vented to the atmosphere so this parameter is beyond control [8-11].

In addition to the design parameters listed above, several other factors influence the residual water content of the sales gas. However, often these factors are fixed and cannot normally be changed when optimizing a unit. First, the temperature of the inlet gas will dictate the total amount of water fed to the unit. Lower plant inlet gas temperatures will require less water to be removed by the glycol. Second, lean glycol temperature at the top of the contactor will affect the water partial pressure at the top stage. Consequently, high glycol temperatures will result in high water content in the overhead gas. However, this temperature is normally no cooler than 10^{o}F above the inlet gas to prevent hydrocarbons in the feed from condensing in the solution[12-14]. This limit is normally maintained by a gas/glycol exchanger that cools the lean glycol to approximately a 10^{o}F approach using the dry gas. Other parameters in the plant have limited or no effect on the dry gas water content. The number of equilibrium stages in the regenerator has only a slight effect on the lean glycol purity. Equilibrium at the reboiler temperature and pressure is approached in the reboiler so that additional stages have no effect. Operating temperature of the lean/rich glycol exchanger only significantly impacts the reboiler heat duty[15,16].

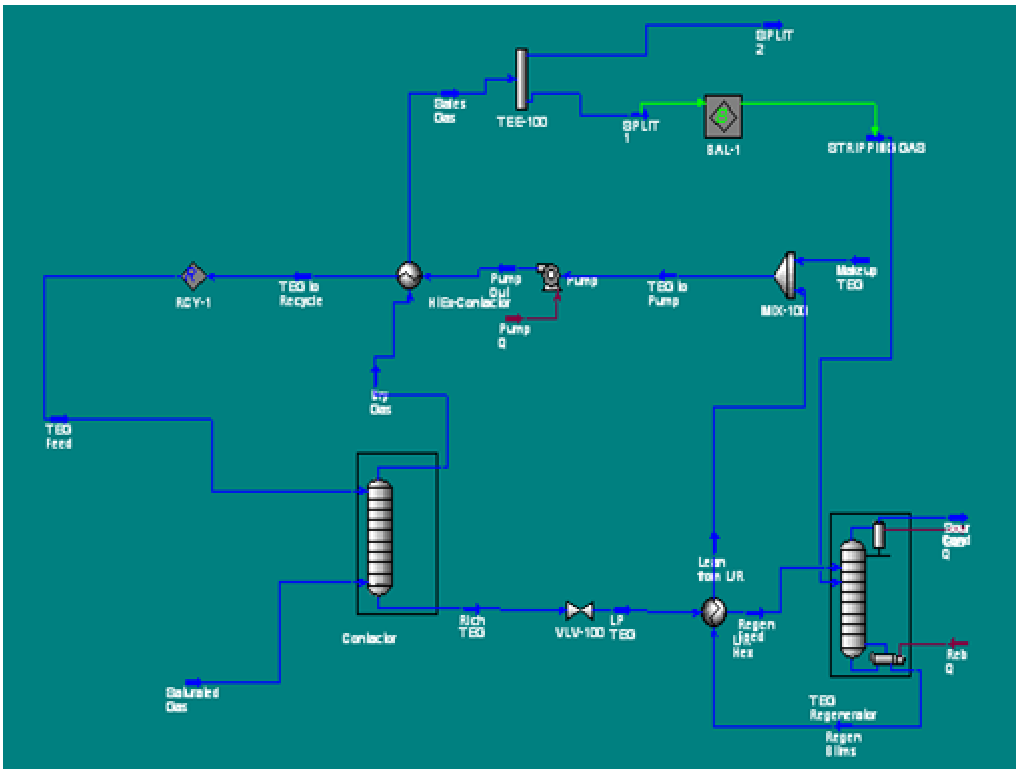

Fig 2: The Optimized Case of the Gas dehydration plant

The existing plant has a FWKO tank to remove the free water from the saturated gas. The initial work of this research is to see the need for the equipment. One way to do that is to see the effect of FWKO tank as it affects the circulation rate of the absorbing medium and the final water content of the gas.The effect of the number of equilibrium stages on the water content of the sales gas for different TEG circulation rates were studied using a reboiler temperature of 400^{0}F. In this case, five cases were considered. The effect of a single stage, two stages, three stages, and five stages were considered. The resulting circulation rates were calculated. The plot of TEG circulation rate against water content of the gas was done for all the stages.

This case considered the effect of the reboiler temperature on the water content of the sales gas for different TEG circulation rate on the process. The reboiler temperature considered were 350^{0}F, 375^{0}F, 400^{0}F.The reboiler temperature was studied for single stage, two stages, three stages, and five stages. The volumetric flow rate of TEGlycol was varied from 0.01m^{3}/h to 0.6m^{3}/h. The water content in the sales gas and mass flow of water in the sales gas were recorded. This helped in the calculation of the circulation rate of the TEG. The plot of TEG circulation rate against water content of the gas was done for all the stages. The stripping vapour will likely be needed to aid the regeneration process for processes requiring gas with very low water content and water dew points. The stripping gas rates considered were 0Scf/gal, 1Scf/gal, 3Scf/gal and10Scf/gal. The effect of stripping gas rate on the water content of the sales gas for different TEG circulation rate was studied for single stage, two stages, three stages, five stages, eight stages. The volumetric flow rate of TEG was varied from 0.01m^3/h to 0.6m^3/h. The water content in the sales gas and mass flow of water in the sales gas were recorded. This helped in the calculation of the circulation rate of the TEG. The plot of TEG circulation rate against water content of the gas was done for all the stages. Basic mathematical calculations were done to see the effect of water content in gas as a function of the circulation rate. The initial base case calculation is shown below. The result indicated that 0.5m^3/h of the TEG was able to reduce the initial mass flow of the water in the gas from 7.7325kg/h to 0.46297kg/h. The water content in the gas was reduced from 653.5mg/m^3 to 39.18 mg/m^3.

Water absorbed = Water in the inlet gas – water in the outlet gas

=7.7325 – 0.4629

=7.2696Kg

$$\text{The circulation rate} = \frac{\text{TEG volumetric flow (litres)}}{\text{Water absorbed (kilogram)}}$$

$$= \frac{500}{7.2696}$$

= 68.7802L/kg

Convert to gal/lb

$$= \frac{68.7802 \times 0.2641720524}{2.204622622}$$

= 68.7802 X 0.1198264262

= 8gal$_{TEG}$/lb$_{H2O}$

Water content in gas = 39.18mg/m^3

Convert to lb/MMscf (conversion factor = 0.0624279606)

=39.18 X 0.0624279606

=2.4459 lb/MMscf

IV. Results and Discussion

Fig.3 illustrates the effect of FWKO Tank on Gas water content for 1-stage contactor. The circulation rate of 8gal$_{TEG}$/lb$_{H20}$ will be needed to approach equilibrium with the gas. The incorporation and non-incorporation of the FWKOT simulations cannot achieve the pipeline gas quality of less than 7lb$_{H2O}$/MMscf as illustrated in the figure.

Fig.4 illustrates the effect of FWKO Tank on Gas water content for 2-stage contactor. The circulation rate of 6gal$_{TEG}$/lb$_{H20}$ will be required to approach equilibrium with the gas. The maximum TEG circulation rates required for a pipeline gas quality of less than 7lb$_{H2O}$/MMscf are 2.2 gal$_{TEG}$/lb$_{H20}$ and 2 gal$_{TEG}$/lb$_{H20}$ for FWKOT and non-incorporation of FWKOT simulations respectively.

Fig.5 illustrates the effect of a free water knock tank on Gas water content for 3-stage contactor. The circulation rate of 3 gal$_{TEG}$/lb$_{H20}$ will be required to approach equilibrium with the gas. The maximum TEG circulation rates required for a pipeline gas quality of less than 7lb$_{H2O}$/MMscf are 1.2 gal$_{TEG}$/lb$_{H20}$ and 1.05 gal$_{TEG}$/lb$_{H20}$ for FWKOT and non-incorporation of FWKOT simulations respectively.

Fig.6 illustrates the effect of FWKO on Gas water content for 5-stage contactor. The circulation rate of 1.6gal$_{TEG}$/lb$_{H20}$ will be required to approach equilibrium with the gas. The maximum TEG circulation rates required for a pipeline gas quality of less than 7lb$_{H2O}$/MMscf are 0.9 gal$_{TEG}$/lb$_{H20}$ and 0.85 gal$_{TEG}$/lb$_{H20}$ for FWKOT and non-incorporation of FWKOT simulations respectively.

These figures show that the incorporation of the Free Water Knock Out Tank reduces the mass flow rate of water in the inlet gas into the contactor to 7.7325kg/h as compared to 9.0076kg/h for a case of no FWKO.

For the two scenarios, the TEGlycol circulation rates required to approach equilibrium with the gas are the same. Fig.7 illustrates the effect of the number of equilibrium stages in the absorber on the water content and required TEG circulation rates.The TEG circulation rates required to approach equilibrium with the gas for 1-stage, 2-stage, 3-stage and 5-stage contactor are 8gal$_{TEG}$/lb$_{H20,}$ 6gal$_{TEG}$/lb$_{H20,}$ 3gal$_{TEG}$/lb$_{H20,}$ and 1.6galTEG/lb$_{H20}$. The maximum TEG circulation rates required for a pipeline gas quality of less than 7lb$_{H2O}$/MMscf are 2 gal$_{TEG}$/lb$_{H20}$, 1 gal$_{TEG}$/lb$_{H20}$ and 0.68gal$_{TEG}$/lb$_{H20}$ for 1-stage, 2-stage, 3-stage and 5 stage contactors.

Fig.8 illustrates the effect of the reboiler temperature of the regenerator after 1-stage contactor on the gas water content. Pipeline quality gas containing less than 7 lb$_{H2O}$/MMscf could not be produced at the reboiler temperature of 350^{0}F. For reboiler temperature of 375^{0}F, approximately 6.6 gal$_{TEG}$/lb$_{H20}$ would be needed as opposed to 5.3 gal$_{TEG}$/lb$_{H20}$ for reboiler temperature of 400^{0}F. The effect of the reboiler temperature of the regenerator after 2-stage contactor on the gas water content is illustrated by Fig.9. Pipeline quality gas containing less than 7 lb$_{H2O}$/MMscf could be produced at the reboiler temperature of 350^{0}F, 375^{0}F and 400^{0}F. For reboiler temperature of 350^{0}F, 375^{0}F and 400^{0}F, approximately 1.8gal$_{TEG}$/lb$_{H20}$, 1.45gal$_{TEG}$/lb$_{H20}$, and 1.25gal$_{TEG}$/lb$_{H20}$ would be required.The minimum water content that can be achieved at 350^{0}F with the minimum circulation rate of 6 gal$_{TEG}$/lb$_{H20}$ is 4.8 lb$_{H2O}$/MMscf. At 375^{0}F with the minimum circulation rate of 6

gal_{TEG}/lb_{H20} is 3.6 lb_{H2O}/MMscf. At 400^0F with the minimum circulation rate of 6 gal_{TEG}/lb_{H20} is 2.7 lb_{H2O}/MMscf.

The effect of the reboiler temperature of the regenerator after 3-stage contactor on the gas water content is illustrated by Fig.10. Pipeline quality gas containing less than 7 lb_{H2O}/MMscf could be produced at the reboiler temperature of 350^0F, 375^0F and 400^0F. For reboiler temperature of 350^0F, 375^0F and 400^0F, approximately $0.95gal_{TEG}/lb_{H20}$, $0.85gal_{TEG}/lb_{H20}$, and $0.77gal_{TEG}/lb_{H20}$ would be required. The minimum water content that can be achieved at 350^0F with the minimum circulation rate of $3gal_{TEG}/lb_{H20}$ is 4.5 lb_{H2O}/MMscf. At 375^0F with the minimum circulation rate of $3gal_{TEG}/lb_{H20}$ is 3.3 lb_{H2O}/MMscf. At 400^0F with the minimum circulation rate of 6 gal_{TEG}/lb_{H20} is 2.3 lb_{H2O}/MMscf.The effect of the reboiler temperature of the regenerator after 5-stage contactor on the gas water content is illustrated by Fig.11.

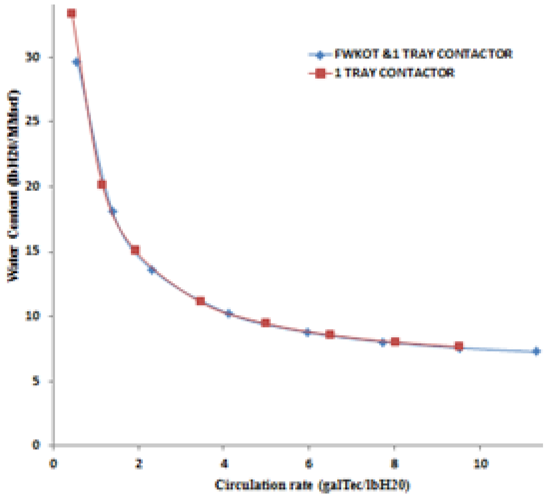

Fig.3: The effect of free water knock tank on Gas water content (1-Tray contactor)

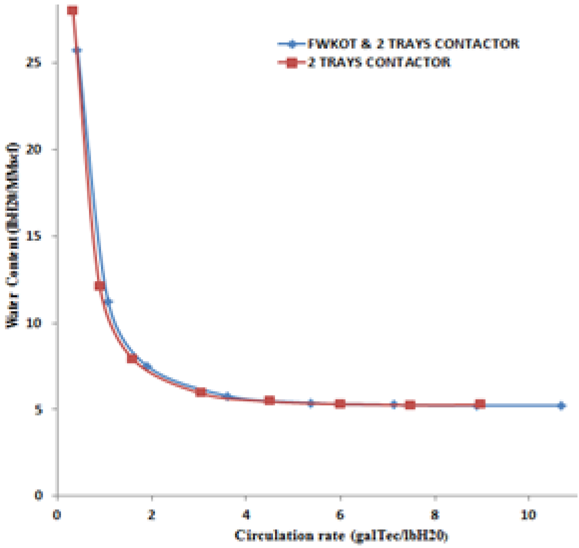

Fig.4: The effect of free water knock tank on Gas water content (2-Tray contactor)

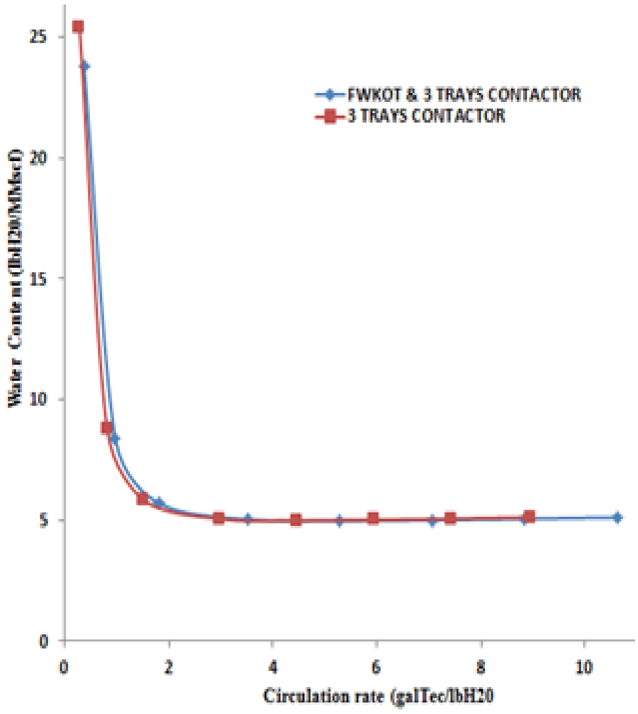

Fig .5: The effect of free water knock tank on Gas water content (3-Tray contactor)

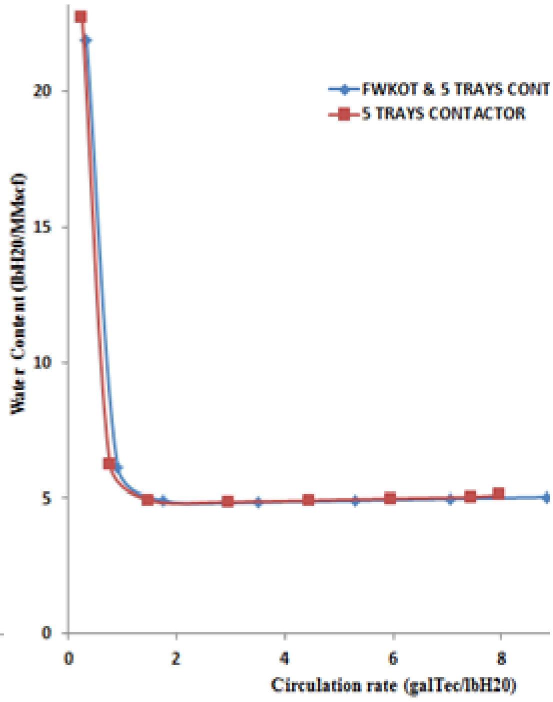

Fig.6: The effect of free water knock tank on Gas water content (5-Tray contactor)

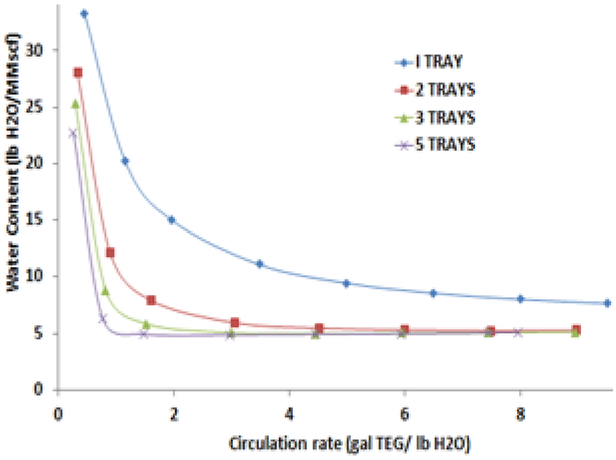

Fig.7: The effect of the number of equilibrium stages in the contactor on the Gas water content

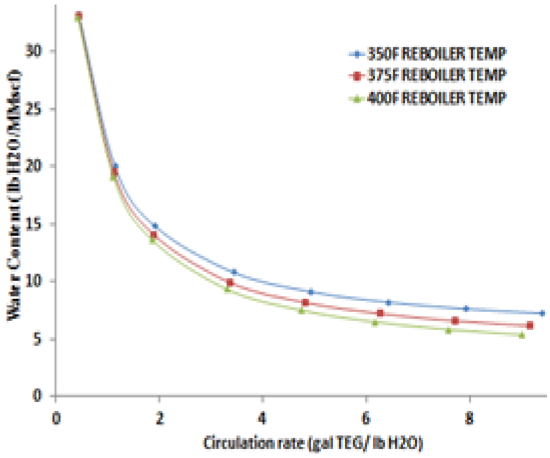

Fig.8: The effect of the reboiler temperature on the gas water content (1-stage contactor)

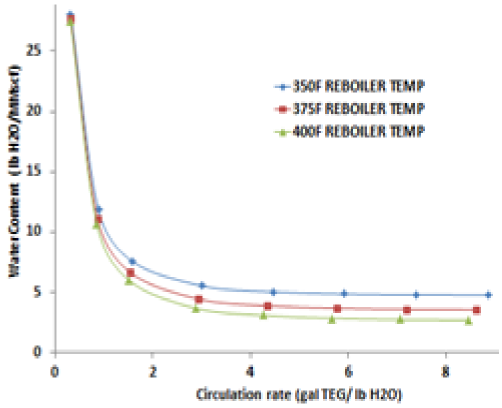

Fig.9: The effect of the reboiler temperature on the gas water content (2-stage contactor)

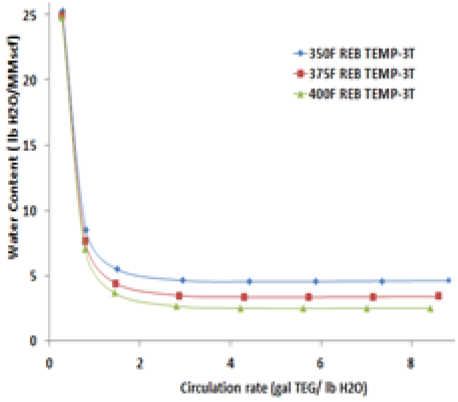

Fig.10: The effect of the reboiler temperature on the gas water content (3-stage contactor)

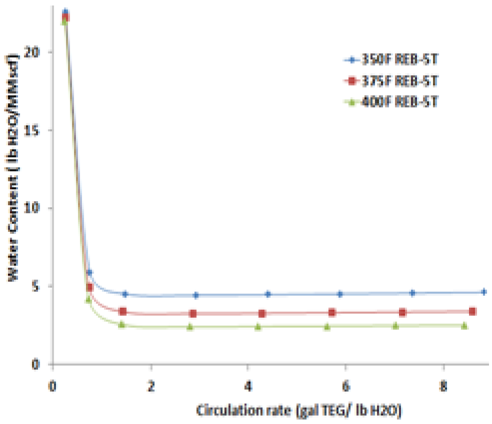

Fig.11: The effect of the reboiler temperature on the gas water content (5-stage contactor)

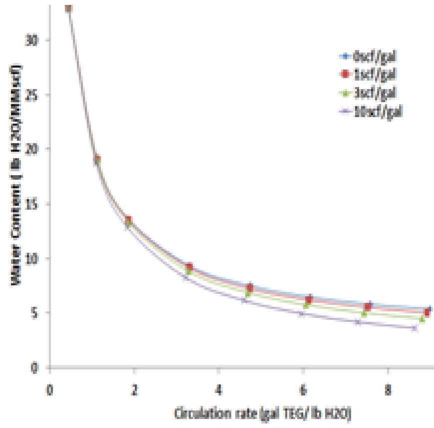

Fig.12: The effect of the stripping gas rate on the gas water content (1-stage contactor)

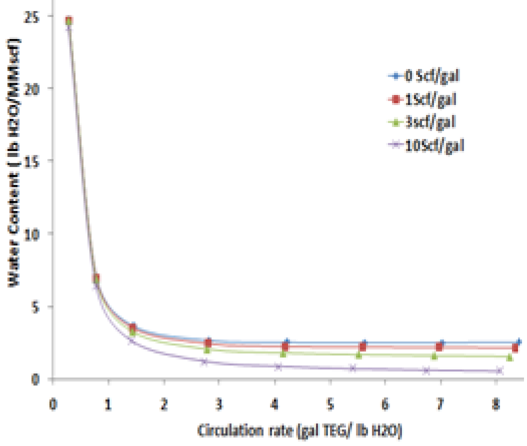

Fig.13: The effect of the stripping gas rate on the gas water content (3-stage contactor)

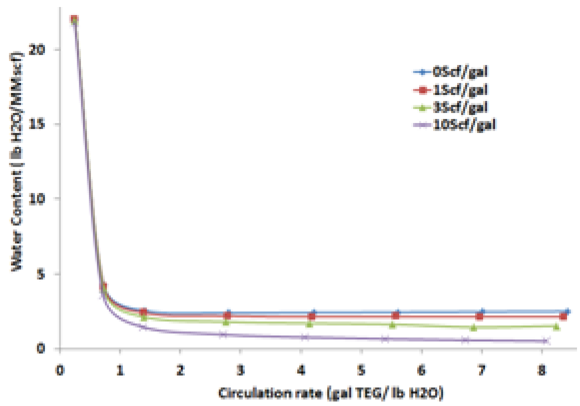

Fig.14: The effect of the stripping gas rate on the gas water content (5-stage contactor)

Pipeline quality gas containing less than 7 lb_{H2O}/MMscf could be produced at the reboiler temperature of 350^0F, 375^0F and 400^0F. For reboiler temperature of 350^0F, 375^0F and 400^0F, approximately $0.72gal_{TEG}/lb_{H20}$, $0.65gal_{TEG}/lb_{H20}$, and $0.6gal_{TEG}/lb_{H20}$ would be required. The minimum water content that can be achieved at 350^0F with the minimum circulation rate of $1.6gal_{TEG}/lb_{H20}$ is 4.4 lb_{H2O}/MMscf. At 375^0F with the minimum circulation rate of $1.6gal_{TEG}/lb_{H20}$ is 3.2 lb_{H2O}/MMscf. At 400^0F with the minimum circulation rate of 1.6 gal_{TEG}/lb_{H20} is 2.1 lb_{H2O}/MMscf.

The effect of the stripping gas rate in the reboiler of the regenerator on the gas water content (1-stage contactor) is illustrated by Fig.12. A constant TEG circulation rate and varying stripping gas rate of 0scf/gal, 1scf/gal, 3scf/gal and 10scf/gal produces a gas having water content of 5.75 lb_{H2O}/MMscf, 5.5 lb_{H2O}/MMscf, 4.85 lb_{H2O}/MMscf and 4lb_{H2O}/MMscf. The effect of the stripping gas rate in the reboiler of the regenerator on the gas water content (3-stage contactor) is illustrated by Fig.13. A constant TEG circulation rate and varying stripping gas rate of 0scf/gal, 1scf/gal, 3scf/gal and 10scf/gal produces a gas having water content of 2.7 lb_{H2O}/MMscf, 2.4 lb_{H2O}/MMscf, 2 lb_{H2O}/MMscf and 1lb_{H2O}/MMscf. The effect of the stripping gas rate in the reboiler of the regenerator on the gas water content (5-stage contactor) is illustrated by Fig.14. A constant TEG circulation rate and varying stripping gas rate of 0scf/gal, 1scf/gal, 3scf/gal and 10scf/gal produces a gas having water content of 2.7 lb_{H2O}/MMscf, 2.4 lb_{H2O}/MMscf, 2 lb_{H2O}/MMscf and 1lb_{H2O}/MMscf.

V. CONCLUSION

The initial design of the Gas dehydration plant as simulated in the base case had FWKOT incorporated in the plant. It is included in the design to remove the free water present in the saturated gas. This research work has proved beyond reasonable doubt that the incorporation of FWKOT does not affect the TEG circulation rate required to approach equilibrium. It has also proved that the incorporation of the FWKOT will increase the TEG circulation rate needed to meet pipeline gas quality.

It has been proven that the number of trays in the contactor, glycol circulation rate through the contactor, temperature of the reboiler in the regenerator and amount of stripping gas used in natural gas dehydration plant are critical parameters to consider in the optimization of the plant. With increase in the number of equilibrium stage, there is decrease in the required TEG circulation to meet Pipeline Gas quality and to approach equilibrium with the gas. With a fixed circulation rate, a lower water content gas can be produced with higher equilibrium stage contactor.

Higher reboiler temperatures have been proved in this research work to reduce the Gas water content. The importance of gas stripping was not left out. This work has also proven the water content of gas can be reduced further by gas stripping. Higher gas stripping rates will cause lower water content in the gas. Where Gas stripping is employed, increasing the equilibrium trays farther than 3 trays will have no significant impact on the water content of the gas produced.

Thus the first two parameters affect the approach to equilibrium at the top of the absorber while the third and fourth dictate the value of the equilibrium water content by limiting the purity of the lean glycol to the absorber. We therefore recommend as follows:

(i) The plant can be optimized by removing the FWKOT equipment from the plant. This will reduce the cost by reducing the circulation rate of the TEG required for a given gas quality. Cost due to installation and maintenance of the FWKOT can be eliminated.

(ii) The reboiler temperature should be set to work at the temperature of 400^0F
(iii) For gas quality of very low water content, stripping should be employed. Higher stripping rates may be used to achieve lower water content
(iv) Where Gas stripping is employed, 3 equilibrium stages should be employed for higher efficiency.

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