

Investigation of effect of process parameters variation in an Iranian natural gas dehydration plant

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ABSTRACT

A natural gas dehydration plant, including both stripping and recovery section, is studied in this paper in order to investigate the major effective parameters and their influences over the dehydration process efficiency. This plant is stated in southern part of Iran and uses diethylene glycol as the dehydrating agent. The whole unit was simulated using a steady state flow-sheet simulator. The main goal of this study is to reveal whether or not the whole process could be optimized and to perform a sensitivity analysis using acquired data from both simulation and the field data. The most important dependant factors which were used in the sensitivity analysis are volatile organic compounds (VOC) emission, dry gas dew point, solvent loss, and process total duty. The output data from the simulator infer that VOC emission is massively sensitive to increment of purity or mole flow of the solvent. Eventually, by considering all of the operation criteria; it was revealed that a ten percent increase in solvent mole flow is applicable in order to reduce dry gas dew point up to six percent without a significant raise in the dehydration unit's total energy consumption and environmental pollutant. © 2015 Trade Science Inc. - INDIA

KEYWORDS

Natural gas;
Dehydration plant;
Sensitivity analysis;
Glycol solvent;
Dew point.

INTRODUCTION

Dehydration is one of the major steps toward treatment of natural gas. It includes all the processes which during them a tremendous amount of "natural gas' along water" is removed and disposed as the waste-water^[1]. This along water may cause many problems while transition of natural gas (especially by pipelines) e.g. hydrates formation, increasing corrosion rate in pipeline, and etc. Water removal from natural gas, therefore, was always a priority and an elementary process for most of gas treating

plants^[2,3]. There have been many methods used by diversity of gas treating plants in order to remove the along water from gas. Some of the most practical methods can be divided in five major categories including using absorption (glycol's groups), adsorption, separation by membrane technology, Natural gas cooling, and separation at ultra-sonic speed^[4,5].

Taking into account all of the above-mentioned methods, natural gas cooling by coolant along with absorption process is the way that will be discussed in this work. In this method, natural gas is cooled under -15 C and consequently a significant fraction

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of its heavy hydrocarbons and along water separated. As a result, natural gas dew point is remarkably reduced. During cooling process, the possibility of hydrate formation due to presence of along water is relatively high; consequently, injecting strong water absorber is usually considered as an effective solution to eliminate this problem. Mono-ethelene glycol (MEG), diethylene glycol (DEG), and triethylene glycol (TEG) are among the most practical and useful liquid absorber and they are widely used for absorbing water from natural gas during dehydration process^[6,7]. Since the dehydration plant that is studied in this paper is using DEG as absorber, therefore this water absorber will be considered as dehydrating agent for performing the simulation.

SIMULATION

In this work, a natural gas dehydration unit along with its absorbent recovery cycle in an Iranian gas refinery company is simulated by using a steady-state flow sheet simulator. The main purpose of this simulation is to conduct a sensitivity analysis in order to examine effective parameters throughout dehydration process and revealing their role on over-

all performance of the dehydrating unit and eventually study the possibility of optimizing the whole process.

Dehydration process overview

Figure 1 shows a schematic outlook of the major facilities in simulated dehydration unit and it contains a natural gas cooling chiller, a packed stripping column for DEG recovery along with its fired re-boiler and air cooler, two-phase and three-phase separators, and finally a glycol transmitting pump. The basic steps of this process can be described as follow: At the first step, natural gas stream enters into the chiller while DEG solvent (known as “lean glycol”) is added to it simultaneously. The chiller uses propane as coolant which it enters at saturated liquid condition and exits as the saturated vapor, approximately. Gas stream output temperature from the chiller differs from -10 to -18 C. After this step, a significant amount of water is removed from natural gas and then the whole output stream is headed into the three-phase separator. At this point, separated gas which now is known as “dry gas” is headed to the market. From the lower part of the separator, in lighter phase, natural gas liquids (heavy hydrocarbons) are separated and

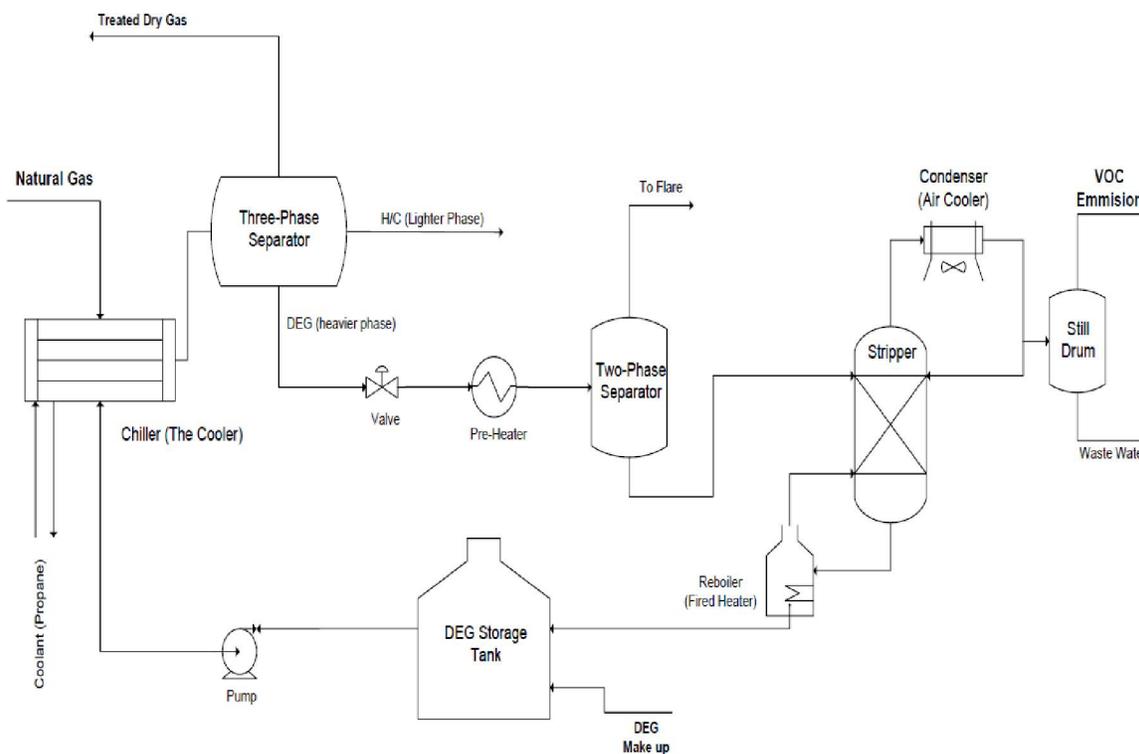


Figure 1 : Process flow-sheet for the simulated natural gas dehydration unit

in heavier phase, water and glycol (“rich glycol”) along with a trivial fraction of hydrocarbons, which have been absorbed by DEG during natural gas dehydration, are removed. Regarding to importance of DEG recovery from economical aspect, at the final step, rich glycol enters to the stripping column in order to get purified and eventually, a major part of its water and hydrocarbons get removed and then the DEG injection cycle continues.

Simulation model

One of the most critical parts of simulation is to choose a proper equation of state (EOS) in order to obtain highly accurate results. Considering the po-

lar nature of water and glycol system and different range of operational pressure for this process (higher than 65 bar at the three-phase separator and lower than 6 bar at stripper), it is vital to select an EOS which can cover all the above criteria. According to^[8,9] suitable models for this situation are: RKSWS, RKSMHV2, PSRK, PRWS, and PRMHV2. In these models, for precise prediction of thermodynamic behavior of vapor components as pure, the first two use Peng-Robinson EOS whilst other models use RKS. All of these models are using different predictive mixing rules in order to predict valid results for tertiary system of water-glycol-hydrocarbons in operational range of pressure and temperature.

TABLE 1 : Suggested models for gas dehydration process with DEG details^[8-9]

Models	Equation of State	Predictive Mixing Rule	Refs
PRMHV2	Peng-Robinson	MHV2	[10]
PRWS	Peng-Robinson	Wong-Sandler	[11]
PSRK	Redlich-Kwong-Soave	Holderbaum-Gmehling	[12]
RKSMHV2	Redlich-Kwong-Soave	MHV2	[13]
RKSWS	Redlich-Kwong-Soave	Wong-Sandler	[12, 14]

TABLE 2 : Natural gas dehydration unit's operational field data compare with calculated results from simulation for each model

Natural Gas Compositions and process parameters		Input Wet Gas	Output DryGas					
			Operational Conditions	PRMHV2	PRWS	PSRK	RKSMHV2	RKSWS
C ₁	kmol/hr	21287.2	21181.6	21131	21274.4	21284.3	21194.7	21276.3
C ₂	kmol/hr	889.6	869.2	865.98	888.41	888.78	872	888.64
C ₃	kmol/hr	344	321.2	321.27	343.46	343.35	325.2	343.6
IC ₄	kmol/hr	78.4	68	69.17	78.31	78.2	65	78.34
NC ₄	kmol/hr	117.2	96.4	98.65	117.02	116.75	99.5	117.08
IC ₅	kmol/hr	51.2	34.8	37.24	51.15	50.93	38.3	51.17
NC ₅	kmol/hr	40.4	24.8	27.01	40.35	40.11	26.5	40.37
C ₆₊	kmol/hr	99.6	26.2	28.43	99.57	98	28.31	99.58
N ₂	kmol/hr	1208	1206	1198.28	1206.8	1207.25	1205.36	1206.77
CO ₂	kmol/hr	57.6	56.8	54.54	57.09	57.48	56.55	57.1
H ₂ S	kmol/hr	0	0	0	0	0	0	0
DEG	kmol/hr	0	0	0	0.53	0	0	0.64
H ₂ O	kmol/hr	30.8	1.03	1.5	1.73	2.8	1.04	1.68
Mass Flow	kg/hr	448244	432895	432442	447498	447444	433929	447562
Temperature	°C	69.6	-12.3	-12.3	-12	-12	-12.3	-12
Pressure	Bar	38	67.7	67.7	67.7	67.7	67.7	67.7
Dew Point	°C	37	-10.17	-5.50	-3.22	3.49	-10.05	-3.61
VOC	tonne/year	--	180	312	Error	205	189	Error
Make Up	kg/hr	--	2.36	7.07	Error	0.06	2.96	Error
Solvent flow	kmol/hr	--	100	100	100	100	100	100

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TABLE 1 shows these models along with their related equation-of-state and predictive mixing rule. To distinguish the most reliable model which can be used in the final simulation, it is necessary to run the simulation for each model individually and then compare the results to operational data. The result of this sequence can be seen on TABLE 2. The best method for comparing these results is to use an error index. In this study, the Absolute Average Relative Deviation percent (AARD%) is used to evaluate accuracy of models individually. Eq. (1) shows the relation for calculating AARD for each result:

TABLE 3 : Calculated AARD% for each model's results from TABLE 2

PRMHV2	PRWS	PSRK	RKSMHV2	RKSWS
6.11	9.47	20.8	0.16	8.9

$$AARD(\%) = \frac{1}{n} \left(\sum_i^n \left| \frac{y_i^{op} - y_i^{cal}}{y_i^{op}} \right| \right) \times 100 \quad (1)$$

Where y^{op} is the actual data, y^{cal} is the calculated result by models, and n is the number of data points. TABLE 3 indicates calculated AARD for each model. According to this table only the models that used MHV2 mixing rule could predict acceptable results (RKSMHV2-PRMHV2).

A reason for this close match in MHV2 compare to other rules can be sought in its unique correlations for involving the derived deviation from thermodynamic properties calculation (for vapor-liquid-liquid and liquid-liquid equilibrium in a wide range of pressure and also gas solubility in liquid for systems containing light hydrocarbons)^[15,16], while Wong-Sandler rule can only predict relatively exact results close to MHV2 when the equilibrium system of vapor and liquid has moderate or high pressures^[17]. Furthermore, among RKSMHV2 and PRMHV2, the first model could provide better and more accurate results compare to the other one. The reason of this accuracy lies behind the different methods for calculating activity coefficient in each model. All of above models can predict activity coefficient in almost every pressure range with adequate accuracy for both polar and non-polar substances. All of these models use UNIFAC group contributing method to estimate these coefficients precisely, excluding

RKSMHV2 model which uses a Lyngby modified UNIFAC method for this matter^[18,19]. UNIFAC group contributing method assumes activity coefficient for each substance in the equilibrium system as summation of the "combinational term" and the "residual term"^[20]. Eq. (2) shows this relation:

$$\ln \gamma_i = \ln \gamma_i^c + \ln \gamma_i^r \quad (2)$$

Where $\ln \gamma_i^c$ indicates related activity coefficients to combinational term and $\ln \gamma_i^r$ is the residual term. Combinational parameters, which consider effects of entropy in their calculations, are function of mole fraction of each component, the surface groups (R_n), and the volume groups (Q_n) whilst residual parameters are function of components' mole fraction, temperature, and associated factors with surface groups and binary interaction coefficients^[21]. Moreover, the residual parameters consider the reciprocal interaction influences of various groups in the equilibrium system. The main difference between UNIFAC method and its modified method by Lyngby is in their dissimilar assumption of calculating R_n and Q_n groups. These groups are containing experimental data and can be accessed for a diversity of substances from empirical data banks which gathered gas-liquid equilibrium information^[19]. Since Lyngby modified UNIFAC method uses more extensive experimental data for estimating R_n and Q_n groups, particularly for gas-liquid equilibrium systems containing light hydrocarbons and polar components such as water and glycol; therefore it gives a better estimation of the activity coefficient values compare to the original UNIFAC group contributing method. According to above mentioned reasons and available results of pre-simulation on TABLES 2&3, the RKSMHV2 model seems to be more reliable and accurate and will be used in final simulation.

RESULTS AND DISCUSSION

Sensitivity analysis

The first step in sensitivity analysis is determining the dependent variables in dehydration process. The most important variables in this process are: the total amount of energy consumed in dehydration

cycle (energy consumed in gas cooling & DEG regeneration), the make-up mass flow rate of the injected DEG to line stream or the amount of lost solvent, the water dew point temperature of processed natural gas as well as the mass flow rate of light gases discharged into the atmosphere called Volatile Organic Compound (VOC). In order to distinguish the effect of the mentioned parameters in operational conditions, some independent variables which can share in two groups could be defined. The first group contains efficient variables on purity of circulated DEG which mostly related to operational parameters of regeneration tower such as recycle stream to the top of the tower, heat duty of re-boiler and pressure & temperature of tower; however, the second group includes operational parameters of natural gas and DEG absorbent like input gas flow rate to dehydration unit and mass flow rate

of the solvent. Therefore, by applying the mentioned parameters, sensitivity analysis could be evaluated for all dependent variables individually.

Input gas flow rate

Figure 2 demonstrates the variation of VOC emission, water dew point of gas, total duty as well as solvent loss versus different gas flow rate. As it is obvious from the graph (a), by increasing gas flow rate the amount of water content is increased respectively, which leads to a fairly linear rise in gas dew point. By increment of gas flow rate, the amount of absorbed water by DEG is increased while the amount absorbed hydrocarbons is decreased linearly, so their emission in environment as VOC in regeneration step become somewhat less which is clear in Figure 2.b. It should be noted that the amount of water removal from natural gas in high percentages

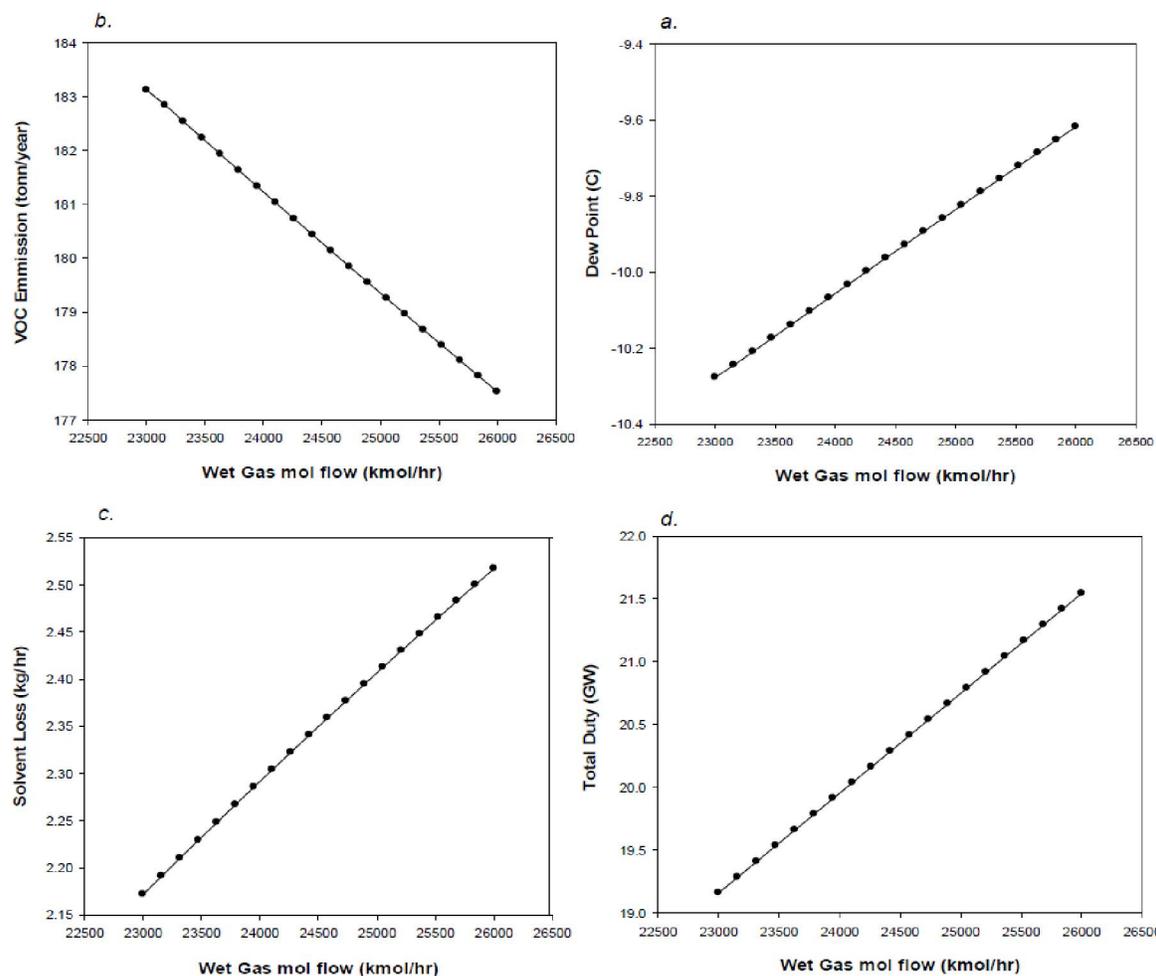


Figure 2 : The effect of input gas molar flow rate on: a) Gas dew point, b) VOC emission, c) solvent loss, and d) total duty

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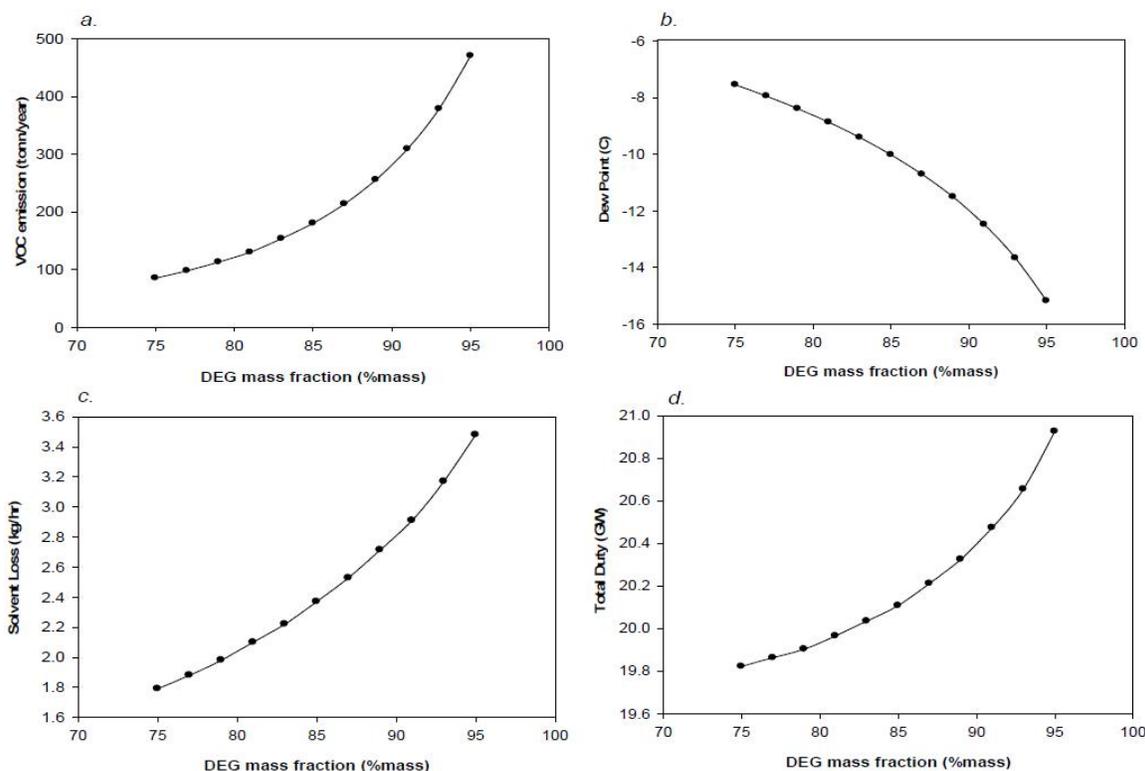


Figure 3 : The effect of solvent molar flow rate on: a) VOC emission, b) Gas dew point, c) DEG loss, and d) total duty

is affected by DEG purity. In this case, when gas flow is exceeded, increment of water removal percentage is limited to a certain extent which is a function of DEG purity. The most DEG loss is occurred from lighter hydrocarbon liquid phase in three-phase separator and somewhat from gas phase, hence as it is clear from Figure 2.c, more gas flow rate causes more retention time of DEG in gas phase, therefore leads to more DEG loss finally. Increment of input gas flow rate causes consuming more energy in dehydration unit (Heat exchanger) and since more water exists in solvent, to separate water from DEG higher thermal power in regeneration unit is consumed which totally leads to more energy consumption (Figure 2.d).

Solvent purity

The next dependent variable, which is considered here as an operational parameter, is solvent purity. Based on Figure 3.b, the water dew point of natural gas could be reduced down to -14°C with 10% enhancement of DEG mass fraction. Since for high solvent purity more water content could be removed from natural gas, steeper graph is justifiable.

Nevertheless, Figure 3.a demonstrates that as the solvent purity raises, more VOC could be absorbed, which causes a significant increment of volatile compounds in environment. The simulation results show that in dehydration process, for 5% enhancement of DEG purity with respect to current level, the VOC emission rate could be increased up to 270 ton/year which causes environmental restrictions and troubles. Solvent loss in the new simulated condition (variation of DEG purity) is another parameter which is demonstrated in Figure 3.c. as it is obvious, higher solvent purity have more driving force and absorb more water and VOC from gas phase which causes a higher solvent loss amount from lighter liquid phase in the three-phase separator. Variation of energy consumption during dehydration process is plotted versus different concentrations in Figure 3.d. As it is expected, an increment trend is obtained for energy consumption. It, however, should be noted that at higher concentration of DEG, more strip slope could be observed.

Effective factors on solvent purity

Operational parameters of stripping column, as

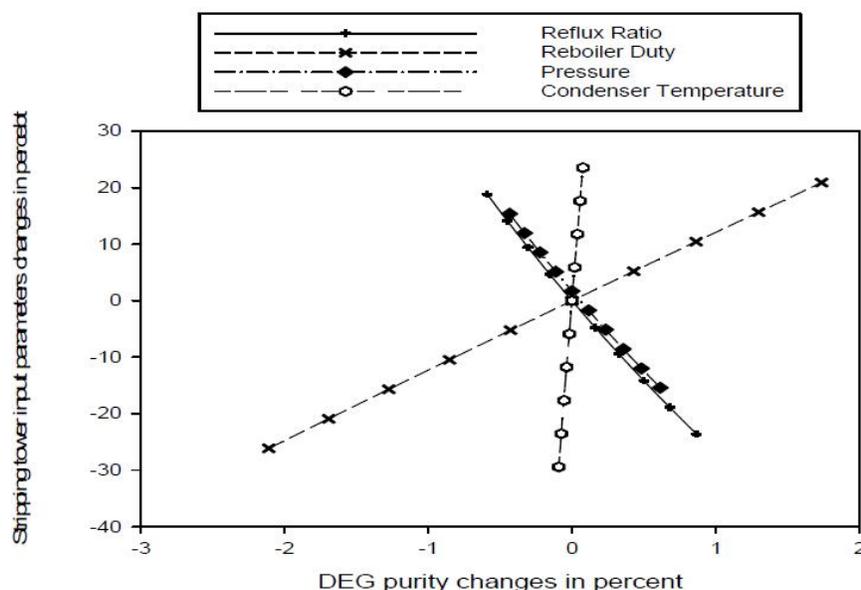


Figure 4 : Different stripping tower dependant parameters change versus variation of solvent purity

it was mentioned before, have the most effect on the purity of injected DEG to the dehydration cycle. In actual conditions, some column's parameters such as re-boiler duty, condenser temperature, reflux rate, and column pressure have easier variability and thus can be used for studying the sensitivity of glycol purity to variation of any of those parameters. Figure 4 shows fluctuate of each parameter in percent and their individual effect on the solvent purity change's rate compare to its initial purity. According to this graph, the foremost influence belongs to re-boiler duty which a 20% increment of it could improve DEG purity up to 2%. It is obvious that the more re-boiler duty increases, the more water will be evaporated from bottom of the column and consequently less water will leave the stripping column with DEG which it means higher purity of the solvent. It, nonetheless, must be noticed that this increment should not exceed the maximum allowable re-boiler duty, which will be met when the temperature of the outlet fluid from the re-boiler overpass 240 °C^[22]. In this temperature, DEG starts to degrade and loose its absorbing characteristic. The lowest influence is gained by condenser temperature changes which almost show no effect upon the outlet solvent purity. Column pressure and reflux rate variations effect on the solvent purity are practically the same and have a reverse trend. Increasing reflux rate at the top section of the column leads to more water to come in

and because of that, water's K_{value} (mole fraction of water in vapor phase to its mole fraction in liquid phase at equilibrium conditions) along the column will decrease which eventually will lead to an increase in water mole fraction at the glycol solution. At low refluxes, however, glycol loss from upper section of the column will insignificantly increase which of course is negligible due to its extremely low value.

Process optimization

By summarizing all the results that have been obtained at the previous sections, a study about possibility of optimizing the gas dehydration process can be carried out. For this purpose, Figure 5 is illustrated based on simulation and practical results. The horizontal axis of this figure indicates the variation of independent variables towards their original operating amount and the vertical axis shows the dependent variables change in percent according to different values of independent variables. It is worth mentioning that the main purpose of the optimization is to minimize independent variables (consist of emission of VOC, dry gas dew point, DEG losses, and overall duty) as low as possible while dry gas production rate doesn't change and even become greater if it is viable. Reducing dry gas dew point, especially in cold seasons, is eminently desirable to ensure a safe transmission of natural gas through

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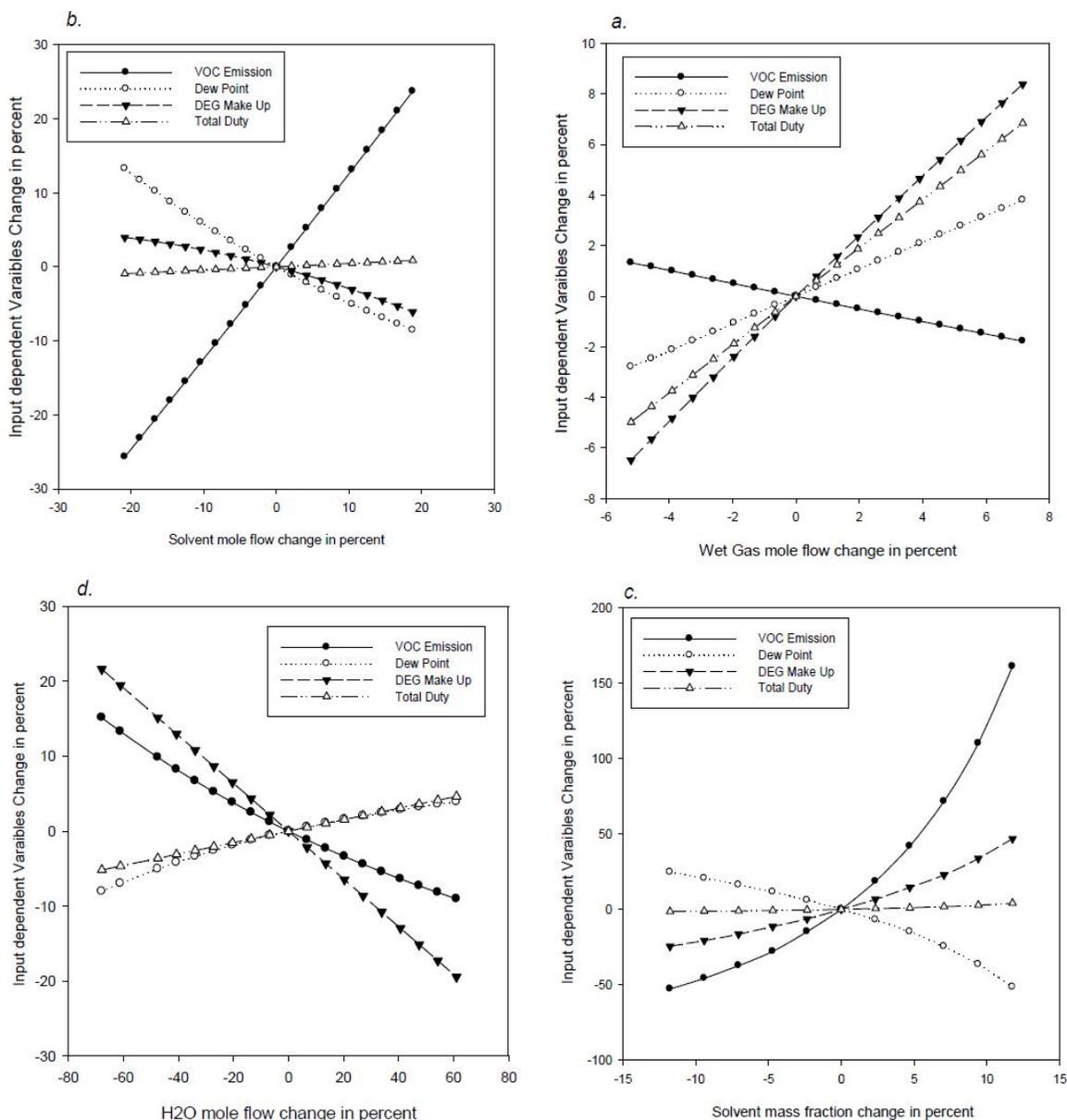


Figure 5 : Optimization of dehydration process variables by variation of: a) wet gas molar flow rate, b) solvent molar flow rate, c) solvent mass fraction, d) H₂O molar flow rate

long distances by pipelines. In the present operational conditions, therefore, lowering dry gas dew point will be assumed as the key parameters for the process optimizing.

By looking closer into Figure 5, it can be revealed that in a constant flow of inlet natural gas, solvent flow increment has the most effect on simultaneous reduction of dew point and solvent loss (Figure 5.a). In this situation, however, a restriction exists in maximum allowable VOC emission to the atmosphere (about 18% of its current operational amount)^[23]. By getting close to this restriction, a

maximum 10% increase is applicable to the solvent molar flow which it will lead to a 6% reduction in dry gas dew point. At the same time, total duty of the whole dehydration process will slightly rise (lesser than 1%) which is insignificant. It must be noted that influence of solvent purity increase on gas dew point reduction is much higher than the solvent flow but due to the dramatic decrease of VOC emission for higher concentration of DEG, performing this change is not optimal (Figure 5.c). When inlet natural gas molar flow to dehydration unit increases, by assuming that mol fraction of water in inlet gas remains

constant while its overall mole flow raises, all of the dependent variables will increase except for VOC emission (Figure 5.a). In this case, concurrent increment of solvent purity and flow can greatly help in reduction of dew point. To avoid over passing maximum allowable amount of VOC emission, for a 5% increase in inlet gas mole flow, increment of solvent flow and purity should not exceed 13% and 2% respectively which it will grant a reduction of dew point approximately between 5% and 9% for both situations (figures 5.b and 5.c). However, in this case the total amount of energy consumption in the entire process will be increased (about 5%). Finally, if mole fraction of along water with natural gas increases due to a possible change in utilization of gas-wells, outlet dry gas dew point can be adjusted to its former value by injecting solvent to the natural gas with more purity or higher rate. For instance, if gas along water's mole fraction raises 20%, solvent mole flow can be increased up to 3% in order to prevent dry gas dew point raises while other dependent variables remains almost constant (Figure 5.d). It should be mentioned that in all cases, before applying any changes, the operating criteria such as minimum and maximum required natural gas and solvent flow for utilization of the dehydration unit must be met in order to avoid any unfavorable complication during the process.

CONCLUSION

In this study, a natural gas dehydration plant, including both stripping and recovery section, was studied in order to investigate the major effective parameters and their influences over the dehydration process efficiency. This plant uses DEG as the dehydrating agent in order to absorb water from natural gas and to prevent the formation of hydrate inside the equipments during the process. In the first step, the whole unit was simulated by importing unit's operational data into a steady state flow-sheet simulator while RKSMHV2 model was used as the simulating model because of its high accuracy and reliability compare to the other models. After running the simulation, a sensitivity analysis based on the process' most important dependent variables

(consisting of VOC emission, dry gas dew point, solvent loss, and process total duty) and independent variables was performed to examine the tendency for each dependent variable to change towards independent parameters variations. The final results revealed that VOC emission is extremely sensitive to an increase in purity or mole flow of DEG while for the wet gas and gas' along water mole flow variations, solvent loss changes are more severe than the other dependent parameters. To study the possibility of optimizing the entire process, all the obtained results were combined and dray gas dew point were considered as the key parameter for the optimization due to its critical role in gas transmission by pipelines. By taking into account all of the operation restrictions and criteria at the existing operational conditions; it was revealed that a ten percent increase in solvent mole flow is applicable in order to reduce dry gas dew point up to six percent without a significant raise in the dehydration unit's total energy consumption and VOC emission.

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