Mitigation of BTEX emission from gas dehydration unit by application of Drizo process: A case study in Farashband gas processing plant; Iran

Majid Saidi, Mahboubeh Parhoudeh, Mohammad Reza Rahimpour*

Department of Chemical Engineering, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71345, Iran

A R T I C L E   I N F O

Article history:
Received 22 February 2014
Received in revised form 9 April 2014
Accepted 12 April 2014
Available online

Keywords:
Gas dehydration unit
Gas stripping
Drizo process
BTEX emission
Process simulation

A B S T R A C T

As greenhouse gas emissions have become a concern to the entire natural gas industry, it is always balanced with the obligation of reasonable investment levels and production costs. According to environmental regulations, emission of aromatic compounds and other hazardous materials from this process is a challengeable issue. In the natural gas dehydration process, glycol solvents use to remove water from the natural gas stream in order to meet the pipeline quality standards. Farashband gas processing plant consists of six dehydration units operate using stripping gas injection. In this study, to mitigate the BTEX compounds emission rate in the Farashband gas processing plant, two alternatives based on the Drizo process for solvent regeneration are proposed. In the first technique, application of a single Drizo process in each dehydration unit is investigated and in the second, use of a complex Drizo process instead of three separated single Drizo processes is suggested. These alternatives aim to minimize environmental disadvantages and improve the most important operating parameters such as dry gas water dew point temperature, glycol loss and glycol purity. Simulation results indicate that TEG as dehydrating agent has a better performance with respect to DEG. Single Drizo process shows the most significant change of water dew point followed by complex Drizo process and conventional stripping gas dehydration process. Also in the case of Drizo process, the water content of natural gas reduces with increasing the reboiler operating temperature from 180 °C to 200 °C. Although the BTEX emission rate in three single Drizo processes is lower than a complex Drizo process, economic evaluations represented that the additional total capital investment decreased from 2.406 million$ to 1.365 million$ using the complex Drizo process instead of three single Drizo processes. Also investigation of different solvents showed that though n-Heptane has the best performance among different solvents, use of the recycled BTEX compounds as a solvent, not only reduces the BTEX emission rate, it decreases the additional costs. Also data analysis represents that by considering this fact that the BTEX emission rate enhances with increasing glycol circulation rate, the optimum TEG circulation rate for both single and complex Drizo processes is approximately 4 (gal TEG/lb water).

1. Introduction

The major concern in the natural gas industry is the presence of impurities such as hydrogen sulfide, carbon dioxide, nitrogen, aromatics compounds, water and other heavy compounds. Natural gas is saturated with water vapor under normal production conditions (Bahadori and Vuthaluru, 2009a,b). Glycol dehydration is a continuous liquid desiccant process in which the water content of natural gas is removed from hydrocarbon streams by selective absorption and then the glycol is regenerated or reconcentrated by thermal desorption. Several units such as slug catcher, gas sweetening, gas dehydration (dew point adjustment unit), glycol regeneration and, etc. have been established for gas treatment in the natural gas processing. Gas dehydration process is an important process in the natural gas processing in order to decrease the water content of the natural gas to some allowable limit (Rojey and Jaffret, 1997; Faulkner, 2006).

Engineering investigations and industrial experiences indicate that controlling and decreasing impurity content of the natural gas is so necessary to ensure safe processing and transmission. Presence of water vapor in the natural gas can cause different operational problems such as equipments corrosion and hydrate formation. The formation of hydrate in natural gas systems has been a problem in the gas processing industry for nearly a century.
which leads to pipeline transmission blockage (Hammerschmidt, 1934; Rahimpour et al., 2011).

Water vapor removal or dehydration process is accomplished by decreasing the inlet water dew point to temperature at which vapor begins to condense into a liquid. Absorption of water vapor in the glycol solution is the common method. The wet gas is brought into contact with dry glycol in an absorber. Water vapor is absorbed in the glycol and consequently, its dew point reduces. The wet rich glycol then flows from the absorber to a regeneration system in which the entrained gas is separated and fractionated in a column and reboiler. The heating allows boiling off the absorbed water vapor and the water dry lean glycol is cooled and pumped back to the absorber.

There are various methods for water removal from the wet natural gas through this unit. One of the most common methods in the large scale is the application of absorbent liquid such as Triethylene glycol (TEG), diethylene glycol (DEG) and mono-ethylene glycol (MEG). Among these compounds, TEG is the most applicable absorbent liquid for natural gas dehydration process due to its high chemical resistance, high water absorption, easy regeneration, low capital and operational costs, fewer vaporization losses and, etc (Paymooni et al., 2011).

There are various methods for water removal from the wet natural gas through this unit. One of the most common methods in the large scale is the application of absorbent liquid such as Triethylene glycol (TEG), diethylene glycol (DEG) and mono-ethylene glycol (MEG). Among these compounds, TEG is the most applicable absorbent liquid for natural gas dehydration process due to its high chemical resistance, high water absorption, easy regeneration, low capital and operational costs, fewer vaporization losses and, etc (Paymooni et al., 2011).

Emission of aromatic compounds, including benzene, toluene, ethylbenzene and xylene isomers (BTEX) compounds and other volatile organic compounds (VOCs), which vent from the reboiler of the glycol dehydration unit is another concern in the natural gas processing (Bahadori et al., 2013a,b). The type and amount of emissions from dehydration unit depends on the actual process design, operating conditions, and the composition and flow rate of the raw natural gas. For a typical unit equipped with a flash separator, the composition of the vented vapors may be expected to vary as water, condensable hydrocarbons, and non-condensable hydrocarbons. BTEX compounds are usually the most concentrated condensable hydrocarbons.

During the natural gas dehydration, the BTEX and VOC compounds are absorbed by glycol, and subsequently during the glycol regeneration process, they release to the atmosphere. The presence of small amounts of BTEX in the natural gas stream can result in very high concentrations in the vented stream. The molar concentration of BTEX at the outlet of the vent can easily be several hundred times higher than in the raw natural gas.

According to the environmental considerations, decreasing the emission of aromatic compounds is gaining importance in the gas processing. So development and selection of process alternatives to decrease the BTEX/VOCs emissions needs more attention during the design phase. Choosing a proper dehydrating agent has a significant effect on the BTEX absorption, so that BTEX solubility in different solvents is as follows: triethylene glycol (TEG) > diethylene glycol (DEG) > ethylene glycol (EG) (Covington et al., 1998).

In the natural gas dehydration process using TEG solvent, it is necessary to develop an appropriate model which can correctly calculate the circulation glycol flow rate, lean glycol purity, dry gas water content and other operating parameters for the water–TEG–methane system phase equilibrium. In 1972, Pearce et al. investigated the gas dehydration process in which glycol as a dehydrating agent regenerated subsequently with toluene (Drizo Process) (Pearce et al., 1972a). Parrish et al. studied the phase equilibrium of water–TEG system and confirmed the equilibrium data that was reported by Herskowitz and Gottlieb (1984) and Parrish et al. (1986). Also, a relation between water activity coefficient and binary mixture temperature was presented by them and nowadays, this relation has industrial application (Parrish et al., 1986). In 1993, a state equation for water–TEG–methane system is presented (Cunningham et al., 1993) and in 2005, the state equation that had provided previously for obtaining the water activity coefficient in water–TEG mixture was modified by Twu et al. (2005). Grizzle proposed an effective economic method for reducing the emission of VOC via burning a mixture of condensable and non-condensable gases as a fuel in the reboiler (Grizzle, 1993). Peinemann and Stegger developed a gas permeation membrane which was applicable in hydrocarbon recovery process such as BTEX and propylene recovery process and gas conditioning processes such as water vapor dew point adjustment, natural gas drying and, etc. (Peinemann and Stegger, 2003). Darwish and Hilal simulated a typical process for natural gas dehydration using TEG as a desiccant via a steady state flow sheet simulator ( Aspen Plus) (Darwish and Hilal, 2008). Also vapor–liquid equilibrium data are measured experimentally for water–TEG and water–TEG–toluene systems, at 85 kPa and various temperatures by Khosravi ion et al. (2009). Bahadori and Vuthaluru developed an estimation model for prediction of the natural gas water dew point temperature in equilibrium with the TEG solution at various temperatures and TEG concentrations (Bahadori and Vuthaluru, 2009a,b).

In another related work, Paymooni et al. proposed addition of volatile hydrocarbon solvents such as toluene and iso-Octane to enhance the glycol purity in the regeneration process. Their results indicated that the liquid hydrocarbon solvent addition can considerably enhance glycol purity and water volatility and remarkably reduce glycol loss (Paymooni et al., 2011).

1.1. Natural gas dehydration process

A simple schematic diagram of natural gas dehydration unit is represented in Fig. 1. As shown in this figure, TWR-100 is a bubble-cap tray absorption tower with 4–10 trays (Bentley, 1991). The wet gas and lean glycol streams enter from the bottom and top of the absorption tower, respectively. Due to direct contact of the glycol solution to the wet gas through this tower, the water in the vapor phase is absorbed by glycol, and then, rich glycol and dry gas streams exit from the bottom and top of the tower, respectively. Amount of water in the rich glycol stream depends on the wet gas composition and the gas dehydration unit design. The temperature of the rich glycol stream increases in the heat exchangers (XCHG-100 and XCHG–101) and then this stream enters the flash tank (VSSL-100) in order to separate the insoluble gaseous hydrocarbons which are used as a fuel gas. Also, the rich glycol stream with high temperature is directed to the desorption tower (TWR-101). This tower is blocked by the desorption tower. This tower, due to much difference in water and TEG boiling point temperatures, TEG and water are well separated, and the regenerated glycol (Lean glycol stream) is returned to the absorption tower (TWR-100). By applying this method, the glycol purity in the natural gas dehydration units will be between 98.5 wt% to 99 wt%.

1.2. Glycol purity enhancement methods

There are several methods in order to enhance the glycol purity in the desorption tower (TWR-101) of the gas dehydration unit (Fig. 1). These methods are listed in Table 1. One method for glycol
purity enhancement is the injection of dry natural gas or inert gas as a stripping gas, directly to the reboiler of the desorption tower, in order to improve the water–TEG separation in the desorption tower and enhance the glycol purity by decreasing the water effective partial pressure and increasing the water volatility in the vapor phase. In 1991, Wieninger et al. reported that by applying this method, glycol purity will increase above 99.5 wt% (Wieninger, 1991). In the Farashband natural gas dehydration units, this method is used to improve the water–TEG separation efficiency. Wasting injected gas into the atmosphere, imposition of additional costs and environmental pollution are the major disadvantages of this method.

In the glycol regeneration process under vacuum condition, the glycol purity will enhance up to 99.9 wt%, but due to the high cost of vacuum system, use of this method is limited. Cold finger is another method for glycol purity enhancement that is presented by Reid in 1975 for the first time (Reid, 1975). The main principle of this technology is to condense and collect water/hydrocarbons from the vapor phase of reboiler and drain it away from the reboiler. Rahimpour et al. reported that using cold finger technology in the natural gas dehydration unit, the glycol purity will be 99.83 wt% (Rahimpour et al., 2013a,b).

Another applicable method to enhance the efficiency of the desorption tower in the gas dehydration process is the use of volatile hydrocarbon compounds such as toluene, ISO-Octane, n-Heptane and, etc. (Drizo process). These hydrocarbon compounds are injected to the reboiler of desorption tower and act similar to the stripping gas after vaporization. Adding these compounds improves the efficiency of water–TEG separation and enhances the glycol purity. In fact, the liquid hydrocarbon solvent increases the water volatility in the water + TEG solution because n-heptane, isooctane and BTEX can form an azeotropic mixture with water and act as a stripping gas after vaporization in the reboiler (Pearce et al., 1972b; Paymooni et al., 2011). Pearce et al. (1972a) concluded that the water content of glycol + water solution could be decreased to less than 1000 ppm by an azetroptic regeneration of glycol via toluene. Also Fowler (1975) reported that the azetroptic regeneration process needed a remarkably lower energy consumption rate with respect to other regeneration processes. In another related work, Paymooni et al. (2011) showed that the liquid hydrocarbon solvent addition can remarkably enhance TEG purity and water volatility and considerably decreases TEG loss. Their results indicated that isooctane performed better than toluene, and a higher TEG concentration, lower water concentration, and duty of reboiler were achieved with isooctane injection. In this process, the outlet vapor stream from desorption tower is directed to a cooler at the top of the tower, and next to the cooler, a triple-phase separator is embedded in order to separate aqueous phase, vapor phase and liquid hydrocarbon phase which contains BTEX. BTEX compounds which are separated in the triple-phase separator can be used as a solvent for the glycol regeneration. This method developed in 1970 by Dow chemical company and called Drizo process (Manning and Thompson, 1991).

There are a lot of impurities such as mercaptans, carbon dioxide, nitrogen and, etc. in the wet gas. Due to the harmful effect of BTEX compounds on the human health, BTEX emission control in the natural gas dehydration units is very important. The BTEX emission in the natural gas dehydration unit depends on the amount of these compounds in the input stream of the absorption tower, temperature, pressure and also the glycol circulation flow rate. After separating these impurities from TEG by injection of high temperature stripping gas, a large part of these compounds are discharged into the atmosphere, whereas in the Drizo process, a large part of these impurities return to the desorption tower as a process solvent. The Drizo process as an effective glycol-enhancement technology results extremely high glycol purities. High glycol purity enables competition with other technology and reduces energy requirements with respect to other common enhanced-glycol processes. One of the most advantages of Drizo process is that due to higher glycol purity, the required glycol flow rate decreases and as a result, the BTEX emissions from the regenerator section reduce. Application of a recoverable and vaporized liquid-hydrocarbon solvent to contact the glycol is the most important characteristics of Drizo process. The hydrocarbon solvent has a relatively narrow boiling point range and vaporizes at high temperature prior to contact with the semi-lean glycol leaving the regenerator. As reported in Table 4, the glycol purity in the Drizo process is more than other methods. Increasing the TEG purity...
dehydrated unit in the Farashband gas processing. Input and output streams characteristics of the absorption tower of the natural gas processing plant are reported in Table 4.

### 2. Objective

The Farashband gas processing plant which is one of the oldest and main plants in the southern part of Iran has been designed to purify and stabilize 1400 million standard cubic feet (MMscf) natural gas per day from the Dalan and Aghar gas reservoirs. The refined gas directed to the national gas transmission line for general consumption, and the condensates of the refinery (about 15,000 barrels/day) transport to the Taheri harbor for exporting (Rahimpour and Jokar, 2012). This plant consists of six dehydration units operate using stripping gas injection. The focus of this study is on the dehydration of Dalan reservoirs gas. In this work, the natural gas dehydration units of the Farashband gas processing plant which operates by injecting stripping gas is simulated using the steady state process simulation software. The major challenges in this process are glycol purity and high emission of BTEX and other VOCs compounds to the atmosphere. So to overcome these limitations, natural gas dehydration by using volatile hydrocarbon solvents (Drizo process) as an effective method is simulated and suggested in this study. Drizo process regenerates the glycol by solvent stripping instead of the conventional gas stripping. Solvent stripping allows to obtain much higher glycol purities than gas stripping and consequently allows to get much larger water dew point depressions: up to 100 °C (180 °F) and even higher in some cases. The solvent required by the Drizo process is usually obtained from the BTEX present in the natural gas itself and in most cases the process will even produce some liquid hydrocarbons. This work compares vent emissions of both Drizo process versus stripping gas for different operating conditions as well as summarized the operational performance of Drizo process.

Also for more investigation, economical and environmental considerations are done and the proposed alternatives are compared with the present operating conditions of the Farashband gas processing plant. The dehydration process is simulated in both summer and winter operating conditions. The operating conditions and feed compositions are presented in Tables 2 and 3, respectively. Also the design parameters of desorption and absorption towers of the Farashband gas processing plant are reported in Table 4.

### 3. Process simulation and validation

#### 3.1. Glycol regeneration using stripping gas injection simulation (case 1)

A schematic diagram of gas dehydration unit of the Farashband gas processing is shown in Fig. 2. As shown in this figure, the stripping gas (Stream no.6, mass flow rate = 80 kg/h) is provided from the produced dry gas in the absorption tower (TWR-100) and the flow rate of this stream is adjusted via the splitter (SPLT-100). The stripping gas flow rate affects on the TEG regeneration process, but excessive increase in the stripping gas flow rate causes glycol loss. In this simulation, instead of a packed tower, a distributor tower (TWR-102) with two ideal trays is embedded. After increasing the temperature of the stripping gas from 4 °C to 36 °C via the heat exchanger (XCHG-103), it enters the distributor tower from the bottom of it and the glycol stream which exits from the reboiler (K-100) is directed to the tower with counter-current operation mode. In the distributor tower, the stripping gas absorbs water and BTEX compounds in the glycol stream. The lean glycol comes out from the bottom of the distributor tower (TWR-102) and enters the absorption tower (TWR-100) after cooling in the heat exchanger (XCHG-104). Due to the glycol loss in the absorption and desorption towers, a TEG make up stream (Stream no.7) is considered in the gas dehydration unit.

The desorption tower of Farashband gas processing plant is a packed bed, but in this simulation, a tray tower (TWR-101) with eight equilibrium stages is considered instead of a packed bed tower where the pressure changes from 1 bar to 1.2 bar trough the length of the tower. Also the absorption tower (TWR-100) is a tray tower with six trays and operates at high pressure. In this
simulation study, it supposed that the trays are ideal. The characteristics and composition of the streams used in the simulation of case 1 are reported in Tables 5 and 6, respectively for the summer operating condition.

According to the simulation results, the water content of the wet gas decreases from 0.07 wt% to 0.00 wt%. Also, the calculated water dew point temperature in this case is about $-25^\circ C$. The glycol purity in the lean glycol stream (Stream no.8) which enters the absorption tower is 99.63 wt%. This case is also simulated in the winter operating condition. All streams and equipments are similar to summer condition, but due to the low temperature of the wet gas in the winter operating condition, the absorption process in winter is more suitable than summer, so water dew point temperature, glycol purity and other effective parameters in winter are more desirable than summer. The most important challenge of the current process (Case 1) is that the outlet stream of the desorption tower (Stream no.4) has high content of BTEX compounds and it releases into the atmosphere and causes environmental pollution. Also, due to the high circulation rate of glycol, the amount of required power in the reboiler (Q-4) of the desorption tower is about 618.33 kW which is high.

3.2. Single Drizo process simulation (case 2)

A process schematic of the proposed single Drizo gas dehydration unit is illustrated in Fig. 3. The Drizo process is an appropriate suggestion for controlling these environmental pollutants. In this process, instead of stripping gas injection, a volatile hydrocarbon solvent such as iso-Octane, n-Heptane, or BTEX compounds are injected to the reboiler of the desorption tower. The Dalan reservoirs gas contains a lot of BTEX compounds, so these compounds are used as the Drizo process solvent.

According to Fig. 3, the outlet stream from the top of the desorption tower (Stream no.4) which is released into the atmosphere in case 1, enters the triple-phase separator (VSSL-101) after cooling in the heat exchanger (XCHG-103). The triple-phase separator is used to prevent emission of BTEX compounds to the atmosphere and recycling of them to the glycol regeneration process as a solvent. In the triple-phase separator to separate the two immiscible liquids, the weirs are often used. Because of different densities of the two liquids, the lightest liquid will after a certain time float on top of the heavier liquid. By applying a weir to have a height greater than the thickness of the heaviest liquid layer, the only liquid allowed to overflow the weir is the lightest. A mixture of water, BTEX and gas enter the triple-phase separator. In the triple-phase separator, the levels of water, BTEX and pressure are controlled independently and phases separate out due to differences in density. The operating conditions of the triple-phase separator which is used in this simulation are $25^\circ C$ and 1.20 bar. Light vapor phase (Stream no.5) and aqueous phase (Stream no.6) come out from the separator. A part of the BTEX stream (Stream no.8) is returned to the reboiler (K-100) of the desorption tower (TWR-101) to regenerate glycol and the other part of it (Stream no.7) is sent to the Aghar gas dehydration units in order to use in

**Table 5**

Characteristics of streams in simulation of case 1 in summer operating condition for the Dalan gas.

<table>
<thead>
<tr>
<th>Streams</th>
<th>Temp. (°C)</th>
<th>Pres. (bar)</th>
<th>Vapor mol. (%)</th>
<th>Liquid mol. (%)</th>
<th>Mass flow rate (kg/h)</th>
<th>Molecular weight (kg/kmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Dry gas)</td>
<td>52</td>
<td>125</td>
<td>100</td>
<td>0</td>
<td>247,170</td>
<td>17.87</td>
</tr>
<tr>
<td>2 (Rich glycol)</td>
<td>52</td>
<td>127</td>
<td>0</td>
<td>100</td>
<td>6144</td>
<td>99.78</td>
</tr>
<tr>
<td>3 (Fuel gas)</td>
<td>105</td>
<td>6.52</td>
<td>100</td>
<td>0</td>
<td>61</td>
<td>21.03</td>
</tr>
<tr>
<td>4</td>
<td>125</td>
<td>1.05</td>
<td>100</td>
<td>0</td>
<td>1187</td>
<td>25.48</td>
</tr>
<tr>
<td>5</td>
<td>199</td>
<td>1.20</td>
<td>100</td>
<td>0</td>
<td>185</td>
<td>25.77</td>
</tr>
<tr>
<td>6</td>
<td>52</td>
<td>125</td>
<td>100</td>
<td>0</td>
<td>80</td>
<td>17.87</td>
</tr>
<tr>
<td>7 (TEG make up)</td>
<td>30</td>
<td>3.72</td>
<td>0</td>
<td>100</td>
<td>3</td>
<td>149.08</td>
</tr>
<tr>
<td>8 (Lean glycol)</td>
<td>62</td>
<td>127</td>
<td>0</td>
<td>100</td>
<td>5504</td>
<td>148.27</td>
</tr>
</tbody>
</table>
the Drizo process. The characteristics and compositions of the streams in the summer operating condition for case 2 are reported in Tables 7 and 8, respectively. Based on the simulation result presented in Table 8, the mass fraction of BTEX compounds in the purge gas (Stream no. 5) is about 6.05%, whereas it is about 92.68% in the BTEX drain (Stream no. 7).

The calculated water dew point temperature in this case is about \(29\) °C which is lower than the computed value in case 1 and the wet gas water content decreases from 0.07 wt% to 0.00 wt%. Another benefit of this case is that by applying volatile hydrocarbon solvent (BTEX) instead of the stripping gas injection, the glycol purity in the lean solution increases to 99.81 wt%. So, based on Tables 5 and 7, the lean glycol solution flow rate in case 2 decreases to 5437 kg/h with respect to case 1, which was 5504 kg/h and as a result, the glycol loss (TEG makeup) will reduce. According to the simulation results, by application of single Drizo process, the required power of the reboiler (Q-4) decreases from 618.33 kW to 457.24 kW, because the circulation glycol flow rate in the reboiler of case 1 is more than the calculated value in case 2.

3.3. Complex Drizo process simulation (case 3)

As mentioned in the previous sections, the Farashband gas processing plant contains three dehydration units for refining the Dalan reservoirs gas. In the Drizo loop for the single dehydration unit (Fig. 3), a triple-phase separator (VSSL-101), a pump (P-100) and two heat exchangers (XCHG-103 and XCHG-104) are added to the common equipments of each dehydration unit which leads to higher capital cost. So application of one complex Drizo cycle instead of three separated single Drizo cycles for three dehydration units is suggested. In this case, the desorption towers outlet of the Dalan gas dehydration units are mixed in a mixer and after cooling sent to the triple-phase separator.

The required BTEX solvent for the glycol regeneration process of the dehydration units are provided from the BTEX drain of triple-phase separator in the complex Drizo process. Another part of BTEX drain is sent to the Aghar gas dehydration unit. The characteristics and compositions of the streams in summer operating condition for case 3 are reported in Tables 9 and 10, respectively.

According to the simulation results, the calculated dry gas water dew point temperature is about \(-25\) °C and the wet gas water...
content reduces to 0.00 wt% in the outlet dry gas. Also the glycol purity in the lean solution (Stream no.15) is 99.72 wt% that is a little lower than case 2. According to Tables 7 and 9, the lean glycol flow rate in case 3 is a little higher than case 2 and as a result the glycol loss (TEG makeup) for each dehydration unit increases from 2.5 kg/h (case 2) to 2.65 kg/h (case 3), nevertheless the glycol loss in cases 2 and 3 is lower than case 1. Based on the simulation results, by application of a complex Drizo process, the required power of reboiler decreases to 463 kW with respect to case 1 (618.33 kW), because the circulation glycol flow rate in the reboiler (K-100) of case 1 is more than the calculated value in case 3. Due to higher circulation glycol flow rate in case 3, the value of reboiler required power is a little higher than the calculated value in case 2.

Since the desorption tower outlets of the three Dalan gas dehydration units are mixed to one stream in the complex Drizo, the required energies of two heat exchangers (XCHG-103 and XCHG-104) and the solvent transmission pump (P-100) in case 3 are more than the corresponding values in case 2 and also the size of the triple-phase separator in this case are larger than case 2. So, in the complex Drizo process, a larger pump and two higher power heat exchangers are used instead of three solvent transmission pumps and six heat exchangers which were used in three single Drizo process.

### 3.4. Thermodynamic investigation and validation

For the basic design and operation of the natural gas dehydration process, thermodynamic investigation of the phase behavior of materials is very important. Khosravanipour et al. (2009) investigated experimentally the binary (water + TEG) and ternary systems (water + TEG + toluene) using Van Laar, quasichemical activity coefficient (UNIQUAC), and nonrandom two liquid (NRTL) activity coefficients models. Their obtained results showed good agreements for the water + TEG system, but for the ternary system only NRTL and UNIQUAC models were appropriate. In this simulation, NRTL model is used to determine the VLE parameters.

To confirm the simulation results, a comparison was made between plant data and simulation results in summer and winter operating conditions for case 1. A comparison of the water dew point temperature in winter and summer operating conditions represents an average error about 3.6 wt% and 4.7 wt%, respectively. Also based on the simulation results, glycol purity in winter and summer operating conditions are about 99.75% and 99.63%, respectively where the plant data are 99.6 wt% and 99.7 wt%, respectively. Table 11 indicates that the present simulation can accurately predict the operating parameters, such as the water dew point temperature, glycol loss, circulation glycol and glycol purity with an appropriate average error.

### 4. Results and discussion

#### 4.1. Effect of operating variables on single Drizo process

The performance of the single Drizo process (Case 2) using different solvents with different flow rates on the gas dehydration effective parameters are investigated in summer and winter conditions. As shown in Fig. 4, for different solvent (BTEX, n-Heptane,
Iso-Octane, 50% n-Heptane and 50% Iso-Octane), the dry gas water dew point temperature decreases with increasing the solvent flow rate. Also, dry gas water dew point temperature values in the winter operating condition are lower than the computed values in summer. According to this figure, the minimum values for the dry gas water dew point temperature in different flow rate of solvents belong to n-Heptane, in both summer and winter operating conditions.

Fig. 5 shows the effect of solvent flow rate on the glycol loss rate. Based on this figure, the glycol loss flow rate reduces with increasing the solvent flow rate. Also, the glycol loss rate values in the winter operating condition are less than the computed values in summer. The performance comparison of different solvents represents that the minimum value of the glycol loss rate can one achieve using n-Heptane, in both summer and winter.

As shown in Table 12, the glycol purity in winter is more than the glycol purity in summer operating condition for each solvent. According to this table, the maximum value for glycol purity belongs to n-Heptane in both summer and winter (99.998 wt% in summer and 99.999 wt% in winter).

4.2. Effect of operating variables on complex Drizo process

The complex Drizo process performance in the presence of various solvents is studied with two different mass flow rates of solvent, 5 and 10 kg/h in both summer and winter conditions. As shown in Fig. 6, in summer and winter operating conditions, for each solvent, the dry gas water dew point temperature in the case of 10 kg/h solvent rate is lower than the calculated value in the case of 5 kg/h solvent rate, so dry gas water dew point temperature decreases with increasing solvent flow rate. As mentioned in previous cases, dry gas water dew point temperature values in the winter operating condition are lower than computed values in summer operating condition. Also Fig. 7 represents the effect of solvent flow rate on the glycol loss rate.

As shown in this figure, by increasing the solvent flow rate from 5 to 10 kg/h, the rate of glycol loss decreases for all solvents. Comparison of the glycol purity in summer and winter operating conditions in Table 13 indicates that the glycol purity in winter is more than summer. According to Figs. 6 and 7 and also Table 13, n-Heptane solvent has the best performance among the different solvents. N-Heptane can enhance water volatility more effectively than other hydrocarbons solvent (Iso-Octane, BTEX and mixture of n-Heptane and iso-octane) because it vaporizes rapidly in the reboiler and enhances the water volatility which increases TEG concentration.

4.3. Comparison of different cases

4.3.1. Dry gas water dew point temperature

The performance of current dehydration unit of the Farashband gas processing plant (Case 1) is compared with two proposed Drizo processes (Cases 2 and 3). As shown in Fig. 8, by application of the Drizo process, the dry gas water dew point temperature for cases 2 and 3 in summer operating condition improves to $-29 \, ^\circ C$ and $-25 \, ^\circ C$, respectively, whereas it is $-25 \, ^\circ C$ for the Farashband gas processing plant. Also the dry gas water dew point temperature for cases 1 to 3 in the winter operating condition is about $-29 \, ^\circ C$, $-72 \, ^\circ C$ and $-67 \, ^\circ C$, respectively. So, the minimum dry gas water dew point temperature belongs to the single Drizo process, in both summer and winter.

4.3.2. Glycol loss

Glycol loss is another important factor which is investigated in Fig. 9. This figure shows that the glycol loss in summer operating...
4.3.3 Glycol purity

According to Fig. 10, in summer operating condition, the glycol purity in the lean glycol stream for cases 1 to 3 is 99.63 wt%, 99.81 wt% and 99.72 wt%, respectively. Also in winter, the maximum glycol purity belongs to the single Drizo process (Case 2) which is about 99.85 wt%. So the investigation of the different cases indicates that case 2 has the best performance among them.

4.3.4 Effect of reboiler temperature on natural gas water content

Proper dehydrating agent is another effective factor on controlling water content of natural gas and BTEX emissions. BTEX compounds are less soluble in diethyleneglycol (DEG) than triethyleneglycol (TEG) and considerably less soluble in ethyleneglycol (EG) (Covington et al., 1998). To be able to choose the best suited absorbent for the injection dehydration concept, the performances of DEG and TEG in natural gas dehydration during single and complex Drizo processes are studied in Fig. 11. Investigation of different cases shows that use of TEG as dehydrating agent has a better performance with respect to DEG. Also it is concluded that the single Drizo process is superior to the complex Drizo process.

4.3.5 Effect of reboiler temperature on natural gas water content

A pressurized reboiler is an effective factor in controlling water content of natural gas and BTEX emissions from glycol gas-dehydration systems. The operating temperature of the reboiler should be as high as possible without exceeding 205 °C to ensure maximum reconcentration of the TEG and thereby suppress the necessary glycol circulation rate. Higher temperatures will lead to excessive glycol losses into the still column vent gas and possibly thermal decomposition of the glycol. For investigating the effect of reboiler temperature on natural gas water content through the single and complex Drizo processes in summer operating condition, the performance of n-Heptane and a mixture of n-Heptane-BTEX as solvent are considered at different temperatures. As represented in Fig. 12, the water content in gas decreases with increasing the reboiler operating temperature from 180 °C to 200 °C. Also comparison of different cases indicates that when pure n-Heptane is used as solvent in the single Drizo process (Fig. 12(a)), the water content is at least.

4.4. Environmental considerations

Table 14 compares the BTEX emission rate in the gas dehydration unit, using the stripping gas injection (Case 1) and the single and complex Drizo process (Cases 2 and 3) with the TEG compounds and n-Heptane as the process solvent in the desorption tower for summer and winter operating conditions. Since the desorption tower overhead stream in the current gas dehydration units of the Farashband gas processing plant which contains a lot of BTEX compounds is released to the atmosphere directly, the BTEX compounds emission rate in case 1 is very high as represented in Table 14. According to this table, due to the separation of BTEX compounds by the triple-phase separator in the Drizo process and recycle of these compounds as a solvent to the desorption tower, the emission rate reduces considerably using the single/complex Drizo process. As reported in Table 14, due to better absorption process in the low temperature operating condition, more BTEX compounds are absorbed from the wet gas by glycol. So, in the winter operating condition, due to the higher content of BTEX compounds in the rich glycol solution, the emission rate of the BTEX is more than summer operating condition for all cases. Although n-Heptane as the Drizo process solvent has the best effect on the gas dehydration unit effective parameters, but due to the lower BTEX emission rate and more inexpensive accessibility for BTEX compounds as the Drizo process solvent, these compounds are suggested as a solvent in this study.

The main objective of dehydration process is reduction of natural gas water content, but due to environmental consideration, decreasing the emission rate of BTEX compound is so crucial. As discussed in the previous section, Drizo process is an effective alternative to reach these goals. It is obvious that increasing the rate of TEG decreases the water content of natural gas, but as represented in Fig. 13, the BTEX emission rate enhances with increasing the glycol circulation rate. So an optimum rate of glycol circulation should be determined. As demonstrated in Fig. 13, increasing the TEG circulation rate more than 4 (gal TEG/lb water) has not significant effect on the water content in both cases of single and
complex Drizo processes, but it increases the emission rate of BTEX. So based on the reported data in this figure and also economical consideration, the optimum TEG circulation rate for both cases is approximately 4 (gal TEG/lb Water). Therefore, the amount of water content in the natural gas is controlled by glycol dehydrator rate. However, since this rate also determines the amount of venting emissions, it is important that the circulation rate not be set any higher than is needed. Fig. 14 shows the effect of adsorption tower pressure on the emission rate of BTEX and water content. According to this figure, increasing the operating pressure of adsorption tower has significant effects on the reduction of BTEX and water content.

4.5. Economic evaluations

In spite of different advantages of Drizo process, the important drawbacks for this technology are that it requires additional equipment both for the stripping column and the regeneration of the liquid hydrocarbon solvent, and heat is required to vaporize and superheat the solvent used for stripping. In this section, the investment decision is based on a comparison between the two presented alternatives, the single and complex Drizo process. After simulating two aforementioned processes via the steady state process simulation software, an economic assessment of each process is evaluated. The profitability of each process is analyzed using the total capital investment (TCI) of each case. The TCI is calculated as follows (Peters and Timmerhaus, 1991):

\[
TCI = FCI + WCI
\]

Table 12

<table>
<thead>
<tr>
<th>Solvents</th>
<th>Glycol purity in summer (wt%)</th>
<th>Glycol purity in winter (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Heptane</td>
<td>99.998</td>
<td>99.999</td>
</tr>
<tr>
<td>50% n-Heptane–50% Iso-Octane</td>
<td>99.990</td>
<td>99.995</td>
</tr>
<tr>
<td>Iso-Octane</td>
<td>99.800</td>
<td>99.991</td>
</tr>
<tr>
<td>BTEX compounds</td>
<td>99.810</td>
<td>99.850</td>
</tr>
</tbody>
</table>

Fig. 6. Effects of different solvents on the dry gas water dew point temperature in case 3 (a) summer, (b) winter.

Fig. 7. Effects of different solvents on the glycol loss rate in case 3 (a) summer, (b) winter.
FCI = Direct cost + Indirect cost  \hspace{1cm} (2)

WCI = 15% TCI  \hspace{1cm} (3)

In case 2, the Drizo process is applied for each Dalan gas dehydration unit separately, so the calculated costs for the additional equipments in case 2 should be multiplied by three. In case 3, a complex Drizo process is extended for three Dalan gas dehydration units, so the size of additional equipments is larger than case 2, whereas the number of additional equipments for three gas dehydration units is less than case 2. The additional equipments in cases 2 and 3, and their purchased costs (PC) are represented in Table 15. These calculations imply that the total purchased cost (TPC) in the complex Drizo process for three Dalan gas dehydration units is about 441.30 thousand$, whereas in the single Drizo process for the three dehydration units is about 778.83 thousand$ (3 \times 259.61 thousand$).

The direct and indirect costs resulting from applying the Drizo process in the one Dalan gas dehydration unit are reported in Table 16. The calculated FCI based on Eq. (2) is represented in this table. TCI of the Drizo process for three Dalan gas dehydration units is calculated from the previous equations and presented in Table 17.

The economic evaluation of these two methods (Cases 2 and 3) is compared in Fig. 15. Although each method has its own advantage owing to preventing the BTEX emission to the atmosphere and consequent problems, a comparison is made to recognize the superior method economically. The comparison of TPC, FCI and TCI for the two methods is shown in Fig. 15. It can be seen that the total costs for case 3 is less than case 2, so applying the complex Drizo process for the three Dalan gas dehydration units is more economic than applying three single Drizo processes.

5. Conclusion

The emission of BTEX compounds in the natural gas dehydration unit is a major challenge in the gas processing industry. In order to determine a suitable method for minimizing the BTEX emission in the Farashband gas processing plant, two alternatives based on the Drizo technology is proposed. For performance investigation of the proposed alternatives, the process simulation and evaluations, environmental considerations and economic evaluations are done and compared with the plant data. Since the main goal of dehydration process is reduction of water content of natural gas, it can be improved by increasing the operating temperature of reboiler, glycol circulation rate and operating pressure of absorption tower. The simulation results demonstrated that, the glycol regeneration process using the Drizo technology instead of the gas stripping injection improves the important operating parameters such as dry gas water dew point temperature, glycol loss and glycol purity in the lean glycol stream and also reduces the BTEX emission significantly. Also data analysis shows that increasing the operating pressure of adsorption tower reduces the emission rate of BTEX compounds. Investigating the effect of various solvents in the Drizo process is an essential step for determining the optimal solution.
Fig. 11. Effect of dehydrating agent on natural gas water content in summer condition: (a) Single Drizo process (Solvent: n-Heptane), (b) Single Drizo process (Solvent: 50% n-Heptane and 50% BTEX), (c) Complex Drizo process (Solvent: n-Heptane), (d) Complex Drizo process (Solvent: 50% n-Heptane and 50% BTEX).

Fig. 12. Effect of reboiler temperature on natural gas water content in summer condition: (a) Single Drizo process (Solvent: n-Heptane), (b) Single Drizo process (Solvent: 50% n-Heptane and 50% BTEX), (c) Complex Drizo process (Solvent: n-Heptane), (d) Complex Drizo process (Solvent: 50% n-Heptane and 50% BTEX).

Table 14

<table>
<thead>
<tr>
<th></th>
<th>Stripping gas (Case 1)</th>
<th>Single Drizo process (Case 2)</th>
<th>Complex Drizo process (Case 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTEX emission rate in summer (kg/h)</td>
<td>912</td>
<td>9.5</td>
<td>10.9</td>
</tr>
<tr>
<td>BTEX emission rate in winter (kg/h)</td>
<td>1023</td>
<td>10.3</td>
<td>12.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>BTEX - 5 kg/h</th>
<th>n-Heptane - 5 kg/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BTEX - 5 kg/h</td>
<td>n-Heptane - 5 kg/h</td>
</tr>
<tr>
<td></td>
<td>BTEX - 5 kg/h</td>
<td>11.4</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
<td>14.5</td>
</tr>
</tbody>
</table>
process showed that although among the different solvents, n-Heptane has the best performance, use of recycled BTEX compounds as the Drizo process solvent, not only reduces the BTEX compounds emission extremely, it leads to cost saving. Economic evaluations represented that the application of a complex Drizo process instead of three single Drizo processes decreased the total capital investment from 2.406 million$ to 1.365 million$. Although due to additional equipments purchased costs, the total capital investment for the three Dalan gas dehydration units using the single/complex Drizo process is higher than current technology in the Farashband gas processing plant (Gas stripping method), the rate of the returned investment using the Drizo process will rectify the additional costs. Finally, Drizo process has proved to be one of the best available glycol dehydration processes. This is not only because of its higher dehydration efficiency, but it is also an

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Single Drizo process</th>
<th>Complex Drizo process</th>
<th>Cost (Thousand$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exchanger-103</td>
<td>Floating U-tube</td>
<td>Fixed U-tube</td>
<td>62.91</td>
</tr>
<tr>
<td>Heat exchanger-104</td>
<td>Duty = 68 kW</td>
<td>Duty = 700 kW</td>
<td>14.70</td>
</tr>
<tr>
<td>Pump</td>
<td>Centrifugal</td>
<td>Centrifugal</td>
<td>56.40</td>
</tr>
<tr>
<td>Splitter</td>
<td>No. of pump = 1</td>
<td>No. of pump = 1</td>
<td>28</td>
</tr>
<tr>
<td>Triple phase</td>
<td>Volume = 1.26 m³</td>
<td>Volume = 2.18 m³</td>
<td>22.60</td>
</tr>
<tr>
<td>separator</td>
<td>Diameter = 0.76 m</td>
<td>Diameter = 0.91 m</td>
<td>75</td>
</tr>
<tr>
<td>Absorption</td>
<td>60 ton.</td>
<td>240 ton.</td>
<td>195</td>
</tr>
<tr>
<td>chiller</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total purchased cost (TPC)</td>
<td></td>
<td></td>
<td>259.61</td>
</tr>
</tbody>
</table>
environmentally friendly process with minimized BTEX emissions and also easy implementation, minimal cost and with no shutdown time compared to conventional glycol units. Occasionally, the Drizo technology can be substituted into an existing glycol unit, but it is necessary to incorporate various modifications and install some new equipment.

References