

## STATE OF THE ART REVIEW AND RECENT DEVELOPMENTS IN GLYCOL DEHYDRATION FACILITY MODELLING AND OPTIMIZATION

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### ABSTRACT

In the last 30 years, process simulators have widely been used in the design and rating of natural gas glycol dehydration (TEG) and refrigeration (EG) facilities. In recent years, the ability of these simulators to accurately predict air emissions in glycol facilities has become increasingly relevant due to more stringent environmental regulations calling for reduced emissions. In gas production and processing, glycol facilities are a significant contributor to emissions; according to the USEPA, “dehydrators and pumps” comprise 12% of all methane emissions. As government regulations continue to evolve and operating companies are expected to look for ways to further reduce emissions, it is more important than ever to accurately simulate these facilities.

In this work, we review various issues associated with the process modeling of glycol facilities:

- Prediction of BTEX (benzene, toluene, ethylbenzene, xylenes) emissions in TEG and EG facilities
- Prediction of VOC (volatile organic compounds) and GHG (greenhouse gas) emissions from TEG and EG facilities
- Effect of glycol circulation and stripping gas on lean glycol concentration and sales gas water content

- Prediction of emissions reductions due to tanks and engineered condensers installed as emissions control methods downstream of the still overhead.

The current work reviews previous information available in the literature as well as some recent developments in the modelling of emissions control technology. Key knowledge gaps are identified and research lines proposed in order to narrow these challenges. Further research is being done in these areas and conclusions gleaned from the current research are also summarized.



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## Background

The upstream oil and gas industry uses glycol dehydrators to remove water from natural gas. The dehydration process also helps to prevent corrosion and hydrate formation in pipelines. A 2004 industry survey identified about 3,900 glycol dehydrators in service in Canada. The majority of the units are installed in rural environments. The units are typically unmanned/unattended<sup>1</sup>. A study by the Natural Gas Star Program (EPA) reports approximately 36,000 glycol dehydration systems in the US natural gas production sector<sup>2</sup>.

Most dehydration systems use triethylene glycol (TEG) as the absorbent fluid to remove water from natural gas. As TEG absorbs water, it also absorbs methane, other volatile organic compounds (VOCs), and hazardous air pollutants (HAPs) such as benzene, toluene, ethylbenzene and xylenes (BTEXs). As TEG is regenerated through heating in a reboiler, absorbed methane, VOCs, and HAPs are vented to the atmosphere with the water, creating an environmental hazard, wasting gas and money.

In a typical TEG dehydration process, wet gas is contacted counter-currently with the glycol which absorbs the water vapor. The dry gas is piped for further processing or for transmission to a sales pipeline. The rich glycol is fed to a reboiler for regeneration; heating the solution to 200 C (392 F) will remove enough water to re concentrate the glycol to 98.5% w/w or better. For processes requiring gas with very low water dew points, or if the wet gas is relatively warm, stripping gas will most likely be needed to aid the regeneration process. For maximum stripping, this gas is normally injected into a short column at the bottom of the reboiler. However, the gas may also be introduced directly into the reboiler<sup>3</sup>.

In the past years, glycol dehydration plants have been successfully designed using “off-the-shelf” process simulators such as Aspen HYSYS, ProMax and other similar tools. While still sufficient for many applications, today improved models are often required to predict the fate of trace elements. In many cases the plant feed will contain small quantities of aromatic hydrocarbons that are quite soluble in the TEG. The aromatics are primarily comprised of benzene, toluene, ethylbenzene, or xylenes (BTEX). These aromatics are carried to the flash tank where a small fraction is released along with other volatile organic compounds (VOC’s). The remaining VOC’s and aromatics travel to the regenerator where the

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<sup>1</sup> CAPP (2006) “Control of Benzene Emissions from Glycol Dehydrators” Best Management Practices

<sup>2</sup> USEPA Natural Gas Star: Lessons learned “Optimize Glycol Circulation And Install Flash Tank Separators In Glycol Dehydrators”

<sup>3</sup> Hernandez-Valencia, V.N. et al. (1992) “Design Glycol Units for Maximum Efficiency” 71<sup>st</sup> GPA Annual Convention

application of heat will remove virtually all volatile gases. Since the regenerator is usually vented to the atmosphere, the plant may have serious environmental impacts, even in small plants where the total benzene emissions can easily exceed 1-5 tonnes/year. Government regulators worldwide have been issuing ever more stringent regulations on the emissions of these toxic compounds to air.

## Modeling and Simulation

In an earlier publication<sup>4</sup>, it was discussed how GRI-GLYCalc and AspenTech's HYSYS are simulation tools frequently used to specifically predict BTEX emissions from glycol dehydration units. GRI GLYCalc has been the software of choice for regulatory agencies in North America with respect to estimating BTEX emissions from glycol dehydration units. However, some drawbacks in the implementation of the calculations in the GLYCalc software were identified and it was shown that it is possible to improve the accuracy and consistency of the air emissions estimations by relying on more sophisticated simulation tools such as HYSYS.

As noted earlier, the vast majority of dehydration units use Triethylene Glycol (TEG) to remove water from natural gas; the ability of these software tools to accurately predict BTEX emissions in TEG dehydration units is therefore of primary importance for both operators and regulatory agencies. In addition, since accurate prediction of dry gas water content is essential for the optimization of dehydration units, the calculation of dry gas water content was also reviewed.

Specifically, the predictions from GLYCalc and both the Peng Robinson and "Glycol" property packages in HYSYS were compared to:

- GPA Research Report 131<sup>5</sup> equilibrium data at contactor, flash tank and regenerator conditions
- Water removal vs. glycol circulation relationships<sup>6</sup>

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<sup>4</sup> Holoboff, J. L. and Khoshkbarchi, M. (2009) "Prediction of BTEX emissions and water content in TEG dehydration units" GPA Annual Convention

<sup>5</sup> H.-J. Ng, C.-J. Chen, D.B. Robinson, GPA Research Report RR-131, The Solubility of Selected Aromatic Hydrocarbons in Triethylene Glycol, December 1991.

<sup>6</sup> Arnold, K., Stewart, M. (1999) "Surface Production Operations – Design of Gas-Handling Systems and Facilities, Volume 2", Second Edition.

It was determined that:

- HYSYS-Peng Robinson, HYSYS-Glycol and GLYCalc all had a reasonable match to the BTEX liquid-phase concentration data from GPA RR-131 at contactor and flash tank conditions.
- HYSYS-Peng Robinson and HYSYS-Glycol had reasonable matches to BTEX concentration data at regenerator conditions. Given the empirical nature of the relationship used to model the regenerator in GLYCalc, it is difficult to make the comparison; however, we conclude that GLYCalc consistently overpredicts BTEX K-values in the regenerator.
- HYSYS predicted dry gas water content more accurately than GLYCalc. It is not uncommon for GLYCalc and HYSYS to give vastly different predictions; we conclude that GLYCalc frequently predicts dry gas water contents 50% lower than expected values. HYSYS-Glycol gave the best predictions here (Figure 1).
- It is further noted that property packages can be modified (most notably by modifying interaction parameters to better represent available experimental and plant data) and selectively applied in HYSYS providing an opportunity to improve on the available methods.

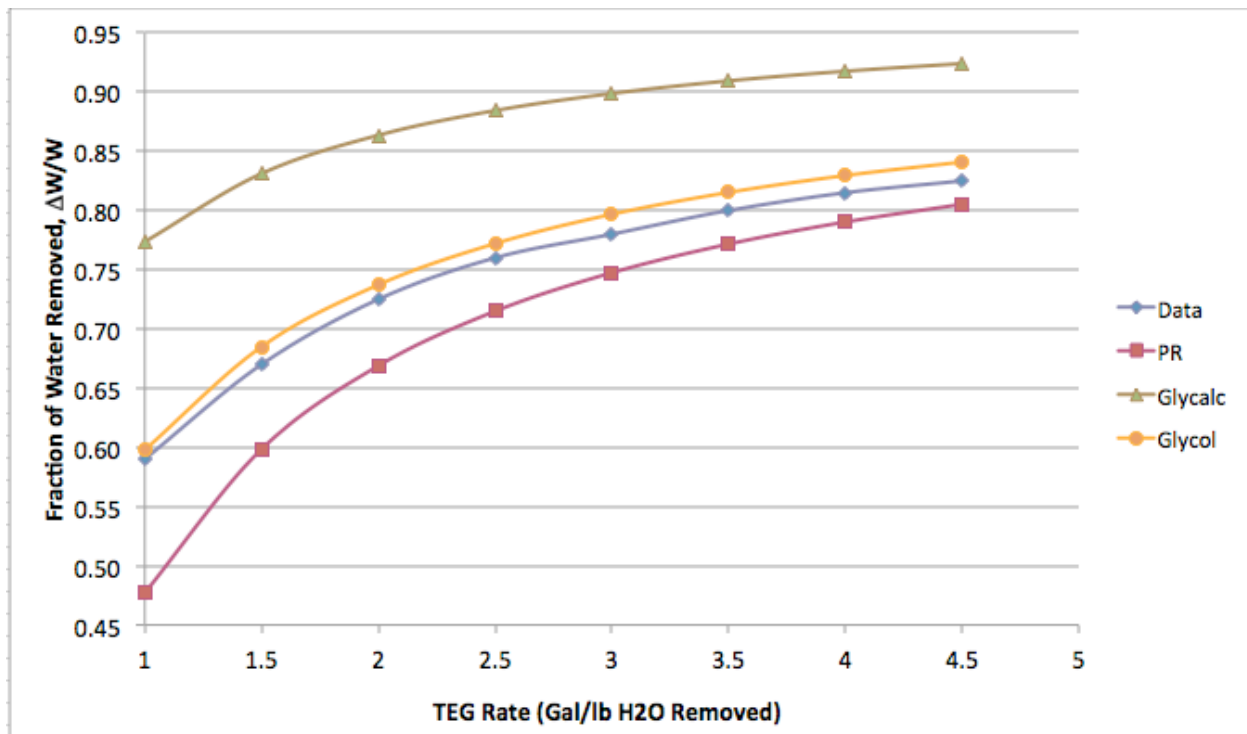


Figure 1- Dry gas water content prediction

Another aspect of BTEX emissions calculations which cannot be ignored is the fact that poor data or faulty assumptions can result in greater inaccuracies than what is inherent in the calculations. As far as

data is concerned, it is important to establish a methodology to ensure that accurate data can be obtained from the field and that errors in transferring data can be minimized. This is an advantage of HYSYS over GLYCalc, which allows for data to be imported programmatically.

In terms of the assumptions used in the calculations, HYSYS features the flexibility to be extended to improve the accuracy and reduce reliance on assumptions; for example:

- The contactor temperature has a significant influence on BTEX emissions and dry gas water content – typically the user assumes it as constant while in reality it can also fluctuate with ambient temperature (e.g., the gas may be compressed/cooled before being routed to the contactor). HYSYS can automatically run a number of case studies to quickly determine the influence of contactor temperature and calculate emissions which take into account changes in contactor temperature. While GlyCalc could be used for this purpose, HYSYS can be automated to make the task much simpler.
- It is generally assumed that as the glycol circulation increases, the TEG purity will also remain constant. This is only true if the reboiler duty is adjusted to maintain a constant reboiler temperature. However, if there is a constant reboiler duty, then the TEG purity will decrease as the glycol circulation increases. HYSYS can be configured to use either option.

While GLYCalc has been successfully used in industry to calculate BTEX emissions in TEG units, there are limitations. A customizable simulation platform such as HYSYS can be used to improve thermodynamic calculations as well as improve on data transfer and modeling aspects.

## EG Hydrate Suppression

A separate review paper<sup>7</sup> considered the accuracy of BTEX emission predictions for ethylene glycol (EG) systems using AspenTech HYSYS, BR&E ProMax and GRI GLYCalc. The predictions of these simulators were compared using a set of operating data corresponding to several refrigeration plants in Western Canada, with the following conclusions:

- The Peng Robinson property package in HYSYS (HYSYS-PR) should not be used for the prediction of BTEX emissions in refrigeration plants. The Peng-Robinson property package predicts negligible amounts of BTEX in the aqueous phase of low temperature separators, resulting (incorrectly) in the reporting of zero emissions.
- For the prediction of BTEX emissions in refrigeration plants, the Glycol property package in HYSYS (HYSYS-Glycol) is recommended by AspenTech and is significantly better than HYSYS-PR for this

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<sup>7</sup> Alva-Argaez, Holoboff, J.L and Khoshkbarchi, M. (2012) “BTEX emissions from ethylene glycol circulation in natural gas refrigeration plants: a process simulation study”, GPA Annual Convention



purpose. Of the three reviewed simulators, HYSYS-Glycol tended to predict the highest BTEX emissions. However, HYSYS-Glycol should be used with caution at lower LTS pressures (less than 2,500 kPa).

- BR&E has published much information related to TEG dehydration facilities and BTEX emissions but very little related to EG (refrigeration). Of the three simulators reviewed in this study, ProMax consistently predicted BTEX emissions higher than GLYCalc but lower than HYSYS-Glycol.
- It was found that GLYCalc often fails to predict a hydrocarbon liquid phase in the low temperature separator, resulting in very high predicted BTEX emissions in those cases. The user must be careful when using GLYCalc for EG (refrigeration) units. When GLYCalc calculates “reasonable” results, it consistently predicts the lowest amount of BTEX emissions among the three simulators reviewed.
- While VLE data has been published for BTEX-hydrocarbon systems at cold separator conditions, we have not found VLLE data in the literature, which would be crucial in understanding how much BTEX would be soluble in the hydrocarbon liquid and aqueous phases, respectively.
- Field data was obtained and the results of the simulators were compared to this data. For two of the three units, HYSYS-Glycol had the closest results to the data for the combined BTEX predictions. For these units, the results of ProMax were about 50-60% of the original data, and GLYCalc significantly overpredicted the results due to the inability to properly predict a hydrocarbon liquid phase in the cold separator. For a third unit, HYSYS significantly overpredicted BTEX emissions, understood to be a thermodynamic issue at lower pressures (less than 2,500 kPa). In this third case, the ProMax results were very close to the data, while GLYCalc results were about 40% of the original data. While these conclusions could be obtained for BTEX overall, individual component predictions were much less comparable to the field data.
- Some effort was made to fit thermodynamic parameters to field data; while it was found that a reasonable match could be made to the field data, it did not extrapolate well to the wide range of conditions required.

While GLYCalc has been successfully used in industry to calculate BTEX emissions in EG units, there are limitations. Customizable simulation platforms such as HYSYS or ProMax can be used to improve thermodynamic calculations as well as improve on data transfer and modeling aspects, especially when combined with knowledge of the range of applicability of each simulator.

### **Optimal operation of TEG dehydration plants**

The impact of operating parameters on emissions and energy efficiency in TEG dehydration plants has been extensively documented; some examples can be found in the references.<sup>8 9 10 11</sup>. Glycol circulation

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<sup>8</sup> Ebeling, Lyddon, Reduce Emissions and Operating Costs with Appropriate Glycol Selection (BRE, 1998)

rate reduction has been recognized as one of the simplest and effective approaches in reducing energy and emissions from these plants. Accurate prediction of dry gas water content is essential for the optimization of dehydration units since the consequences of reducing the glycol circulation rate under a safe range to accomplish the required dehydration can cause major operational problems (e.g. hydrate formation, off-spec gas, etc.); in fact it has been observed that field personnel reluctance to act on optimization opportunities may be a result of previous experience with underestimated water contents in simulation studies leading to freezing problems.

The potential for emissions and energy reduction is very significant once reliable and actionable information is available. More conventional systems have helped in improving regulatory emissions reporting workflows; however, these tools typically do not have the resolution required to identify opportunities and could result in misleading conclusions.

The results of the rigorous simulation provide the required information to report the BTEX emissions as a function of the glycol circulation rate. The models also report emissions of all other components included in the fluid definition, some of which are of particular relevance to industry. Other aromatic compounds and VOCs are available for reporting and analysis if required (for instance, facilities that require reporting for NPRI in Canada) as well as Greenhouse Gas emissions from venting and combustion sources.

The energy requirements for regeneration of the glycol are also calculated by the simulation model and, by assuming reasonable heater efficiencies, the fuel gas consumption of the unit is also calculated by the system. Armed with an estimation of fuel gas use, it is then possible to perform comparisons of current operation to industry best practices and uncover potential opportunities for energy reduction in glycol dehydration units.

Alva et al <sup>12</sup> reported the evaluation of a simulation-based web system approach, which was implemented for approximately 100 operating dehydration units operated by Encana Corporation (Encana) in Western Canada. For a subset of 96 operating TEG plants the total potential fuel gas savings identified amounted

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<sup>9</sup> Braek, et al. (2001) "Optimization of process parameters for glycol unit to mitigate the emission of BTEX/VOCs." Trans IChemE Vol 79, Part B.

<sup>10</sup> Hernandez-Valencia et al. (1992), "Design Glycol Units for Maximum Efficiency". GPA Annual Convention

<sup>11</sup> USEPA Natural Gas Star "Natural Gas Dehydration. Lessons Learned. ", Producers Technology Transfer Workshop 2006

<sup>12</sup> Alva-Argaez, A. et al. (2011) "Model-based emissions management systems: managing energy, emissions, and regulatory reporting in gas processing". GPA Annual Convention

to over \$680,000 per year<sup>13</sup> and an associated reduction in greenhouse gas emissions of approximately 10,000 tonnes CO<sub>2</sub>/year or the equivalent of taking 1,800 cars off the road each year<sup>14</sup>. These reductions only considered the fuel gas usage in the reboiler and would be significantly higher if stripping gas and vented emissions were included.

As can be seen from Figure 2, 80% of the available opportunities for fuel gas conservation could be found in the top 26 units. A well-focused effort has since been taken by Encana to perform more detailed studies on those top 25-30 dehy's that offer the greatest potential for fuel gas recovery.

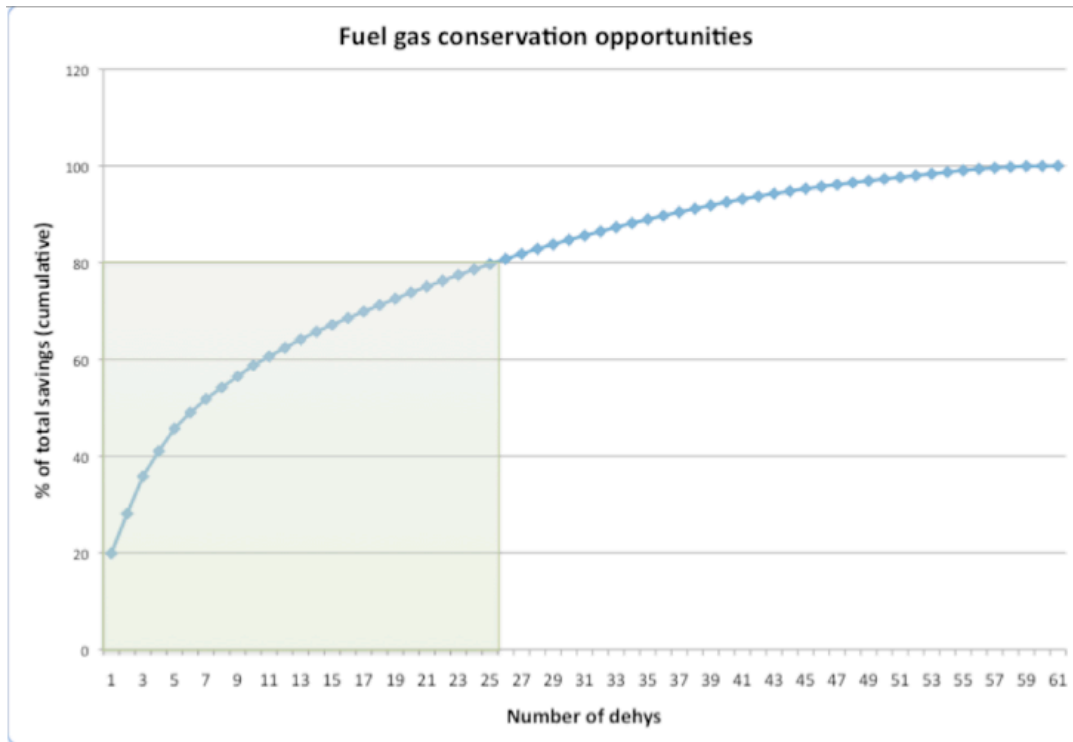


Figure 2- Cumulative fuel gas savings for Encana's dehy facilities

<sup>13</sup> All figures in Canadian Dollars. Fuel Gas price assumed at \$4/GJ

<sup>14</sup> To translate GHG reductions into an equivalent number of cars off the road, annual emissions from a typical passenger vehicle should be equated to 5.5 metric tons of carbon dioxide equivalent or 1.5 metric tons of carbon equivalent. (<http://www.epa.gov/oms/climate/420f05004.htm>)

It is also worth noting that there is no relationship whatsoever between benzene emissions and energy optimization opportunities, which shows that a narrow approach to emissions calculation that targets only dehy subject to benzene (BTEX) emissions regulations, could miss on important opportunities for optimization.

### **Greenhouse Gas Emissions**

The process simulation models are also useful to calculate the flow rates of various greenhouse gases (GHG) that are emitted from process vents. In the case of dehydrators with a flash tank installed, it is essential to correctly identify the fate of the flash gas as it will be mainly composed of methane- a potent greenhouse gas. Gas-assisted glycol pumps (Kimray) are known to be a major source of GHG emissions from dehydration plants. Another key factor in the determination of GHG emissions is the use of stripping gas in the glycol regeneration step; units that vent directly to atmosphere will have a significant contribution from methane releases for this source.

Similarly, dehydrators that process high-CO<sub>2</sub> gas can also vent significant amounts of greenhouse gases.

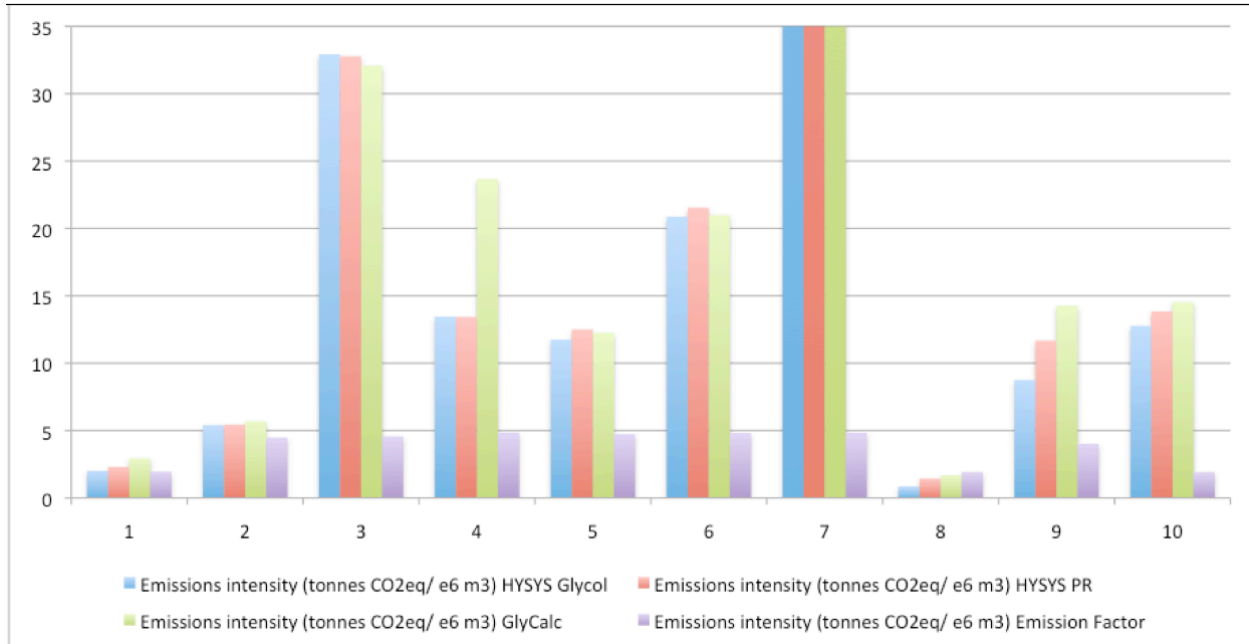
EPA's Mandatory Reporting of Greenhouse Gases, particularly Subpart W of 40 CFR Part 98, indicates that for all dehydrators with gas rates higher than 0.4 MMSCFD, emissions from venting may be calculated using a software program such as GRI GlyCalc or AspenTech HYSYS. For smaller dehy an emission factor may be used to estimate these sources.

Process Ecology conducted a random sample of ten dehydrators for a preliminary comparison between the emissions calculation methods available. The results from applying generic emission factors (API 2009) are significantly different from the rigorous simulation results and in general tended to underestimate emissions. The generic emission factor approach fails to take into consideration the full effect of stripping gas use in the methane emissions venting from glycol dehydrators.

It was also noted in API 2009<sup>15</sup> that these emissions factors would overestimate emissions from a glycol dehydration system with a flash tank separator that routes the flash gas to a vapor recovery system. Furthermore API does clarify that some dehydrators introduce stripping gas in the regenerator to help strip water and other absorbed compounds out of the glycol by increasing the vapor flow rate in the reboiler still. Any methane in the stripping gas will pass directly through the regenerator; therefore, the use of dry natural gas will increase CH<sub>4</sub> emissions from the regenerator. Simulation software should be used to estimate CH<sub>4</sub> emissions in this situation, as the default approaches presented in subsection 5.1.1 of the API Compendium do not account for the use of stripping gas. Figure 3 presents a comparison of the results applying these different approaches.

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<sup>15</sup> API "Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry", 2009



**Figure 3- Comparison of greenhouse gas emissions calculations (intensity)**

### Stripping Gas Effects

Glycol concentrations up to 99.6 % w/w can be achieved by sparging stripping gas directly into the reboiler<sup>16</sup>. Stripping gas is typically dry fuel gas. The use and rates of stripping gas should be adequately evaluated because it is typically emitted into the atmosphere from the still vent and will therefore significantly affect greenhouse gas emissions due to the high methane concentration of the stripping gas. Charts are available in standard references such as the GPSA data book<sup>17</sup> and other vendor publications, and may be consulted for estimating the stripping gas requirements for specified sets of conditions. Reductions in stripping gas consumption can translate directly into savings both in operating cost as well as increased fuel gas recovery.

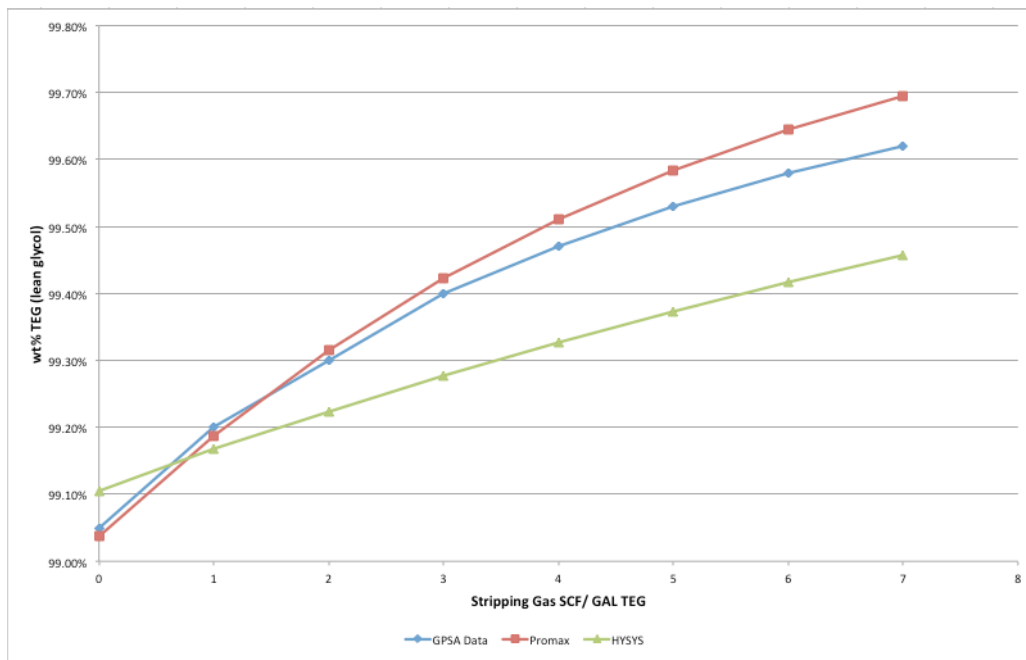
It is therefore essential for the optimal operation of the unit to determine whether stripping gas is actually required to achieve the desired dew point suppression. Dehydration plants that handle relatively warm inlet gas will tend to require stripping gas to meet sales gas specifications, however in practice it has been

<sup>16</sup> Manning, F.S. (1995) "Oilfield Processing of Petroleum". Volume 1, Chapter 8 "Gas Dehydration Using Glycol"

<sup>17</sup> GPSA Engineering Data Book 12<sup>th</sup> Edition, 2004

observed that a large number of units operate with stripping gas when it is not needed, leading to increased fuel gas use and emissions.

A comparison was performed between results from Promax and HYSYS to GPSA data, which showed a reasonably good match to the available data. However, HYSYS appears to somewhat underpredict the effect of stripping gas on increasing the TEG purity at higher stripping gas flow rates; the match with Promax was better but both tools are considered to be sufficient to identify the requirements for stripping gas use (Figure 4).



**Figure 4- Stripping gas effects on TEG purity**

The simulators can also be used to predict the inlet gas temperature at which stripping gas would be required, for a given dry gas water content.

It is noted that the elimination of stripping gas may bring additional operational benefits for units where still vent condensers are in use to control BTEX emissions; the elimination of stripping gas would increase the condenser performance dramatically.

### Other optimization opportunities

Many TEG dehydration plants are not equipped with rich glycol flash tanks; the main purpose of a flash tank is to remove dissolved gas from the rich glycol stream and improve the glycol regeneration process. In addition, the liberated gas can often be used as fuel gas, flared, vented, or conserved. Similar to the

effect of eliminating stripping gas, the use of a flash tank increases the effectiveness of condenser systems by removing the non-condensibles from the vent stream. The installation of a flash tank should be evaluated as an optimization opportunity to recover fuel gas, reduce emissions and improve operations.

Gas-assisted glycol pumps are widely used in dehydration facilities and exhaust significant amounts of gas to the atmosphere. Gas-driven pumps have an inherent design requirement that extra high-pressure gas be added to supplement the gas absorbed in the rich TEG from the contactor (about two volumes for one) to provide mechanical advantage on the driver side. This means that a gas-assisted pump passes about three times as much gas to the regenerator as an electric motor driven pump would. Optimization opportunities include routing the exhaust gas back into the fuel gas header for firing the reboiler (linked with a flash tank) or changing the drive mechanism to an electric motor (when electric power is available). These opportunities are site-specific, but do provide potential benefits such as reduced fuel gas consumption and reduced methane emissions.

### **Air emissions controls**

Supplementary or “add-on” emission controls are used to remove or destroy pollutants in the still column vent emissions. The most common practices involve the use of condenser and thermal systems, either separately or in series. These emission control options could be considered as an optimization of facility design and are best handled on a site-specific basis.<sup>18</sup>

#### Condenser Systems

Condensers reduce the temperature of the still column vent vapours to condense water and hydrocarbons (including BTEX). The condensed liquids are then collected for further treatment or disposal. Generic types of condensers are air-cooled, gas-cooled, water-cooled, glycol-cooled, and ground-cooled. Air-cooled condensers typically rely on the ambient air for removing the heat from the condenser; the condenser may use fins or a fan to improve heat exchange. Gas-cooled and glycol-cooled condensers utilize cool medium (dry gas or rich glycol) from the glycol dehydrator operation as the heat exchange mechanism. Water-cooled condensers follow similar principles, but have not been used in Canada due to freezing concerns. Ground-cooled condensers consist of piping and storage vessels installed below surface grade, where the surrounding soils act as a heat sink.

An approach currently used by some operators is to route the still column vent (off gas) line to either an aboveground or underground storage tank for cooling. This approach can be effective in cold climate locations where ambient temperatures act as a convenient heat sink. It also lends itself to further emissions control through rerouting flows from the tanks to a flare or incinerator system.

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<sup>18</sup> CAPP Control of Benzene Emissions from Glycol Dehydrators BMP, 2006

Condensing systems benefit from (and may require) a flash tank in the glycol process upstream of the exchange mechanisms to liberate non-condensables (e.g. methane, ethane, etc.). The use of stripping gas (being comprised mainly of methane) reduces the efficiency of condenser units. Condensing system designs can range from a simple vessel and piping-modification to commercial type heat exchangers.

In cold climates, above ground condensing units are susceptible to frequent operating problems due to freezing of the condensates (e.g., as water, benzene). Proper heating and insulation are required to prevent or minimize problems from freeze-ups, however, the cost of such measures can be prohibitive. Ground-cooled installations are made relatively resistant to such freeze-ups by carefully laying the pipes and tanks sufficiently below grade.

### Thermal Systems

Thermal treatment systems include flare systems and incineration systems. Both can provide effective control of benzene emissions from glycol dehydrators. Both types of systems have been installed at glycol dehydrator locations in North America.

### Flare Systems

A flare system design involves the collection of off-gas vapours (i.e. instrument vents, flash tank, pump exhaust, still column vent) to an underground tank where condensibles are collected, and venting the tank to a low-pressure flare. A fuel gas purge is recommended to sweep the system (and/or use of a flame arrestor) to prevent flare flashback. This system may be used in conjunction with underground piping and a collection tank ground-cooled condenser. Flaring will help BTEX destruction through combustion and improve emission dispersion by elevating the point source emission which subsequently reduces ground level concentrations. It is possible to attain higher combustion efficiencies by choosing properly designed atomizer and burner systems that promote complete combustion of the BTEX compounds. However, the fuel gas consumption needed to maintain sweeping gas and burner firing increases operating costs as well as emission of carbon dioxide.

### Incineration Systems

Off gas can be directly incinerated or an incineration system can be installed after a condenser system. Incineration at temperatures of 730 °C (1500 °F) can provide almost complete (>99%) destruction of BTEX and eliminate hydrocarbon odours. Incinerator stack height and location should be based on safety and ground level concentration requirements. There are also freezing protection and fuel gas related costs associated with the decision to install incineration systems.



## Modelling Condensers

As indicated above, a method of reducing benzene emissions from the glycol regeneration vapour stream is to pass the vapour through a condensation tank or some other form of condensation equipment. These condensation methods are allowed by the regulating agencies in Western Canada (ERCB) as a method to reduce benzene emissions to regulated levels as long as the final benzene emission levels are measured directly in the field, usually through a total capture test (“TCT”). This measurement is a costly and dangerous activity. Although process simulators can perform VLE calculations at the condenser temperature and pressure, it is necessary to conduct more detailed modeling of specific condenser configurations to determine the validity of “approach to ambient” assumptions usually employed.

Ideally, a vapour-liquid-liquid equilibrium (“flash”) calculation using an appropriate equation of state could be used to accurately calculate the amount of benzene in the product phases off a glycol still condenser. In essence, this requires knowledge of the condenser conditions (pressure, temperature) and composition of the still overhead vapour to the condenser.

However, in reality, this calculation is complicated by a number of factors:

- **Composition:** The composition of the still overhead vapour is not directly measured and must be calculated. Simulators such as GRI GLYCalc, AspenTech HYSYS, and BR&E ProMax are conventionally used to model the facility (contactor or low temperature separator as well as glycol regeneration). The simulators are used to calculate facility benzene emissions as required by regulatory agencies such as the Energy Resources Conservation Board (ERCB). The calculated composition of the still overhead vapour will vary according to changes in process conditions as well as which simulator is used.
- **Pressure:** The condenser will be close to atmospheric pressure; however a small amount of backpressure in the condenser would have some effect on the flash calculation. Additionally, the elevation of the facility determines the local atmospheric pressure. In principle it should not be difficult to estimate a reasonable condenser pressure.
- **Temperature:** The ambient temperature will vary significantly both on a daily and yearly basis, requiring a calculation which considers this variance.
- It is also known that reboiler firing cycles can result in a fluctuating still overhead temperature and composition.
- The temperature to which the overhead vapour will be cooled (the difference between this temperature and the ambient temperature is called the “approach”) is a function of the condenser characteristics.

- In principle, the condenser temperature could be measured in the field and used as the basis for the calculation, however:
  - The measurement may not directly correspond to condenser conditions, depending on where the measurement is taken, and especially if a temperature gun is needed to make the measurement.
  - Even if an accurate condenser temperature is measured, one must extrapolate the year-round condenser temperature based on the anticipated ambient temperature variance and performance of the condenser. One could assume that the approach remains constant but this is likely not a good assumption (a linear function which assumes the approach varies with ambient temperature may be sufficient). It would be better to model the performance of the condenser so that the condenser temperature can be predicted for a range of inlet and ambient conditions.
  - Condenser Device: There are a variety of condensing devices used in industry ranging from simple tanks to engineered condensers. A very common condenser used in Western Canada is the “TankSafe” condenser which is a primary focus of ongoing research. Other less common options include standard aerial coolers, Ruffneck coolers and specific operator configurations.

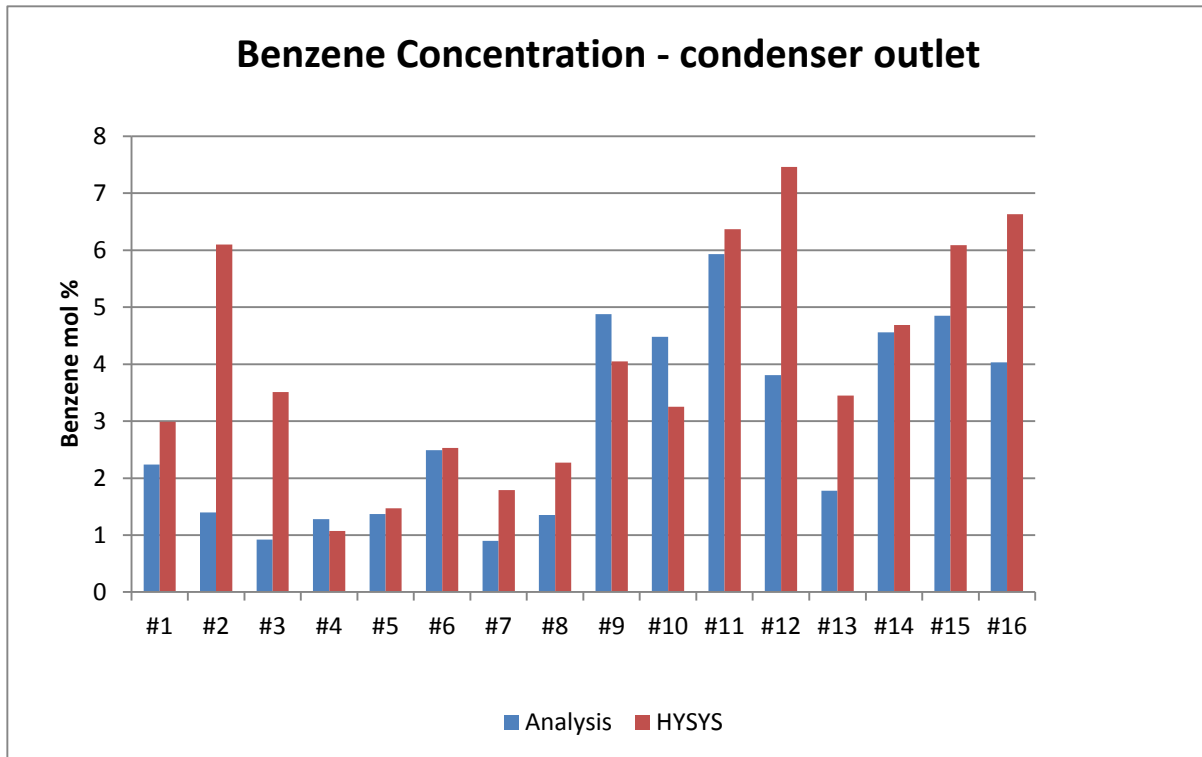
In Alberta, the regulator (ERCB) does not accept the prediction of benzene emission reductions in condenser devices, instead requiring companies to obtain field analyses (Total Capture Test) if they wish to claim the corresponding reduction in benzene emissions.

The reason for not accepting the simulated results is in part likely due to reporting errors from the operating companies, (e.g., assuming that a fixed benzene reduction can simply be applied, often as quoted by the condenser vendor).

Nevertheless, sufficient accuracy can be achieved with a properly designed simulation model which accounts for seasonal effects in ambient conditions (when estimating annual benzene emissions), and careful specification of key parameters such as stripping gas use.

In principle, a vapour-liquid equilibrium (“flash”) calculation using an appropriate equation of state could be used to accurately calculate the amount of benzene in the product phases off a glycol still condenser. In essence, this requires knowledge of the condenser conditions (pressure, temperature) and composition of the still overhead vapour to the condenser. In reality, the calculation is complicated by a number of factors, notably the requirement (when reporting annual emissions) to account for annual variance in ambient conditions. Ideally, the condenser would be rigorously modeled, otherwise a temperature approach must be assumed.

An evaluation of TCT data to HYSYS was conducted to evaluate the prediction of benzene emissions reduction in the condenser. The following figure shows the condenser outlet benzene concentration for 16 locations (note that the inlet composition to the condenser was specified, and therefore was identical, for the TCT data and HYSYS).



**Figure 5- Condenser outlet concentrations of benzene**

The calculated compositions match reasonably well in most cases. Where there is not a good match, the HYSYS results are usually **conservative**; i.e., the calculated HYSYS benzene mole percent is higher, which would result in higher predicted benzene emissions. In these cases, we anticipate that a poor match can be attributed to inaccurate field data (obtained with the TCT analyses). In particular, stripping gas rate is often inaccurately reported, and this has a crucial impact on condenser performance.

With the support of the Alberta Upstream Petroleum Research Fund (AUPRF Fund), this is currently an area we are evaluating, with the ultimate objective of developing a rigorous thermodynamic and heat transfer model which can be used to estimate benzene emission reductions in condensers.

### **Overall optimization strategy**

Based on our experience it can be recommended that the optimization efforts to reduce energy consumption and air emissions from glycol dehydration plants be closely linked to regulatory compliance efforts. The need to gather field data and perform simulation calculations for regulatory reporting purposes should be leveraged by operations and engineering groups to identify and further explore the most promising opportunities for dehy optimization at least on an annual basis. This exercise will ensure that the plants are operated consistently at close to optimal conditions and that, even with high operator turnovers, both energy and emissions can be minimized.

A comprehensive approach to dehy optimization needs to include the various aspects discussed in this paper, namely glycol circulation rate, flash tank operation, stripping gas use, glycol pump type as well as a number of other design parameters such as hydraulic behavior at the contactor, heat exchanger performance and general maintenance practices.

The analysis can be efficiently performed and requires the aid of fine-tuned process simulation models that can provide the necessary evaluation of trade-offs reliably. With greenhouse gas emissions and energy efficiency as main drivers, it is likely that operating companies will have to allocate significant efforts to these units since they do offer very good opportunities for improvement. Ever more stringent regulations will continue driving this trend.