DESIGNING MOLECULAR SIEVE DEHYDRATION UNITS TO PREVENT UPSETS IN DOWNSTREAM NGL/LPG RECOVERY PLANTS

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ABSTRACT

Molecular sieve dehydration is the industry-standard method of removing water from natural gas upstream of cryogenic NGL/LPG recovery units when significant recovery of light hydrocarbons (ethane and propane) is desired. The design of the dehydration system regeneration and subsequent cool-down operations can, however, have negative unforeseen impacts on the downstream cryogenic processing unit.

Ortloff has designed four cryogenic NGL/LPG recovery units over the last 10 years where undesirable transient effects due to the upstream dehydration system design have been observed. In each of these facilities, the switching of a freshly regenerated mole sieve bed led to temperature and, in some cases, compositional disturbances at the inlet to the cryogenic unit, which then propagated through the entire unit over a 15-30 minute period. These disturbances caused process excursions which affected the recovery level of the unit, plus introduced some undesirable temperature variations at the heat exchangers.

This paper analyzes data from the plants in question to show the effects on the cryogenic processing unit associated with the upstream dehydration unit design, and presents recommendations for the design of molecular sieve dehydration units which can minimize the disturbances.

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Introduction

"How do I get a stable, steady plant?" is a question that is asked by every operator in every gas processing plant. An often overlooked aspect of plant design that affects the stability of a NGL/LPG recovery facility is the dehydration system.

The idea of a dehydration system for gas processing is a fairly simple one: reduce the water content in the process gas to a level acceptable for both the process design and associated equipment. For plants where significant amounts of propane or ethane are recovered, the industry-standard dehydration technology is molecular sieve desiccant. As simple as the design of a molecular sieve system is, choices made in the design phase can create disturbances that influence stability of cryogenic processing units downstream. In plants that Ortloff has designed over the past few years, it has been observed that the dehydration systems introduced cyclical fluctuations in both temperature and inlet feed composition.

The objective of this paper is to provide an introduction to mole sieve systems, especially as they relate to NGL/LPG recovery plants, provide explanation and examples of possible disturbances caused by mole sieve systems, show the associated effects, and offer alternative design strategies that dehydration system designers can implement to minimize such disturbances in future projects.

Dehydration/Molecular Sieve Fundamentals

There are two basic methods of dehydrating a natural gas stream. One is the use of glycols (most commonly triethylene glycol) to absorb water by direct contact with the gas stream. The water-rich glycol is then separated into dry glycol and water by distillation and the now regenerated dry glycol then repeats the cycle. Glycol dehydration has several benefits; however, it is limited in its ability to reach the exceptionally low water dewpoints required in cryogenic processing units. As such, it can be used in concert with another dehydration system where the glycol unit provides bulk water removal and the secondary system provides "polishing" water removal down to the required levels for cryogenic applications.

The other basic method for dehydrating a gas stream involves using a solid desiccant to adsorb water from the gas as it passes through. There are several choices for the adsorbent including activated alumina, silica gel, and molecular sieve. Molecular sieves are aluminosilicates (zeolites) which are capable of obtaining the lowest water dew points in dehydration service. Additionally, molecular sieves can be used to simultaneously remove sulfurous contaminants and dry the natural gas in preparation for further processing. It is possible with molecular sieve dehydration units to get the water content of the gas stream down to around 0.1 ppm by volume. In processes where cryogenic temperatures will be encountered, molecular sieve desiccant is used exclusively. Mole sieve dehydration is more complex and expensive than glycol dehydration because of the added infrastructure and switching required for regenerating and cooling the desiccant beds; however, only mole sieves can reach the very low water dewpoint values (-150°F [-100°C] or lower) required for cryogenic gas processing.

A continuously operating molecular sieve dehydration system requires two or more beds containing the desiccant. For the simplest two bed case (Figure 1), one bed is in active adsorbing service while the other is going through the desiccant regeneration process. Generally, the active bed is designed to be in service for between 4 and 24 hours depending on the design. After the adsorbing cycle time has elapsed, the active bed is switched into regeneration service and the freshly regenerated bed is put into adsorbing service.

The regeneration process involves heating the bed to a temperature well in excess of the boiling point of water (as high as 600°F [315°C]) to ensure that all adsorbed water is driven off. After a sufficient time at high temperature to ensure complete desorption of the water, the bed is cooled back down to prepare it to again receive process gas. It is common practice to use the same dry gas supply for both the heating and cool-down of the bed. In the heating case, the dry gas is heated by some means to the required temperature and in the cool-down case the gas is used "as-is" or cooled by some other heat exchange system (e.g., air cooling, water cooling, external refrigeration.)

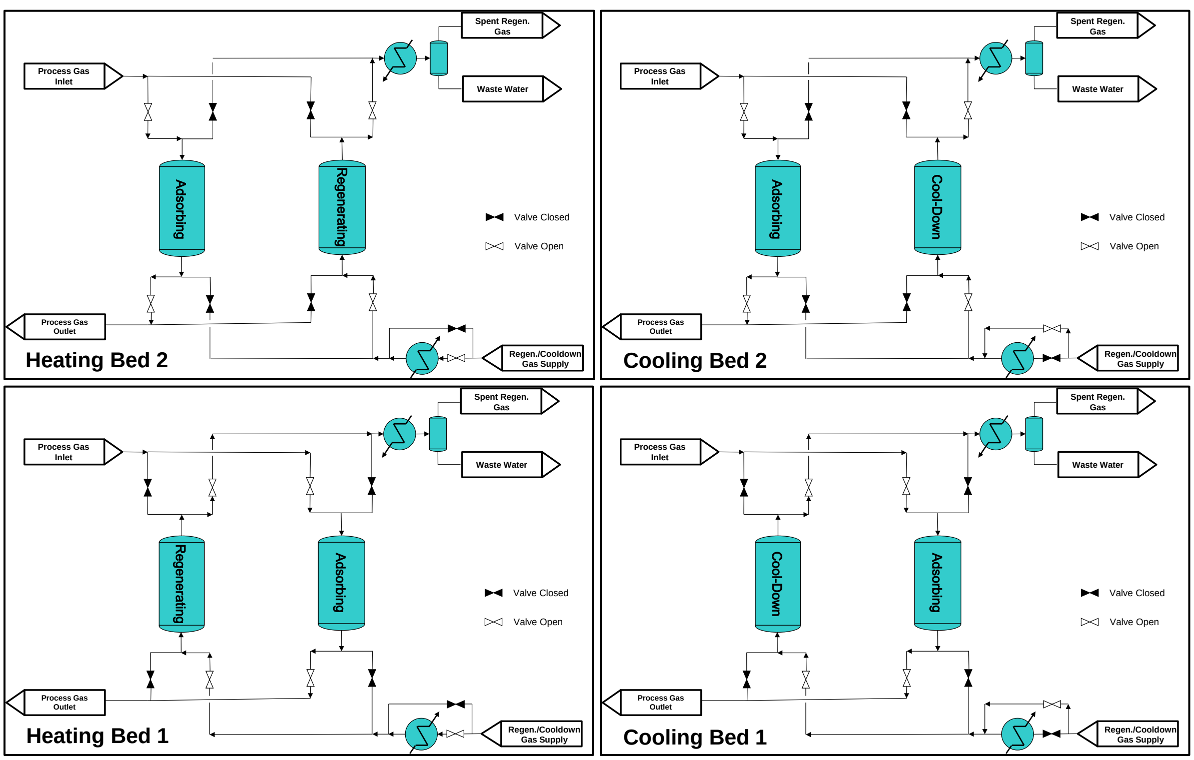

Figure 1: Simplified Process Flow Diagrams of a Two-Bed Molecular Sieve Dehydration System showing the Regeneration Cycle.

Frequently, dehydration systems with more than two beds are utilized to control cycle time, equipment size for a given throughput, and possibly provide redundancy. The array of beds is intended to ensure that there are always enough active adsorbing beds to handle the processing capacity of the facility, while the inactive beds are either in the heating or cool-down phase of the regeneration cycle.

Introduction to Cryogenic Gas Processing

Ortloff designs units for the recovery of propane+ and ethane+ products from natural gas streams. These plants take natural gas at high pressure and expand it using turboexpanders to produce a two-phase mixture, which is then distilled to provide a liquid product meeting industry specifications and a residue gas product which is subsequently recompressed by the turboexpander-coupled compressor and, in most cases, a larger independent compressor. After recompression, the residue gas is sent to a pipeline, utilized as fuel gas, or otherwise used as the facility owner desires.

These plants, like any turboexpander cryogenic gas plant, are sensitive to changes in the inlet conditions. Since there is a large degree of heat integration between streams, a change in temperature at one location leads to temperature changes at every point in the unit. Even the utility units (external refrigeration, for example) experience changes in load as a result of a change in the process temperature. Additionally, the rotating equipment is sensitive to changes in temperature as energy developed from expansion and energy required to compress both vary with the temperature of the incoming gas.

Changes in gas composition also affect the unit operation. For any gas processing facility, inlet gas composition is a critical design point. For instance, as the inlet gas composition becomes leaner in ethane and/or propane, the amount of heat required in the distillation process to meet a target specification on the liquid product is reduced and the flow rate of product at the bottom of the column decreases. Additionally, the operation of the distillation column is disturbed as every stage in the column must come to a new, leaner equilibrium.

The main control in a NGL/LPG cryogenic facility affected by temperature and composition disturbances is the reboiler heat input for the distillation column. The reboiler heat is controlled to maintain the desired composition of the liquid product. As the temperature and composition of the column inlet change, the heat required to keep the product at specification also changes. The controller increases or decreases reboiler heat input to the bottom of the column based on the product temperature, and in some cases a reading from an on-line analyzer. Unfortunately, the response of on-line analyzers is quite slow, as cycle times are generally 5-10 minutes. With only 3 distinct samples taken during a 30 minute disturbance, the ability of a composition controller to correct the effects of a disturbance is very limited. However, the changes set in motion by this controller do add to the state of flux in the column during the disturbances because of the adjustments made to the heat input.

Controllers on the temperatures around the heat exchangers are also affected by temperature and composition disturbances, but the effect on the process is usually less significant than that of the column controls. These controllers are common in plants that include refrigeration systems as part of the NGL/LPG facility, but are not present in all plants. The bypasses around the exchangers are typically small enough to make slight adjustments in the outlet temperature, but not big enough that the controller can mitigate the temperature disturbances mentioned above. It was observed that during temperature disturbances exchanger bypasses would close fully to attempt to lower the rising temperature. However, as mentioned earlier the temperature would continue to rise despite controller action until the disturbance ended. As the temperature cooled, the bypass would open again, but not before the temperature fell below the normal observed value. Eventually, the controller would reestablish operation around the controller setpoint.

The plant DCS will attempt to maintain process efficiency by automatically correcting any departure from set temperature or composition values. The control system varies valve positions to regulate process-side exchanger outlet temperatures and the heat input to the column based on product temperature or composition readings. Therefore, the temperature and composition profile of the distillation column will remain in flux as the inlet composition varies because the stages in the column are coming to a new equilibrium and the heat input to the column is changing. Eventually, the column and plant will settle down to a new steady operating point, but in the interim time the process operates inefficiently.

This basic presentation of how varying the inlet conditions of a NGL/LPG recovery unit affect the process is critical to understanding how the dehydration system can introduce instability into the process unit.

Why/How Molecular Sieve Dehydrators Cause Issues in Downstream Cryogenic Units

Temperature Disturbances

The most common disturbances in downstream cryogenic units due to molecular sieve systems occur as a result of a freshly regenerated bed being brought on-line. One such disturbance is the result of having a freshly regenerated mole sieve bed switched in while still warmer than the average temperature of the other on-line beds. A bed is often switched back into service after a set cool-down time. However, the bed temperature after this time is often in excess, sometimes significantly so, of the temperature of the inlet gas to the dehydration system and thus the average temperature of other on-line beds. The end result is that the inlet gas finishes the cool-down of the bed in question.

This is especially true of plants where external refrigeration is present upstream of the dehydration beds. External refrigeration and a separator are sometimes put in place upstream to remove as much water as possible by lowering the process gas temperature before it encounters the desiccant beds. This strategy allows for longer absorption times for given equipment, or allows for the use of smaller equipment for the same facility throughput.

Another related issue that can lead to a bed being warmer than the inlet gas at the end of the cool-down step of the regeneration cycle is the choice of heating/cool-down gas supply. One of the common dehydration system design strategies is for plants to use a slipstream of the residue gas to function as both the heating medium for the beds and the cool-down gas. In the heating stage, the residue gas is passed through a heater and then through the bed to get the temperature in the bed up to about 500°F [260°C]. In the cool-down step, the same residue gas bypasses the heater and is sent through the beds. This works well, except in the case where the ambient temperature (which the air-cooled compressor aftercooler can only approach) is significantly warmer than the inlet gas to the desiccant beds. If that is the case, then no flow rate or amount of time will cool the beds down to dehydration system inlet gas temperature. As described above, the inclusion of any chilling upstream of the dehydration beds only exacerbates the problem.

In any case, if a bed is switched back into adsorbing service before it reaches the temperature of the inlet gas to the dehydration system, the heat of the bed will cause a transient temperature rise in the inlet gas to the cryogenic plant as the cooler inlet gas completes the cooling of the bed. The temperature change observed at the inlet of the cryogenic unit is proportional to the difference between the bed temperature at the time of switch-over and the temperature of the dehydration inlet gas temperature. The magnitude of this effect is also related to the number of beds in the dehydration system. The more beds present in the system, the lower the flow through any one bed, and thus the smaller the impact on the cryogenic unit inlet temperature when the outlets of all the beds are combined.

The change in the cryogenic unit inlet temperature propagates through the entire unit affecting recovery efficiency and causing controllers to take action to correct the effects of the disturbance. This effect is well known in the industry, as most operators know small temperature "bumps" occur when regenerated beds are switched into service. However, as it becomes more common to refrigerate the gas before it reaches the beds, the problems associated with switching in a warm bed become more significant since the magnitude of temperature disturbances becomes greater.

Typically, no controller in the cryogenic unit can be configured with the ability to make adjustments required to correct the temperature disturbances caused by switching in a warm bed. An additional concern is the over-correction associated with the controllers not working quickly enough to compensate for the rapid cooling which occurs as the warm bed comes back down to design temperature. If the valve/controller positions before a warm bed switch-in are considered the baseline conditions, the controllers will at first take action to cool the process back down to the setpoints (i.e., fight the now warmer inlet conditions) by closing exchanger bypasses and increasing refrigeration load. However, the cryogenic unit inlet temperature will drop rapidly as the bed comes back down to its normal operating temperature. This rapid cooling results in the process variables falling significantly below controller setpoints before the unit will level out again.

Compositional Disturbance

Some molecular sieve units also have the ability to adsorb mercaptans and other contaminants from the feed gas. This is desirable as chemical solvents (amines) commonly used in the gas processing industry for the removal of sulfur-bearing contaminants do not remove mercaptans very well. Mole sieves can capture trace contaminants like mercaptans from a gas stream by adsorbing molecules based on those molecules having a critical diameter smaller than pore size of the sieve. Unfortunately, this means that any sieve capable of removing mercaptans will also adsorb propane, since the critical diameter of propane

(4.9 Å) is smaller than ethyl mercaptan (5.1 Å). When a freshly regenerated and cooled mercaptan removal bed is returned to adsorbing service, it will initially cause a significant drop in the propane content of the cryogenic unit inlet. The effects of leaning out the composition of the inlet to the cryogenic unit described earlier will be observed until the propane saturates the desiccant bed. The composition at the inlet to the cryogenic unit will then return to approximately the same value observed before switching-in the regenerated bed.

The effects of a temperature disturbance often are exacerbated by the effects of a compositional disturbance, since the switching of a freshly regenerated bed into adsorbing service is the root cause of both. If these disturbances happen in addition to the normal swings seen as different gas wells are brought on-line or taken off-line then the effects can be very significant. In any case, some period of fluctuating operation is to be expected and during this time distillation tower bottoms composition controls are challenged and temperature rates of change may be larger than desired.

Analysis of Plant Data

Ortloff has designed a number of plants over the last 10 years which, once built, experience some of the disturbances described above. Table 1 below outlines the basic design information for the plants that will be analyzed throughout the paper, and Figures 2 and 3 show the process configurations of these plants.

Name	**Plant #1**	**Plant #2**	**Plant #3**	**Plant #4**
Throughput (MMSCFD [10^6 Nm^3/D])	577[15.5]	370[10]	1469[39.3]	1469[39.3]
Type	C_2 / C_3	C_2 / C_3	C_3	C_3
Normal Inlet Temp (°F [°C])	84[29]	84[29]	77 [25]	77[25]
Normal C_3 Composition (mole-%)	4.64	4.00	1.84	1.84
Number of Beds	4	4	5	5
Time Between Bed Switches (Hours)	4	4	3	3

Table 1: Basic Design Data for Plants

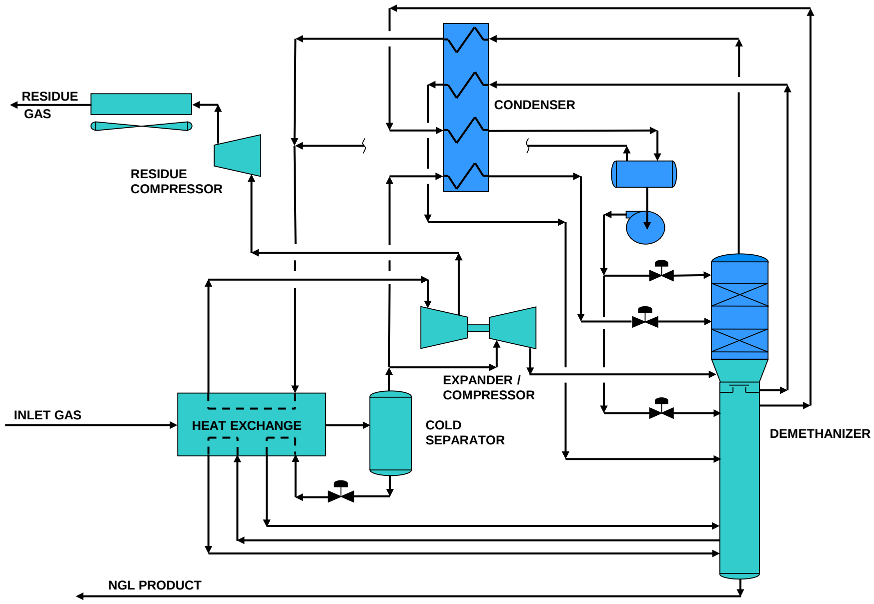

Figure 2: Process Flow Diagram for Supplemental Rectification Process (SRP) Process Used In Plants #1 & #2

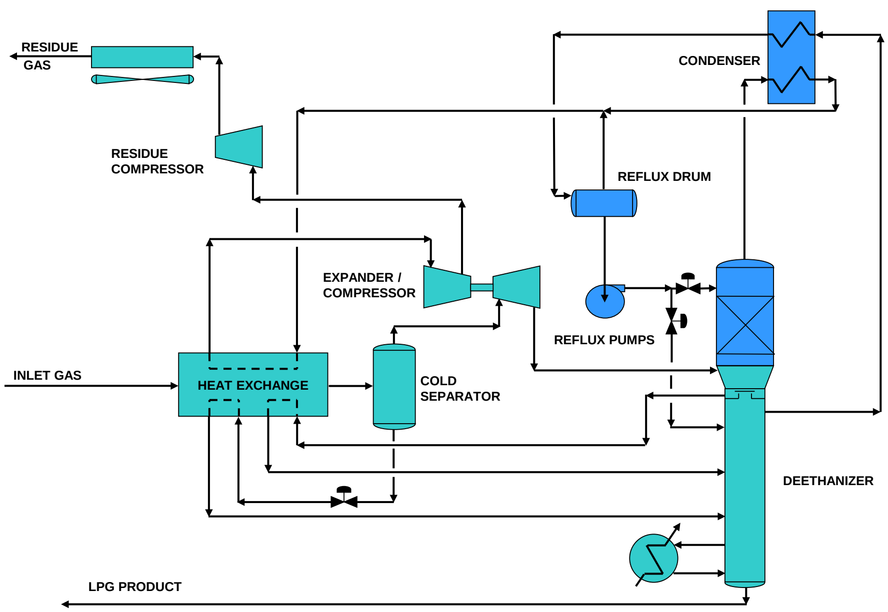

Figure 3: Process Flow Diagram for Single Column Overhead Recycle (SCORE) Process Design used in Plants #3 & #4.

All of the analyzed plants are located in the Middle East and data were collected between May 2010 and March 2011. In each case, the mole sieve regeneration gas supply was the plant residue gas containing less than 0.10 mole-% propane. Plants #1 and #2 are process designs which allow for the selection of a desired level of ethane recovery at ultra-high (>99%) propane recovery. Plants #3 and #4 are propane recovery plants (>99%) that are upstream of LNG liquefaction units.

Temperature Disturbance

All plants demonstrate the thermal effect of switching-in mole sieve beds while they are still warmer than the process gas. In all the plants the cool-down portion of the regeneration cycle was deemed to be complete when a certain amount of time had passed. However, according to the design conditions, this temperature was 45°F [25°C] above the temperature of the process gas at that point in the plant. The result, as can be seen in the graphs shown in Figure 4, is that the inlet temperature to the cryogenic unit rapidly rises at every bed switch, as the inlet gas completes the bed cooling.

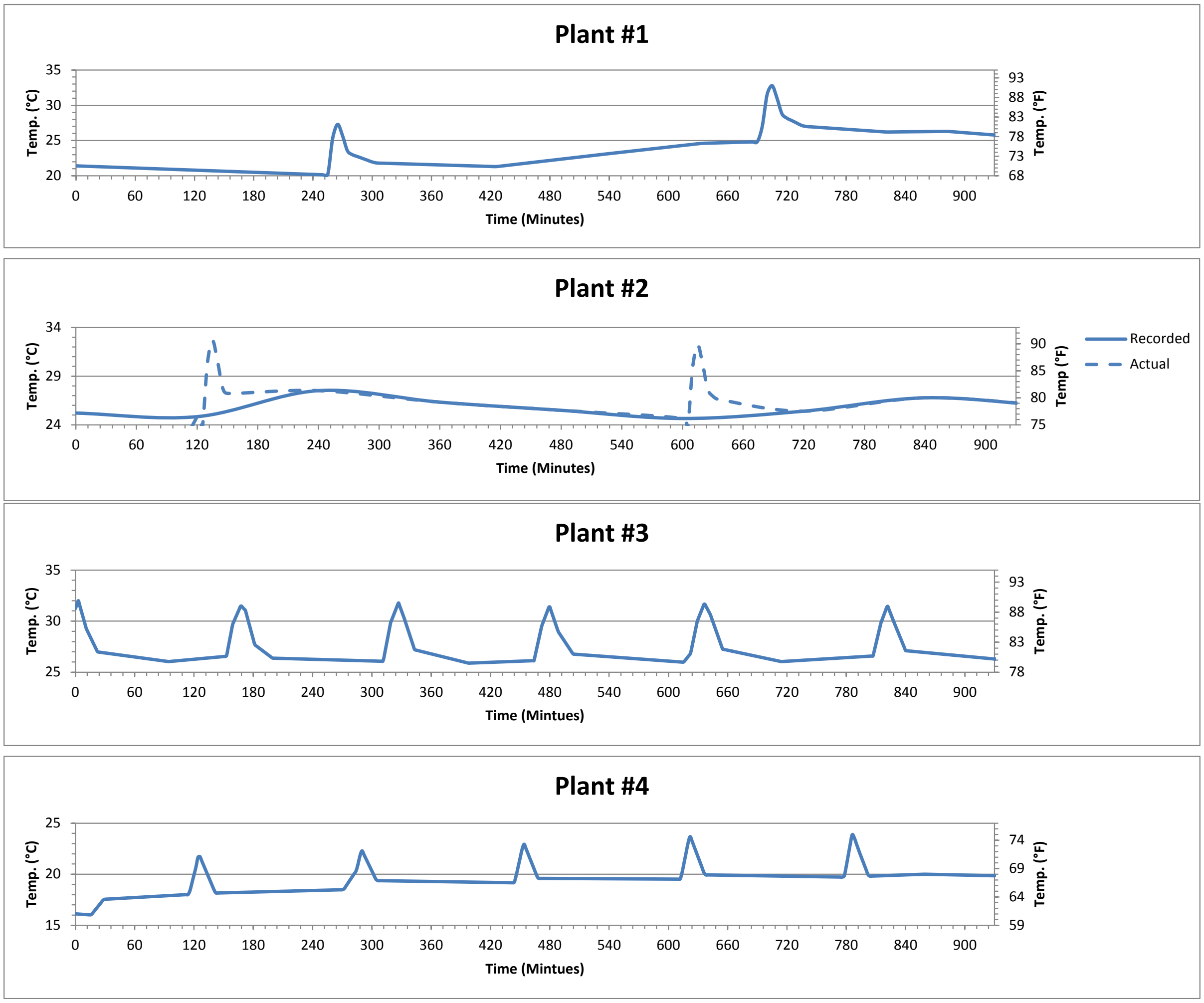

Figure 4: Feed Temperature for the Four Plants

The disturbance to the cryogenic unit inlet temperature ranges between 18°F [10°C] and 7°F [4°C], depending on the plant. The reason for this variation is two-fold. First, two of the plants observed had four beds while the other two plants had five beds. As noted above, the more beds that a plant has the lower the magnitude of the temperature disturbance associated with switching-in a regenerated bed. The second reason for differences in the magnitude of the observed temperature disturbances is that the re-compressed residue gas was used as both the heating medium and the cool-down gas. In the case of cool-down, the residue was cooled using the residue compressor air cooler and then fed to the beds. The plant data showing smaller variations during bed switching was collected in the winter of 2010/2011 when the ambient temperature was about 45°F [25°C] cooler than the plant exhibiting larger variations. This cooler ambient temperature allowed for the cool-down gas to get the bed temperature down closer to the feed gas temperature in the same allotted cycle time. However, even this smaller temperature variation was enough to have a noticeable effect on plant operation.

The recorded data for Plant #2 seems to show less effect than the others. However, this is not due to a difference in design, but a difference in available data. The data historian for Plant #2 was configured to collect one reading every two hours. This masks the magnitude of the disturbance, as in the other facilities the entire disturbance occurs and is corrected within one hour. For the other plants, the historian collected data at least one reading every two minutes. However, even with the low time resolution readings for Plant #2, a variance in temperature around the bed switch times is clearly visible. The dashed line has been added to the plot to better show what was actually observed by Ortloff personnel on site.

Compositional Disturbance

Plants #3 and #4 both exhibit a compositional disturbance when a freshly regenerated bed is brought on-line, due to use of mole sieve that is capable of removing mercaptans in the gas phase. As can be seen from the plots of feed gas propane composition for Plants #3 and #4 in Figure 5, there are significant dips when a fresh bed is brought on-line. No data is presented for Plants #1 & 2 because they did not have mercaptan capture mole sieves and thus showed no compositional disturbance.

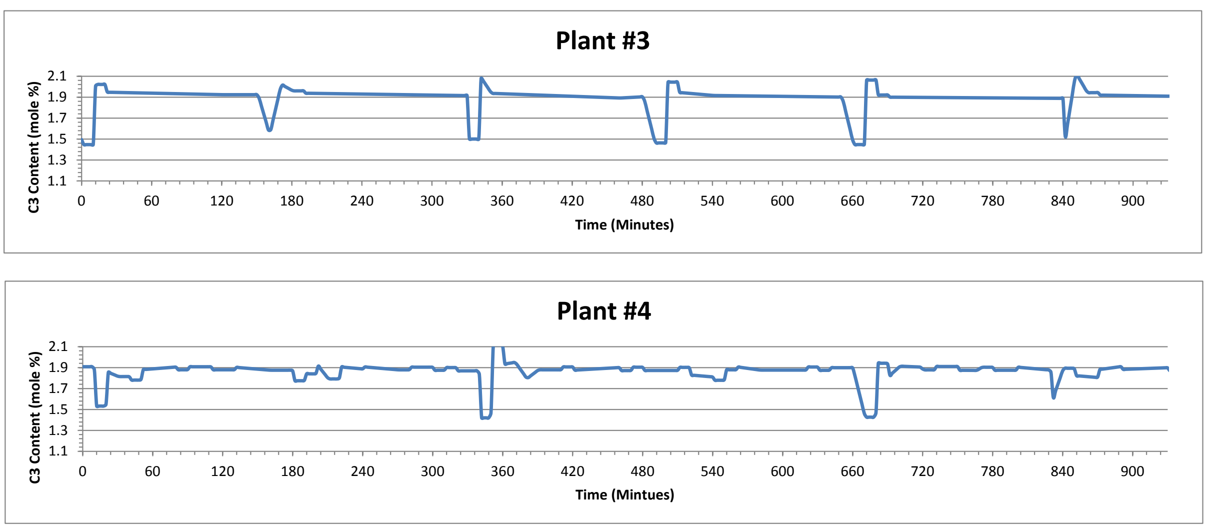

Figure 5: Feed Composition for Plants #3 and #4

In Plant #4 there were issues with one of the desiccant beds which had, in an unrelated incident, liquid carry over into the bed. This liquid carry-over event caused a drop in mercaptan removal performance for that bed since part of the bed was deactivated. Where the composition disturbance effects are not as noticeable for Plant #4, the reason is the decreased effectiveness of that bed. A similar loss of effectiveness was observed on-site for the water removal capacity of that bed.

Cost Analysis

The cost of the disturbances observed in a plant is an interesting problem to consider. The lost propane or ethane that could have been recovered and the revenue associated with the BTU differential price of those products is probably the best measure of what the disturbances actually cost. For the purposes of calculating an actual dollar figure, the original design process simulation for one of the facilities described above was used to generate an approximation of how the temperature and composition disturbances might impact the facility's economics. The simulations, as opposed to plant data, were used because the collected data either does not contain the desired data points, the instruments used to collect the data do not update quickly enough to provide needed data, or the individual facility's data does not capture all the aspects of the disturbances needed to measure the effects.

The Plant #1 facility was used to build the data set that will be discussed throughout this section. It is important to note that the facility in question did not actually experience all of the effects that have been simulated. The molecular sieve units at this site did not attempt to remove mercaptans and as such did not exhibit the compositional disturbances described above. The results in this section are hypothetical, but representative of what is expected to occur and how much economic impact is expected as a result of a given disturbance.

The methodology for estimating cost involved taking the steady-state simulation of the plant at normal conditions and modifying it to represent the worst departure from the normal values in the midst of a simultaneous temperature and compositional disturbance. Based on the disturbances observed, the inlet temperature to the cryogenic unit was raised by 7°F [4°C] and the propane composition was lowered from 4.65 mole-% to 3.76 mole-% (the average magnitudes of temperature and composition disturbances in the observed data). The disturbances were modeled by modifying the temperature and composition at the plant inlet and matching the design exchanger UA values by modifying the simulated plant temperature profile. The change in the flow rate of a specific product (either ethane or propane) due to the disturbance is calculated from the differences in the two simulations. Since the modified simulation represents the "worst" departure from design values during the disturbance, the product flow difference is divided by 2 to average the effect over the entire length of the disturbance. This average flow difference is then multiplied by the length of a disturbance to obtain a total volume of ethane or propane that is not recovered as a liquid product. Finally, the cost is determined by multiplying the total volume of product by the margin price for that product. (The margin price is the difference between the price of a product per gallon as a standalone liquid product and its heating value price as fuel gas.) In this way, the calculated costs captures the difference between recovering the specific product as desired, versus any use of the spent regeneration gas for which the facility owner could still extract some value.

Plant #1 was designed for and is analyzed in an ethane recovery mode. This allows for the analysis of the cost of a disturbance for both products and gives insight into how the disturbances will affect the recovery of a facility in either recovery mode. The results of the cost analysis are presented below in Table 2. The difference in disturbance time between the ethane and propane case was used to reflect the fact that the propane is primarily affected by the composition disturbance and the ethane primarily affected by the temperature disturbance. To fairly estimate a cost, a shorter disturbance time was used because the composition recovered more quickly than the temperature after the beginning of a disturbance.

Species	Differential Product Flow (bbl/day)	Disturbance Time (Min)	Product Loss (Gal)	Assumed Margin Price ($/gal)	# of Disturbances per Day	Annual Total Cost
Ethane	828	30	362	US $0.203	3	US $73,000
Propane	3,354	15	734	US $1.024	3	US $751,000

Table 2: Cost Data by Product

The results of the simulations show an interesting trend. The effects of the two types of disturbances seem to be basically independent. The temperature disturbance seems to have little impact on the propane recovery level, and likewise the compositional disturbance does not seem to impact the ethane recovery significantly.

The impact on ethane recovery can be primarily attributed to the temperature disturbance. The increase in temperature causes an upset in the process which causes the temperatures throughout the process to warm up. As the temperatures warm up, the amount of ethane condensed in the unit falls, causing the ethane recovery efficiency to fall.

The cost associated with propane is primarily due to the dehydration beds holding on to propane when initially switched into service and the loss of that adsorbed propane to either the residue or fuel gas systems. Whatever propane is not recovered as a liquid product represents a significant cost because the margin price for propane has been very high. In fact, in most cases it is this margin price that initially justified the use of patented processes for very high propane recovery.

It is important to remember that the costs estimated above are a best case scenario. The costs presented assume that only the lost recovery or adsorbed and retained propane impacts the amount of product produced and that in a short time frame all variables stabilize and return to design conditions. In reality, the fact that the plant does not operate in a steady fashion could lead to various other operational inefficiencies.

One example of an expected operational inefficiency is various controller setpoints being chosen to minimize process impact, as opposed to optimize the performance of a unit. Another strategy to dealing with disturbances is the placing controllers in “manual”. This prevents the control system from adjusting the operating variables to design setpoints, leading to a loss in unit efficiency. In addition to operational inefficiencies, problems can arise with continuous daily cycling of the temperature of equipment designed to be operated at a constant temperature.

Recommendations

Each facility and its dehydration system must be analyzed to determine how best to address the issues raised in this paper. However, it is possible to give some guidance on what options there are for minimizing the impact on a downstream NGL/LPG facility.

Regarding temperature disturbances, the best advice is to ensure that the beds are cooled as close to the temperature of the inlet gas as possible. Reaching the normal operating temperature is of special importance in the case where there is refrigeration cooling upstream of the beds because this can lead to air-cooled cool-down gas still being too warm to get the beds down to an acceptable temperature before switching.

The most appropriate solution to this problem depends on a wide range of factors including: availability of chilling medium, economics, and plant location. Two solutions are presented here as a starting point for finding the custom solution that will work best. The first solution is to take chilling duty from the same system cooling down the inlet gas to chill the cool-down gas. This makes it possible to get the bed down to the appropriate temperature (given sufficient time). A second solution is to take the cool-down gas from a point in the system where the temperature is not significantly different than the temperature at the inlet of the dehydration system. This solution utilizes gas at a temperature very close to the temperature of the beds to ensure it will be possible to get the bed that needs cooling to the approach the appropriate temperature.

Composition disturbances are a more complex problem to solve, at least in the case where mercaptan removal is desired in the gas phase and in the same mole sieve bed as the dehydration. Any mole sieve that has the ability to adsorb mercaptans heavier than methyl mercaptan will also adsorb propane. Given this fact and that the propane-free residue gas is used as regeneration gas, it is best to be aware of the problems created and prepare for the consequences. At the facilities mentioned, it was common practice to put controllers in “manual” so they would not drift significantly from their setpoints during the disturbance. This does little to protect against the effects of the composition disturbance, but can shorten the time required to stabilize once the disturbance has ended. If the source of cool-down gas had a significant propane content, the bed would then be brought on-line already saturated with propane. (In fact, any molecular sieve which adsorbs propane will also adsorb methane and ethane, but since every facility considered in this paper used residue gas as the regeneration medium, the beds were already saturated with those compounds even when freshly regenerated.)

Of course, mercaptan removal is also possible after the NGL/LPGs have been removed from the feed gas, again using mole sieves. This has the advantage of not affecting the cryogenic unit, but does add the complexity of another sub-unit for NGL/LPG treating. Therefore, if this option is available and economically justified, it is recommended over attempting to do both the dehydration and purification in the gas upstream of the cryogenic plant.

One solution that could address all the problems described in this paper is using the dried cryogenic unit inlet gas as the regeneration gas supply. Since this gas is directly downstream of the dehydration system, no temperature offset problems exist. The only concern that remains is designing the cool-down cycle length to be of sufficient time for the bed to reach a temperature which will not disturb the cryogenic unit. The gas still contains a significant proportion of propane and it will saturate the beds prior to switching-in a freshly regenerated bed and avoid the compositional disturbance. There are some complications associated with this strategy. First, the dehydration beds will have to be larger than if the source of regeneration gas was the residue gas. This size increase is due to the recycle of the spent regeneration/cool-down gas upstream of the beds. When the source of gas is the residue, the spent regeneration/cool-down gas generally rejoins the residue gas and leaves the plant or is used in a fuel gas system. In either of these cases there is no recycle flow and thus smaller equipment can be used. Second, at the temperatures encountered in the regeneration process, other trace contaminants which react with hydrocarbons (such as oxygen) could be an issue if this gas is used for the heating stage of the regeneration cycle. That being the case, using this approach to deal with the disturbances would depend on the composition of the gas being processed. Finally, regenerating at the higher feed gas pressure requires more gas flow to regenerate in the same amount of time, as higher pressure gas does not hold as much water as lower pressure gas. However, the cost associated with designing the dehydration system to deal with the complications mentioned is significantly less than the estimated cost of dealing with the disturbances.

Conclusion

Gas processing facilities are often comprised of many different units designed by several different firms. This division of labor, while efficient, can lead to one unit inadvertently causing issues in another. These events, such as the disturbances noted above, do little to affect the system which generates them. (In fact, the dehydration system in the plants described above continued to work with no observed issues in all of the facilities discussed even during the disturbances noted.) However, downstream units were predictably and significantly disturbed by consequences of the design of the dehydration system. It is hoped that this brief overview will encourage designers to consider the effects of their design choices on a wider scope and collaborate with other unit designers to minimize the impact of these issues in the future.