Dry-out Design Considerations and Practices for Cryogenic Gas Plants

Presented at the
93rd Annual Convention
of the
Gas Processors Association
April 14, 2014
Dallas, Texas

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ABSTRACT

Time is often lost during startup of new cryogenic gas plants due to inadequate planning and execution of dry-out. Lost time can be minimized or avoided if dry-out provisions are included in the original design and if good practices are followed during the dry-out period.

This paper presents the following:

- Background explaining why cryogenic plant dry-outs are important to a successful plant start-up
- The negative effects of water in a cryogenic plant
- Dry-out options
- Recommended design features for closed-loop dry-out
- Guidelines to execute and monitor a successful closed-loop dry-out

The objective of this paper is to explain the importance of drying out a cryogenic plant prior to startup. It will also explain the advantages of closed-loop dry-out, which in our experience, can significantly reduce the time required to thoroughly dry the cold plant prior to cool-down compared to the other options. These guidelines and dry-out practices are applicable to any turbo-expander cryogenic plant process design.
INTRODUCTION

A cryogenic plant dry-out is a critical step during startup but it often does not receive proper attention early on in the project that would allow successful execution. For the purposes of this paper, “cold plant” refers to a cryogenic turbo-expander plant for natural gas liquids recovery which recovers liquids comprised of either ethane and heavier components (often referred to as C\textsubscript{2+} liquids or Natural Gas Liquids) or propane and heavier components (often referred to as C\textsubscript{3+} liquids or Liquefied Petroleum Gas).

A cold plant dry-out can be executed correctly the first time and the owner/operator can be confident the cold plant is dry prior to cooling down when proper design features are implemented and guidelines are followed. All gas processors know that water must be removed from the cold plant. However, knowing the best method for removing water, how much water has been removed during the course of the dry-out period, and when dry-out is complete can be challenging. Far too often a dry-out is stopped before the cold plant is completely dry.

BACKGROUND

The solid that forms when water is present with a hydrocarbon stream is not “ice”, but a crystalline structure known as a hydrate. Hydrates can form at conditions where solids would not be expected, and will form above the freezing point of water. They are a physical combination of water and other chemical constituents, like those found in natural gas processing, which have an “ice-like” appearance\textsuperscript{(1)}. Hydrates form when enough water is present at the right combination of temperature and pressure and tend to favor systems with low temperature and high pressure\textsuperscript{(2)}. For the gas plant owner/operator, this means when the plant begins to cool down, hydrates will begin to form in the process areas where sufficient water is present which will restrict or completely obstruct the process flow.

It is not uncommon to see hydrates obstructing flow through heat exchanger passes or the strainers that protect the heat exchanger from construction dirt and debris. Hydrates can cause enough pressure drop to rip apart strainers, allowing dirt and debris to enter and damage the downstream heat exchanger. In the case of thermosyphon reboilers and side heaters, hydrate formation may restrict the flow through the exchanger and reduce the amount of heat input to the column enough to prevent achieving the bottoms liquid product purity specification.

Hydrates may also form on the cold plant fractionation column trays and packing. The result is a decrease in efficiency causing low product recovery and potentially off-specification liquid product. Hydrates are also known to plug control valves and plant instrumentation.

Water can enter the plant equipment through rain or condensation from open piping during construction and through water left after hydrostatic testing. The single most important step that can be taken prior to startup of a cold process plant is to drain and blow out as much free water as possible from the piping and equipment. Eventually, all the water must be removed from the cold plant to the parts per million (ppm) level in order for the cold plant to operate safely and efficiently. Not all of the water can be removed simply by draining low-points. The remaining water must be removed by a combination of moving the water to a low point where it can be drained and absorbing the water in a vapor stream so it can be removed from the cold plant equipment and piping. Several options for eliminating this remaining water are presented in the next section.
DRY-OUT OPTIONS

The following options are common approaches to drying out a cold plant prior to cool-down. A description of each option is given, discussing its advantages and disadvantages, in order from the least cost-effective to the most cost-effective option.

Option 1 - Pressure Cycling with Nitrogen

In this approach, sections of the cold plant are isolated to be pressurized and de-pressurized multiple times using nitrogen. This method requires no piping design considerations other than properly locating low point drains and ensuring the drains are of sufficient number and size to remove water from the system.

This dry-out approach requires a large quantity of nitrogen be available and can be very expensive because of the amount of nitrogen consumed. This dry-out option is less likely to be successful if large quantities of free water (i.e., puddles of water) are still present in the system. It is more difficult to determine the amount of water remaining in the cold plant after nitrogen purging and determining if all water has been removed from the system compared to the other dry-out approaches. Water content readings must be taken at many more locations to get an accurate assessment of the amount of water remaining in the system.

Option 2 - Once-Through Dry-Out

Another approach is to flow warm, dehydrated inlet gas through the cold plant equipment and then to the flare stack, re-injection, or a sales gas pipeline. The dry-out path is operated at as low a pressure as possible. The pressure drop through the cold plant is minimized to prevent any Joule-Thomson (J-T) expansion that would cool down the process while drying the plant. The flow rate should be maintained to move any free water to the low point drains, or to absorb the water in the vapor stream and remove it from the process. A pressure reducing device (such as a temporary flow orifice or valve) must be included to take the pressure drop upstream of the cold section of the plant. Figure 1 illustrates the main process flow path for this dry-out method.

![Diagram](image-url)

Figure 1 – Once-through Dry-out
Keep in mind, the dry-out flow rate may be limited by the flare system’s tolerance for flaring or re-injection system capacity. If the wet gas is sent to a sales gas pipeline, monitor the gas water content to ensure it remains below the maximum amount specified. The once through dry-out is an effective approach, and has been used on many projects; however the dry-out flow rate can be limited by the flare system or re-injection capacity. For this scenario, the dry-out period will most likely be longer in order to remove all the water in the cold plant.

**Option 3 - Closed-Loop Re-circulation**

In this approach, warm dehydrated gas is re-circulated in a closed-loop through the cold plant back to the dehydration system inlet using a residue gas compressor. The dry-out loop is operated at as low a pressure as possible without shutting down the residue compressor. The pressure drop is minimized through the cold plant to prevent any J-T expansion that would cool down the process while drying the plant. Again, the goal is to minimize pressure drop through the cold plant but still maintain a high enough flow rate to “sweep” free water to low point drains or carry the water away in the gas to be removed by the front-end dehydrators.

A re-circulation line is required that connects the residue gas line downstream of the residue gas compressors to the inlet gas piping upstream of the dehydrators to make the “closed-loop”. A pressure reducing device (such as a temporary orifice or valve) must be included in the dry-out design to take the pressure drop upstream of the cold plant. Figure 2 illustrates the main process flow path for this dry-out method.

![Figure 2 – Closed-Loop Re-circulation Dry-out](image)

The closed-loop re-circulation approach is our recommended approach, as it achieves a proper dry-out in the shortest time period. This dry-out option removes both free water and ambient condensation, and does so without excessive amounts of nitrogen as with nitrogen pressure cycling, or excess flaring as with a once-through dry-out with dehydrated inlet gas. Nitrogen cycling is only effective at removing ambient condensation within the cold plant and does a poor job of moving free water to the low-points where it can be removed from the system. The once-through dry-out option must have a location to discharge the wet dry-out gas after passing through the cold plant.
Monitoring dry-out progress using the closed-loop re-circulation is relatively straightforward. Once dry-out is complete, transitioning to cool-down can be done quickly with minimal effort, simply by shifting the pressure drop from the dry-out pressure reducing device to the J-T valve. If desired, cool-down can commence using the dry-out re-circulation gas prior to introducing fresh inlet gas.

**CLOSED-LOOP RE-CIRCULATION GUIDELINES**

A well-executed dry-out begins during the detailed design phase by determining the dry-out features required for a specific cold plant design. A dry-out procedure should be prepared prior to dry-out; including any cold plant design limitations as well as the specific steps to follow for removing water and monitoring the cold plant water content during dry-out.

**Cold Plant Design Features Needed to Execute Dry-out**

Several design features should be considered during the detailed design phase for the cold plant to be included as part of the cold plant design package. Although some of the features listed in this section are required specifically for dry-out, many will be used for alternative purposes as well (such as depressurization and venting hydrocarbons from process equipment prior to maintenance or repair, isolating equipment, monitoring the dehydrator outlet water content, etc.).

These features are:

1. Re-circulation piping
2. Pressure reducing device and location
3. Drain valves
4. Provisions for stagnant process areas
5. Location to monitor cold plant water content

1. **Re-circulation piping**

A re-circulation line connecting the residue gas line downstream of the residue gas compressor(s) to the inlet gas piping upstream of the dehydrators should be included to complete the “closed-loop”. For designs which include a cold plant bypass, the plant bypass can be designed to also function as the re-circulation line during dry-out. Figure 3 shows the typical re-circulation piping connection points.
2. Pressure reducing device and location

The location of the pressure reducing device to take the plant pressure drop upstream of the cold plant is dependent on the dehydrator regeneration system design and source of regeneration gas.

When selecting the pressure reducing device location, the cold plant designer must be mindful of the location chosen for dehydrator regeneration gas supply and return to ensure the regeneration compressor has enough compression head to return the wet regeneration gas to the plant. For example, in plant designs which use inlet gas for regeneration, the pressure reducing device must not be located between the dehydrators and the piping take-off for the regeneration gas supply. The regeneration gas compressor will not be able to overcome the pressure difference. Figure 4 shows possible locations to consider.

![Figure 4 – Possible Locations of Pressure Reducing Devices for Dry-out](image)

Typically a temporary flow orifice, manual valve, or automated valve is used as the pressure reducing device. As an example, if a temporary orifice is to be installed at location 2 in Figure 4, the temporary orifice can be installed downstream of one of the molecular sieve dust filters inside its isolation valves (Figure 5). Typically two, full-flow dust filters (one filter in service
and one spare filter) are included as part of the dehydrator design package allowing easy orifice installation and removal. The orifice plate should be of sufficient thickness to handle the pressure drop, which in many cases will exceed 500 pounds per square inch (psi) or 35 bar.

![Figure 5 – Detail for Temporary Orifice](image)

The pressure reducing device should be sized to take the full plant pressure drop at the maximum dry-out flow rate. The maximum dry-out flow rate is set by the maximum flow the cold plant J-T valve can pass when fully open with a pressure drop of ~30 psi (2 bar).

The dry-out gas flow rate will end up being approximately 30% of the cold plant nameplate capacity without introducing too much pressure drop across the fully open J-T valve. Typically, even a single full plant rate residue compressor can be operated on its surge control line at reduced speed to provide a pressure rise of less than the normal operating pressure rise. The pressure reducing device can then be sized for the expected pressures when running the compressor at reduced speed on its surge line. The surge control valve will then remain in control in parallel with the dry-out loop flow for the duration of the dry-out procedure. If multiple machines are used, it may be possible to use one machine with its surge control valve closed during dry-out.

The closed-loop operating pressure on the residue compressor suction side must be high enough to clear the low pressure shutdowns for the compressor. The discharge pressure will be determined by the permissible operating point for the compressor.

3. **Drain valves**

During model review, identify all low points around major process equipment, and add drain valves as required. Hard-pipe all low-point drains to a closed-drain system. Design the low-point drains to be easily accessible. The low-point drains will be used periodically to drain any collected free water from the system. A one inch (1") drain is the minimum size recommended. There must not be any internal projection at the drain connection.

The turbo-expander and booster compressor low points are always inside the machines’ isolation valves and therefore are not available to drain free water during dry-out. As a result, the lowest spot around both machines may then move just outside the isolation points during dry-out. In this situation, ensure low-point drains are installed at these locations to drain any free water that may collect during dry-out.
4. **Provisions for stagnant process areas**

The following process flow diagrams (PFD) are examples of two typical cold plants designs; one designed for ethane recovery (Figure 6) and one designed for propane recovery (Figure 7). Each PFD identifies major process equipment, control valves, and highlights the main re-circulation flow path through the cold plant as well as the stagnant flow areas during dry-out.

![Figure 6 – Ethane Recovery Plant](image1)

**Figure 6 – Ethane Recovery Plant**
(Main Dry-out Path and Stagnant Areas)

![Figure 7 – Propane Recovery Plant](image2)

**Figure 7 – Propane Recovery Plant**
(Main Dry-out Path and Stagnant Areas)

Several piping and equipment loops as well as the lower section of the fractionation column below the expander outlet feed are stagnant (no dry-out flow). Unless a flow is introduced, these areas of the cold plant will remain wet. Design provisions have to be included to introduce flow into each stagnant area.

A source of dry-out gas located downstream of the dehydrator dust filters (also downstream of the pressure reducing device used for dry-out) but upstream of the cold plant should be selected to provide dry-out flow to each stagnant area. As an example, for a 200 million standard cubic feet per day (MMSCFD) or $5.4 \times 10^6$ normal cubic meters per hour (Nm³/hr) cold plant, a four inch (4”) minimum pipe size is recommended from the dry-out gas source in order to provide adequate flow of dry-out gas to multiple stagnant areas at once. As the cold plant nameplate capacity increases, scale up the dry-out gas source pipe size accordingly to ensure adequate flow at the recommended 30 psi allowable J-T valve pressure drop during dry-out.

**Typical Cold Plant Stagnant Areas**

- i. Thermosyphon Reboiler Loops
- ii. Reflux System (Propane Recovery Plant)
- iii. Lower Fractionator Section (Below Expander Outlet Feed)

**i. Thermosyphon Reboiler Loops**

There is no obvious location to introduce dry-out gas flow into a thermosyphon reboiler loop unless isolation valves are installed around the strainers for the exchanger. Some cold plant
designs include isolation valves for the strainers in order to have the capability to remove a plugged strainer without de-pressuring and clearing a much larger plant section (if not the entire cold plant) of hydrocarbons. This is the easiest location to introduce dry-out flow because the isolation valves can be used to direct flow where needed. For this case, connect the dry-out gas source between the exchanger startup screen isolation valves (Figure 8). A two inch (2”) minimum dry-out connection is recommended.

![Figure 8 – Possible Dry-out Connection for Reboiler Loops](image)

If strainer isolation valves are not installed, or another means to direct flow through the stagnant pipe loop is not provided, it is likely that portions of the loop will see smaller amounts of dry-out flow (or no flow at all) potentially leaving unknown water in the piping and equipment. Any flow path that leaves the fractionator and then returns back to the fractionator will be stagnant; therefore, consider the same dry-out approach as for a thermosyphon reboiler loop.

**ii. Reflux System (Propane Recovery Plant)**

Many technologies for propane recovery have a more complex reflux system and can be difficult to dry-out without proper dry-out connections. A section of the reflux system from Figure 7 which typically is stagnant during dry-out is shown in Figure 9. A two inch (2”) minimum dry-out connection is recommended.

The lowest point in the reflux system is the reflux pumps. The reflux system should be designed to free-drain to the lowest point. The dry-out gas source can be connected to the suction side of the reflux pumps inside the pump isolation valves as shown in Figure 9. The pump isolation valves can then serve to direct dry-out gas flow downstream of the pumps through the reflux piping to the deethanizer column.
iii. **Lower Fractionator Section (Below Expander Outlet Feed)**

The lower section of the fractionator column below the expander outlet feed requires an external flow source to remove water from the mass transfer equipment inside the column. A pipe connecting dry-out gas to the column bottoms outlet piping should be designed and installed as shown in Figure 10. The piping and connection size must be large enough for this dry-out connection to be effective. For a 200 MMSCFD ($5.4 \times 10^6$ Nm$^3$/hr) cold plant, a four inch (4”) connection is recommended. As the cold plant nameplate capacity decreases, so can the dry-out connection size, but use at least a two inch (2”) connection.

For propane recovery plants, it is important to note that any water remaining inside the deethanizer column after cool-down will become trapped; eventually freezing because the column overhead is colder than the freezing point of water and the column bottom is warmer than the boiling point of water.

5. **Location to Monitor Cold Plant Water Content**

A sample location for monitoring the wet gas water content at the outlet of the cold plant upstream of the residue gas compressor must be available (Figure 11). The wet gas at this
location is representative of the amount of water present in the main dry-out circulation loop. Any water carried away by the warm dry-out gas that will then be removed by the dehydrators can be measured at this point.

![Diagram of dry-out process](Image)

**Figure 11 – Recommended Location to Monitor Dry-out Water Content**

**Before Starting Dry-out**

Ensure the following before beginning a cold plant dry-out:

i. The pressure reducing device is installed at the designated location.

ii. The residue gas compressor is operational and running in total recycle before starting dry-out gas flow through the train.

iii. All dehydrator beds are available for service in their normal cycle. Each bed should have already had at least one successful regeneration cycle, and the water content of the dry gas exiting each bed should be less than 1 part per million by volume (ppmv). At least one bed should be on-line with one bed in regeneration (assuming a two bed design).

iv. The dehydrator dust filters must be available for service. A typical design includes two full-flow filters (one in service and one off-line).

v. All control valves and manual valves which would restrict flow through the main flow path are open, except the J-T valve.

vi. The fractionator bottom is isolated from its downstream equipment.

vii. The expander/booster compressor is completely isolated, with flow through the J-T valve and around the booster compressor through its bypass line.

viii. The moisture analyzer which will be used to monitor the cold plant water content is in service.

**System Design Limitations**

The following design limits must be adhered to in order to keep from damaging process equipment during dry-out.

i. The recommended maximum dry-out gas feed temperature to the cold plant is 140°F (60°C), limited by the brazed aluminum heat exchangers (BAHE) design.
temperature of 150°F (65°C). Warmer dry-out gas is better. Adjust the louvers on the residue gas compressor discharge cooler to provide a temperature near the maximum.

ii. Understand the flow rate limitations which would result in reaching the maximum velocity limitations across major process equipment (dehydrators, filters, and mass transfer equipment) during dry-out as a result of system flow at lower pressure. However, while it is prudent to know the plant process design limits to keep from damaging equipment, the maximum flow calculated to limit J-T expansion through the cold plant will most likely be less than the process equipment maximum velocity limits.

**Dry-Out Sequence**

At this point, all process requirements should be met so dry-out can begin.

**Summary of steps**

1. **Initiate dry-out gas flow through equipment**
   - With the J-T valve pressure controller in “manual”, slowly open the valve to 100% valve position. Increase the dry-out gas flow if necessary by increasing the residue gas compressor speed until the calculated gas circulation flow target is reached. As the circulation rate is established, continue to monitor the system pressure. In order to maximize the velocity through the cold plant, dry-out system pressure should be set as low as the residue compressor operation will allow. Add fresh gas as needed to maintain the minimum system pressure during dry-out.

2. **Circulate dry-out gas through the main flow path**
   - The pressure drop across the fully open J-T valve should be low enough so that no significant cooling occurs. In most cases, a pressure drop less than 30 psi (2 bar) should be low enough to minimize cooling in the plant.
   - Monitor the cold plant temperatures. All the equipment will cool slightly, but the temperatures should stabilize. If equipment starts cooling significantly, slow down the residue compressor until the pressure drop across the fully open J-T valves decreases enough so that the cooling stops. No hydrocarbon liquid should form. If liquid accumulates in any vessel, it should be just the free water moved to the vessel by the dry-out gas flow.

3. **Periodically drain system low points**
   - As circulation flow is established, free water will move to the process low-points where it can be drained. Mark all low point drains in the field and on a set of Piping and Instrument Diagrams (P&IDs) to ensure all low-points are drained during dry-out. We recommend maintaining an operator log listing all low-point drains and the times each were blown down for the duration of dry-out.
The best method for purging the plant is by opening all low-point drains and allowing any water present to purge to the closed drain system throughout dry-out. However, this approach increases the amount of flaring, and having a constant purge to flare throughout dry-out may not be allowed. If a constant purge is not allowed, establish a routine frequency for draining all low-points (say, once every two hours). Open each drain for at least 30 seconds to remove any free water at that location. The operator might be able to hear the water draining and feel the water flow as the drain valve is opening. Add fresh gas as necessary to maintain the minimum system pressure during dry-out.

4. Establish flow through stagnant piping loops

Once the main dry-out flow path is dry, establish flow through stagnant piping and equipment loops which would otherwise not dry out. The stagnant piping loops discussed in this paper should be designed to free-drain to the lowest point. Drain any free water collected at the piping system low-point first. Use the method described in step 3 for draining water at each process low-point. Once the free water is drained, the quantity of remaining water in the loop should be small enough to be picked up and carried away by the warm dry-out gas introduced.

PLANT MONITORING

Once the dry-out process has been established, how does the operator know if dry-out is progressing and when dry-out is complete?

Monitoring During Dry-out and Time to Completion

Establish the baseline water content in the cold plant when dry-out starts, and record water content readings throughout dry-out to track progress. Having an on-line moisture analyzer to monitor dry-out is helpful because its water content readings can be collected and trended in the plant’s data historian. As discussed earlier, the recommended location to track the water content is at the outlet of the cold plant upstream of the residue gas compressor suction. In addition to monitoring at this location, it is also helpful to have a portable moisture analyzer to collect periodic readings in stagnant piping systems where additional dry-out gas flow had to be introduced.

Figure 12 is an example of the general water content trend during dry-out. As process flow paths are changed and flow is introduced into stagnant areas, do not be surprised if the water content increases at times during dry-out. This is an indication that additional water has been absorbed by the vapor stream and removed from the process equipment and piping.
The suggested maximum water content for a cold plant to avoid forming hydrates is 10 ppmv. Dry-out is close to completion once the water content decreases below 10 ppmv, but we recommend continuing dry-out for a short duration afterward (8 hours). During this time, re-introduce dry-out flow into stagnant areas and force more flow through portions of the main circulation path by manipulating valves in order to ensure the plant is completely dry. Dry-out is complete if the cold plant water content does not increase above 10 ppmv after this time period.

The length of time required to execute a closed-loop re-circulation dry-out is dependent on the quantity of water in the cold plant. Usually four (4) to six (6) days is a reasonable estimation if the guidelines described in this paper are followed. In cold plants where nitrogen cycling occurs before a closed-loop re-circulation dry-out, the time required may be as little as two (2) days.

If the gas dew point is measured during dry-out instead of the actual water content, it is important to understand the pressure at which the dew point is measured has a significant effect on the dew point reading. Determine if the dew point analyzer being used is reading the dew point at line pressure or atmospheric pressure, and understand the dew point conversion between the two pressure points.

Establish the maximum allowable water content criteria before dry-out starts. The maximum set value will help establish agreement between all parties involved as to when dry-out is complete. At times parties involved become too eager and decide to begin cool-down prematurely only to have to go back into dry-out mode again after freezing the cold plant.

“WHAT IF?” SCENARIOS

What if the plant shows signs of freezing after cooling down?

As discussed in the background section of this paper, there are several process indicators which may mean that hydrates have formed in the cold plant. First, the owner/operator must determine if higher system pressure drops or poor fractionation is a result of hydrates or some other cause, like construction dirt/debris. Second, the owner/operator must determine the extent to which the hydrate
formation is effecting plant operation. Can the owner/operator live with current plant performance, or does action need to be taken to remove the hydrates and improve plant performance?

If hydrates are affecting plant performance, the owner/operator can try injecting methanol into the process stream where the hydrates are located. The larger the hydrate formation, the more methanol required to remove it. At some point after starting methanol injection, the owner/operator must determine if the process performance is improving enough to continue injecting methanol. In some cases, the hydrate formation is so large it completely obstructs the process flow and methanol will not remove it. At this point, methanol injection becomes costly to the owner/operator without any process benefit. The only other option for removing hydrates is to warm the cold plant back up. Dry-out flow must then be re-established until all water is removed as previously described.

**What if I use methanol?**

Methanol is effective at removing the hydrate by lowering the temperature of hydrate formation; however, it does not eliminate the water. In order to remove the hydrate, it must be injected at the location where the wet gas was cooled to its hydrate temperature, and in a manner to allow good distribution. Having gas flow at the injection point greatly improves methanol distribution.

Many plants with ultra-high ethane recoveries operate at temperatures colder than -150°F. Before injecting methanol, the owner/operator should know the methanol concentration being used and its freezing point. Even if the process temperature at the hydrate location is slightly warmer than the methanol freezing point, the methanol liquid becomes more viscous once injected into the process, resulting in poorer distribution and less effectiveness for removing the hydrate. The following graph (Figure 13) shows the freezing point versus concentration for aqueous methanol solutions.

![Figure 13 – Freezing Points of Aqueous Methanol Solutions](image-url)
As previously mentioned, larger amounts of hydrates require a larger quantity of methanol to remove them. When water is dissolved in the methanol and moves to the fractionation column, it will exit the cold plant out the fractionator bottoms and leave with the liquids product. Significant amounts of methanol injected into the cold plant can cause operational problems in downstream processes. For some cold plants operating in propane recovery mode, methanol may become trapped within the column or reflux system because the column overhead is too cold and the column bottom is too warm, and some remaining methanol cannot exit.

CONCLUSION

Ortloff has witnessed many cold plant dry-outs during commissioning and initial startup over the years. A well-conducted cold plant dry-out will help ensure plant commissioning and startup goes smoothly and does not last any longer than necessary. There are multiple dry-out options which can remove water from the system; however, there are drawbacks to some of them. The closed-loop re-circulation dry-out does the best job at effectively removing water from the system while easily monitoring dry-out progress, and allows for a quick transition to plant cool-down after dry-out is completed.

REFERENCES CITED