PROTECTING CRYOGENIC HEAT EXCHANGERS

Carl Hahn and Matt Thundyil, Transcend Solutions LLC (a CECO Environmental Company), USA, explain how preventing fouling in cryogenic heat exchangers can provide operational benefits for LNG liquefaction plants.

LNG liquefaction plants convert natural gas (primarily methane, with some mixture of ethane) from a gaseous form to a liquefied form. The liquid is generally at -260°F (-162°C) and at a maximum pressure of approximately 4 psig (125 kPa). LNG can be safely stored and transported in non-pressurised containers. LNG is the world's 14th most traded product, accounting for nearly 1% of world trade.[1]

The process commences with pipeline natural gas. This feedstock is generally treated to remove sulfur and mercury, often by guard-beds. Following this, carbon dioxide (CO_2) is removed (to 50 ppmv), usually in an amine system. The gas is then dehydrated through molecular sieve dehydration beds to around 0.1 ppmv (compared with pipeline natural gas which has a moisture content of 7 lb per million ft^3/d or 143 ppmv). Dehydrated and treated gas then enters the cryogenic section of the LNG plant.

The cryogenic section involves contact of the gas with cooling fluids through a cryogenic heat exchanger.

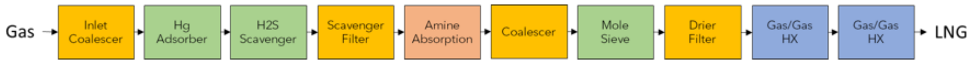

Figure 1. Block flow diagram of the warm section of an LNG liquefaction plant.

Cryogenic heat exchangers have a very high specific surface area (surface area per exchanger volume), ranging from 200 - 2500 m^2/m^3. The high specific surface area necessitates extremely small flow channels, which are very sensitive to fouling by solids and high viscosity liquids.

The efficiency of a cryogenic heat exchanger has a direct impact on both operating costs and capital costs. For example, it has been demonstrated that a 1% improvement in heat exchange efficiency of a cryogenic air separation plant reduces OPEX by 5%.[2] In an LNG facility, fouling of the exchanger not only drives up operating costs, but also limits the production of liquefied, saleable products. Consequently, protection of cryogenic heat exchangers should be a critical process step.

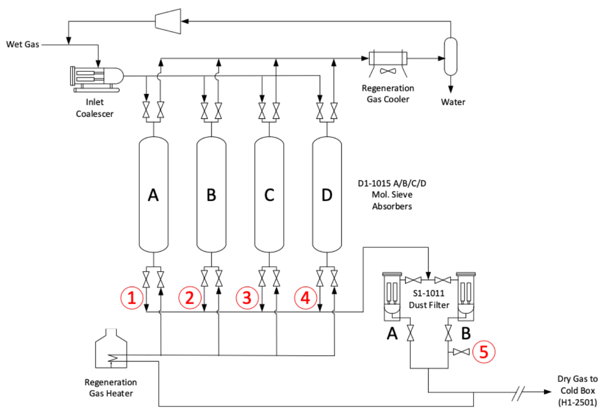

Figure 2. Process flow diagram indicating analysis locations.

Case study

A US Gulf coast LNG liquefaction facility reported fouling on the 'warm' exchangers on all three of its existing trains. Each train processed approximately 630 million ft^3/d of natural gas. A block flow diagram of the various systems that the natural gas flows through is shown in Figure 1, with critical filtration and separation equipment identified in the orange boxes.

Fouling of the Gas/Gas HX immediately downstream of the molecular sieve driers and drier filters was the primary focus of this study. The cleaning of the exchangers required a multi-day shut down, costing over US$10 million in lost profit per event. The plant suspected that the fouling was caused by condensable hydrocarbons and molecular sieve dust fines.

Table 1. Summary of the data collected from the drier beds

Sample location	Measured contaminant concentration (mg/ft^3)	Contaminant load (kg/d)
Drier A – outlet	0.003 500	0.816
Drier B – outlet	0.000 600	0.133
Drier C – outlet	0.000 030	0.007
Drier D – outlet	0.001 400	0.331

Table 2. Data from dust filter

Sample location	Measured contaminant concentration (mg/ft^3)	Contaminant load (kg/d)
Dust filter – outlet	0.000 600	0.038

Contamination analysis

The sampling locations were:

- Outlet piping immediately downstream of each of the drier beds.
- Outlet piping immediately downstream of the dust filter housing.

A process flow diagram is shown in Figure 2. The samples 1 - 4 were immediately downstream of each of the drier beds, and sample 5 was immediately downstream of the dust filter housing.

The sampling technique involved the use of a high efficiency membrane intended to capture the solids in the stream, along with a quantification of the gas flowed through the housing to allow for a gravimetric assessment of the solids captured (in terms of mg/ft^3 and therefore in kg/day). The captured material can be further analysed to obtain elemental or other signatures that can be used for root cause analysis.

Table 3. Elemental analysis of the samples

Sample location	Primary contaminants
Drier A – outlet	Carbonaceous material, iron oxide (corrosion products) with a small amount of molecular sieve dust (aluminosilicates; $NaAl_xSi_yO_z$) relative to the iron oxides
Drier B – outlet	Molecular sieve (aluminosilicates; $NaAl_ySi_zO_z$) and iron corrosion products (iron oxide; Fe_2O_3), with some evidence of alloy steel corrosion products (Cr), sulfur (likely present as sulfate), and calcium
Drier C – outlet	Molecular sieve (aluminosilicates; $NaAl_ySi_zO_z$) and iron corrosion products (iron oxide; Fe_2O_3), with some evidence of alloy steel corrosion products (Cr), sulfur (likely present as sulfate), potassium and calcium
Drier D – outlet	Iron corrosion products (iron oxide and manganese oxides; Fe_2O_3, MnO_2) and molecular sieve (aluminosilicates; $NaAl_ySi_zO_z$), with some evidence of calcium
Dust filter – outlet	Iron corrosion products (iron oxide; Fe_2O_3) and molecular sieve (aluminosilicates; $NaAl_ySi_zO_z$)
Cold box – inlet	Molecular sieve (aluminosilicates; $NaAl_ySi_zO_z$) with some iron corrosion products (iron oxide; Fe_2O_3)

A summary of the data collected from the drier beds is noted in Table 1.

The average daily load from all four driers is 0.3 kg/d. The data from the dust filter is noted in Table 2.

The data suggests that the existing filters had an efficiency of 88%, and the solids load was equivalent to 15 kg/yr of foulant entering the heat exchangers.

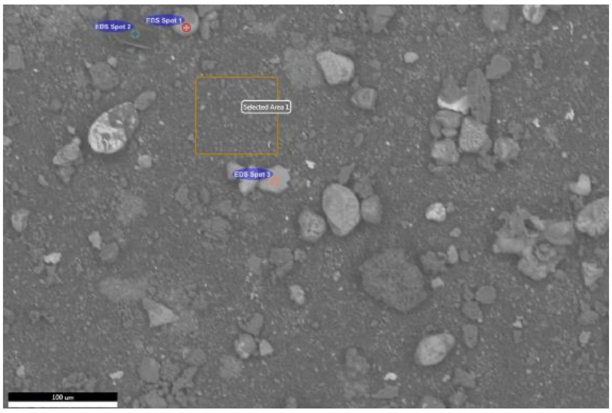

Figure 3. Scanning electron micrograph of contaminant entering the cryogenic exchanger.

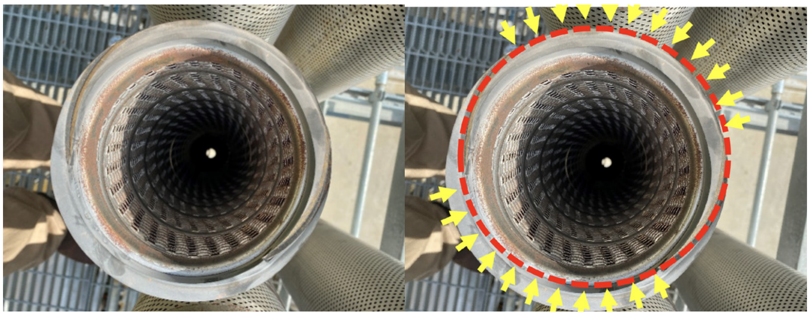

Figure 4. Sealing surface of the dust filters. The picture on the left shows the groove of the 'knife edge' sealing surface. The picture on the right illustrates the regions where the elastomer does not seal.

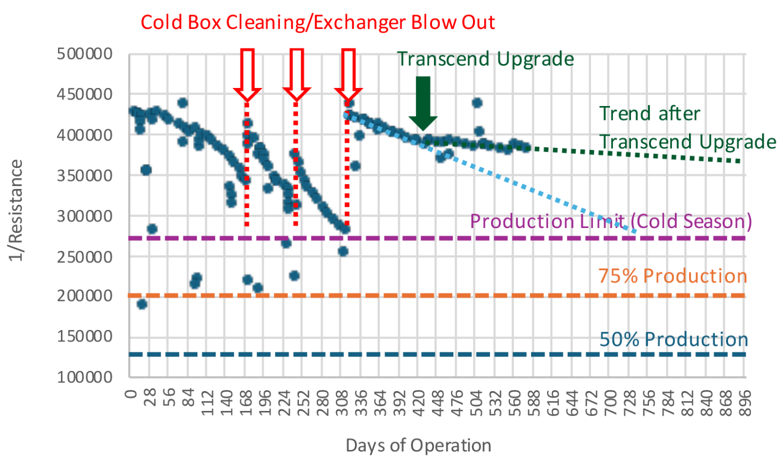

Figure 5. Heat transfer resistance over time, showing the impact of the Transcend upgrade.

The elemental analysis of the samples from the various locations is summarised in Table 3, along with an additional sample from the inlet to the cold box. Figure 3 shows a photomicrograph of solids found on the analytical membrane, indicating the particle sizes that were observed.

Dust filter analysis

The observation of contaminant in the line after the dust filter prompted an evaluation of the dust filter elements. These revealed poor sealing, as can be seen in Figure 4, and the use of inefficient media technology. An upgrade to the conventional separator was developed to improve the sealing and media efficiency, as well as to enhance operating ergonomics.

The upgrade allowed the plant to use the existing pressure vessel without needing to take it out of service.

Results

Following the upgrade, the resistance across the heat exchangers continued to be monitored. The results are indicated in Figure 5 and demonstrate the dramatic impact of high efficiency filtration on the fouling tendency of cryogenic heat exchangers. The Y-axis is the inverse of resistance across the heat exchangers, which is a measure of the fouling inducing pressure drop and reduced heat transfer efficiency.

When the curve bends down, it is a measure of increasing resistance across the heat exchanger. Within 150 days of operation, the cold box needed cleaning. This required an outage. It is also noticed that the exchanger does not return to its original value, and the subsequent data indicates increased rapid fouling.

After the third cleaning, the trend is noticed to be less steep than it was originally. This is due to the plant seeking to ensure that the elements were installed better and not bypassing (as much). However, there was still a downward trend, likely reaching production limiting conditions within 350 days. The upgrade to Transcend clearly demonstrates that the fouling rate has slowed down significantly. The slight downward trend is reflective of contaminant previously carried over and sealing challenges related to the poor original design.

However, the reduced rate of fouling is attributable solely to better sealing and improved media technology.

Considerations for licensors, engineering companies and end-users

This case study would not be complete without a discussion of the licensors, engineering and construction company, and end-customer choices that led to the use of the poor separations in the first place.

Licensors often focus on the refrigeration train to a much greater extent than on the separation of critical solid and liquid contaminants. As a result, most licensors leave separations out of their scope of critical supply.

Engineering, procurement and construction (EPC) companies rely on the vendor claims for efficiency and sealing. Once they have the vendor claims, the EPC firms make a choice based on lowest cost. Multiple case studies have shown that poorly performing separators for solid and liquid removal may be provided.

End users typically have no leverage during the detailed design process once the contract is signed, and these kinds of contaminant-related operating issues typically only materialise after the performance warranty period.

Given that the risk is inherent, some separations are so critical to the ongoing operation of the plant that the end-customer and licensor should consider working with companies that have technology expertise and manufacturing capability.

Summary

The need to protect cryogenic heat exchangers from solids and liquid contaminants is well understood in the industry. However, that understanding does not always translate into the implementation of effective separations. This case study provides a clear example of how high efficiency separations can result in operational benefits.

Although the plant was focused on condensable hydrocarbons at the outset, effective solids removal prior to the exchanger was able to solve their challenges. However, this does not mean that high efficiency aerosol removal does not have a role to play. The presence of carbonaceous material on the molecular sieve tests indicates the persistence of either inlet contamination (pipeline lube-oil etc.) or process treating fluids (amine carryover from the amine absorption system).

The most persistent contaminants in a gas stream are sub-micron in nature. This means that effective solutions must be able to capture and remove contaminants in this range. In the case of solids, the requirements are two-fold, the filter element must seal (if it does not seal, gas bypass will carry solid contaminants with it). Secondly, the filter element itself has to be effective at removing the solids in the range that they exist. In the case of liquids, the requirements have additional dimensions, in that the separator must seal and capture the contaminants and be able to handle the liquid challenge without flooding and shedding the liquid back into the gas stream.[3]

References

1. https://oec.world/en/profile/hs/natural-gas-liquefied.
2. POPOV, et al, 'Cryogenic heat exchangers for process cooling and renewable energy storage: A review', *Applied Thermal Engineering,* Vol. 153, 275 - 290, (2019).
3. HAHN C. W., 'Impact of Aerosol Contamination on RSV Efficiency', Proceedings of the Laurance Reid Conference, (2023).