THE IMPACT OF AEROSOL CONTAMINATION ON RSV EFFICIENCY

Laurance Reid Gas Conditioning Conference
February 20-23, 2023 – Norman, Oklahoma USA

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ABSTRACT

NGL recovery typically uses cryogenic heat exchangers. The presence of contamination in the gas (either solids [molecular sieve fines], or liquids [compressor oils]) can have a major impact on plant throughput, NGL recovery and overall profitability. A case study of optimization efforts at a 400 MMSCFD cryogenic gas plant is provided. The operator faced compressor oil carryover in the feed to a cryogenic exchanger in the RSV reflux loop. Data was collected around the horizontal filter separator that was in service, which evidenced little separation efficiency. The root cause was determined to be ineffective capture and removal of the aerosol. A vertical separator was designed, installed, and then tested, with a separation efficiency improvement of greater than 2 orders of magnitude. The upgraded installation was paid back in a matter of months.

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Introduction

The value of NGL and chemical feedstocks derived therefrom (ethane, propane, butane, pentane, etc.) has led to an extensive use of cryogenic gas plants to optimize liquids recovery from raw natural gas. Much of the natural gas recovered from fracking contains significant amounts of associated NGL. Gas produced in the Bakken region has particularly high levels of associated NGL resulting in very high raw gas BTU levels. Raw gas from the wellhead in the Bakken can easily exceed 1400 BTU/cf. NGL content in Bakken gas can range from 6 – 12 gallons per MMSCF[1] and the propane content of Bakken gas can exceed 11%[2].

To take advantage of the high liquid content of Bakken gas, Recycle Split Vapor (RSV) plant design[3] and various RSV derivative technologies can be employed to increase liquids recovery relative to conventional Gas Subcooled Process (GSP) plant designs. The RSV plant design utilizes a recycle of a portion of the residue gas to the demethanizer column to increase the reflux and improve recovery of ethane, propane and NGL. The RSV design can allow complete (99+%) propane recovery, relative to ~89% - 90% recovery when the RSV reflux is not in operation. In a 200 MMSCFD plant design, this can result in recovery of $5MM - $10MM per year of additional propane, or consequently result in a loss of that magnitude if the RSV reflux loop is inoperable.

It is critical for effective RSV plant operation that the residue gas recycled to the demethanizer is completely free of lubricating oil. Lube oil viscosity rises significantly at low temperature, and at cryogenic temperatures (-140 °F) will solidify. Most RSV gas plants utilize reciprocating compressors for residue gas compression. Reciprocating compressors require lube oil injection into the cylinders. The injected lube oil is aerosolized upon compression and exits with the compressed gas as an extremely fine mist. A substantial portion of the oil mist in the residue gas is present as a sub-micron aerosol. Aerosols in this size range are the most challenging to remove from the gas. Failure to remove the oil aerosol results in carryover to the cryogenic exchangers which cool the gas for return to the demethanizer. At the low exchanger outlet temperature, any entrained lube oil will freeze resulting in rapid increase in differential pressure across the exchanger which will limit flow or result in shut-down of the RSV reflux loop.

The following case study looks at the experience of an RSV cryogenic gas plant in the Bakken region. The plant started production with two 200 MMSCFD gas processing trains (total processing capacity 400 MMSCFD). During a pressure survey shortly after startup of the facility, substantial amounts of oil were found in the piping downstream of the residue gas coalescer. Investigation revealed that the residue gas coalescers on each process train were ineffective at removing lube oil from the residue gas resulting in both contamination of the take-away pipeline and the RSV reflux loop.

After a period of troubleshooting with the initial coalescer, the facility elected to replace the residue gas coalescers with larger horizontal filter coalescers from another vendor. The horizontal filter coalescers also failed to adequately remove lube oil from the residue gas resulting in continued inoperability of the RSV residue gas reflux loop. A poorly sized, poorly designed, or poorly operated filter separator can almost completely fail to provide the benefit it is supposed to provide.

At this stage a more extensive evaluation of the residue gas and the horizontal filter coalescers was undertaken to characterize the separation efficiency and quantify the oil aerosol content of the residue gas stream. This characterization provided the basis for an informed coalescer design which alleviated the lube oil carryover, resulting in cessation of lube oil contamination of the take-away pipeline and eliminating fouling of the cryogenic exchangers in the RSV reflux loop. Once the facility installed properly designed residue gas coalescers, the plant was able to fully operate the RSV reflux loop driving propane recovery from 89% to 99+%. The RSV circuit has been operational for nearly one year with no operational issues associated with the new residue gas coalescers.

Facility Background

The plant is in the Bakken region of North Dakota processing gas from a local gathering system. The plant consists of two trains, each capable of processing 200 MMSCFD of gas. The facility makes use of a typical RSV plant design. The generalized process flow diagram is provided in Figure 1. Each train operates three residue gas compressors, each rated at 7,000 horsepower. The discharge pressure can run as high as 1800 psig, although the discharge pressure for the plant operates at 1,250 psig to 1,500 psig depending on the receiving pipeline operating pressure. The gas temperature exiting the aftercooler is 120 °F and is pipeline limited at 130 °F. The residue gas compressors feed a single residue gas coalescer that treats the full gas flow. A portion of the residue gas is recycled through the RSV loop, while the remainder becomes sales gas to the pipeline.

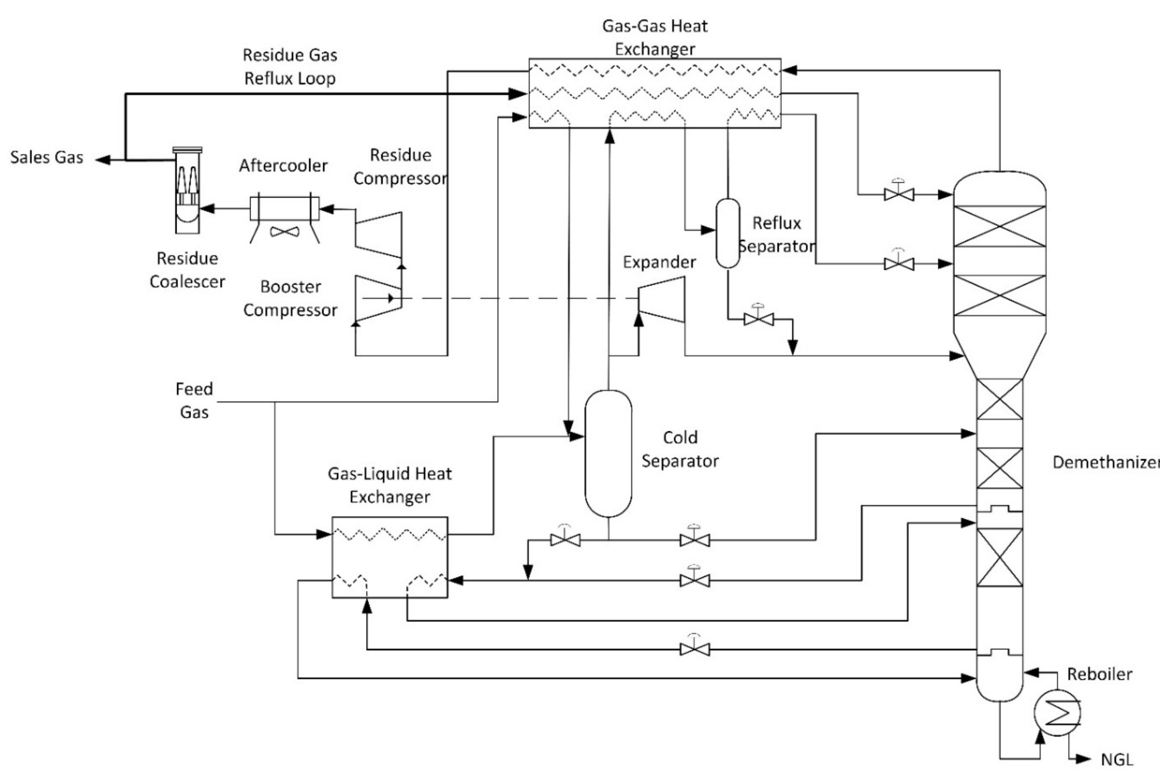

Figure 1 – General process scheme for RSV cryo plant.

The location of the facility in North Dakota exposes it to highly variable seasonal temperature swings with potential seasonal summer highs above 100 °F, and potential seasonal winter lows below -25 °F. This can have a material effect on residue gas coalescing, as the winter lows can produce residue gas temperatures well below the 100 to 110 °F target temperature at the discharge of the aftercoolers. Ambient cooling of the exposed pipe during winter months can drop the actual gas temperature to 85 °F at the residue gas coalescer.

Figure 2 – [A, left] Residue Gas Compressor Skid. Residue Gas Compression utilizes 3 x 7,000 hp reciprocating compressors per train. [B, right] Horizontal Filter Coalescer evaluated in July 2021.

The plant was originally designed with a vertical coalescing filter which saw significant oil carryover. Troubleshooting of the original coalescer was not able to remedy the oil carryover. The original vertical coalescer was replaced with a horizontal filter coalescer from another vendor. The replacement horizontal filter coalescer also failed to stem the oil carryover after significant troubleshooting by plant and vendor personnel. The troubleshooting efforts included evaluation of instrumentation and controls to ensure that the source of the failure was not due to mechanical failure of associated control systems.

Evaluation of Horizontal Filter Coalescer Performance

The performance of the horizontal filter coalescer (Figure 2B) on the residue gas was evaluated by placing a high-efficiency test coalescer at the outlet of the vessel and monitoring the captured liquids under various operating conditions. The inlet oil load to the coalescer can be measured with a test apparatus as well, although in residue gas compression applications, the oil concentration in the residue gas after compression can also be determined by monitoring the oil injection rate into the compressor cylinders. During the period of evaluation, the oil injection rate to the cylinders was 5 gpd per compressor. In this type of evaluation, monitoring operating conditions of the test equipment (temperature, pressure, and flow) coupled with measurement of recovered liquids allows analytical determination of the oil content in the residue gas stream. The analytical test apparatus is illustrated in Figure 3 in both summer and winter (insulated) mode. The initial evaluation of the horizontal filter coalescer was conducted in July 2021. The peak ambient air temperature recorded at the site during the evaluation was 111 °F. Under peak operating temperature, the residue gas coalescer should see the highest oil separation performance due to the reduced oil viscosity.

The analytical test apparatus was installed on a sample port at the side of a vertical section of pipe approximately 20 feet from the discharge nozzle of the residue gas coalescing vessel. A slip stream of the residue gas (~145 SCFM) was routed to the analytical test apparatus. Flow through the test apparatus was maintained near isokinetic rates with the main process piping to minimize flow effects on the sampling. The outlet of the test apparatus was routed through a pressure reducing valve to the flare system. The analytical evaluation was operated continuously for approximately 96 hours.

Figure 3 – [A, left] Analytical test apparatus (summer). [B, right] Analytical test apparatus (winter).

The analytical test equipment requires an initial period to saturate the test element. Once fully saturated, the test apparatus will continuously measure the oil content of the gas. Due to both available gas and oil carryover from the residue gas coalescer, the facility primarily operated at 2/3 capacity with only two of the three residue gas compressors in operation. For the coalescer evaluation, all three compressors were operated to simulate full plant operation, with the excess gas recycled to the front of the compression skid.

With three compressors in operation, the analytical test apparatus was fully saturated in ~ 8 hours. Once fully saturated, the recovered oil was continuously monitored to determine concentration in the residue gas downstream of the residue gas coalescer. With three compressors in operation, the measured oil concentration in the residue gas downstream of the residue gas coalescer was 0.001069 mL/SCF gas. This equates to an oil carryover of approximately 56 gallons per day. This level of oil contamination far exceeds the acceptable operational limit for an RSV system, or any residue gas coalescer application. The measured oil content in the residue gas stream was greater than the calculated inlet oil concentration. This is attributed to super-saturation of the coalescing elements. The coalescing elements reached an equilibrium oil saturation limit at normal operation of 2/3 plant capacity (2-compressor operation). When the facility started the third compressor to initiate the full flow simulation, the 50% increase in gas flow through a super-saturated element results in excess carryover as the super-saturated element sheds additional oil to re-establish a new equilibrium at the higher gas flow and oil load. Consequently, a higher outlet oil concentration is measured at the discharge under these conditions. Had the operation at full capacity continued, it is expected that the oil concentration at the discharge would eventually fall to match the inlet oil load.

Once suitable data had been generated at the full three-compressor load (~12 hours), one compressor was shut down to monitor the performance at 2/3 plant capacity. Data was collected for an additional 18 hours to establish the oil concentration downstream of the residue gas coalescer at the two-compressor flow rate (~124 MMSCFD). The measured oil concentration downstream of the residue gas coalescer under two-compressor operation was 0.000288 mL/SCF oil in the residue gas. While this is a greater than three-fold decrease in the oil carryover relative to full flow operation, it represents approximately 10 gallons of oil per day and is equivalent to the oil concentration at the inlet to the coalescer indicating a 0% removal efficiency at 2/3 plant capacity.

In addition to the in-plant evaluation of the live process gas stream, a laboratory evaluation of the residue gas coalescing element was also performed. The coalescing filter element was challenged with a sub-micron oil aerosol generated with a Laskin nozzle. A Laskin nozzle produces a very narrowly distributed aerosol between 0.1 and 0.6 microns. This represents both the most penetrating aerosol distribution for coalescing elements and closely approximates the finest oil aerosol discharge from a reciprocating compressor. The coalescing element, when challenged with a Laskin nozzle aerosol showed significant visible aerosol downstream of the element, indicating that the coalescing media employed was ineffective at intercepting these finest oil aerosols.

The laboratory evaluation of the coalescing element coupled with the live process sampling under varying operational conditions indicated that the horizontal filter coalescer suffered from both an inability to intercept fine oil aerosols with high efficiency and a design that placed it in a state of continuous super-saturation (element flooding). Consequently, measured outlet oil concentrations at the discharge of the residue gas coalescer are equivalent to the inlet oil load, or greater depending on operational parameters and gas flow dynamics.

Design and Evaluation of Vertical Residue Gas Coalescer

Based upon the field evaluation and proprietary internal design criteria, Transcend Solutions provided vertically oriented residue gas coalescers to the facility. The design accounts for fundamental design properties which drive effective gas coalescing – namely high-efficiency media capable of intercepting the finest sub-micron aerosol droplets, effective liquid drainage mechanisms internal to the separator elements, and optimized flow dynamics in the vessel. Additionally considered were critical operating parameters at the facility as well as the gas and contaminant properties to deliver an effective residue gas separator.

The vertical coalescing design takes advantage of gravity to assist drainage of the recovered liquids, and the design parameters assure that the separator elements are well below their liquid saturation threshold. Coupled with the internal drain mechanisms of the element, the design assures that the oil-wetted outer surface of the separator elements constitutes only the lower few inches of the element, where annular velocity is the lowest and potential for re-entrainment is smallest. The draining liquids are directed away from the bulk of the gas flow. Additionally, in a vertical orientation the liquids drain to the sump directly without impacting other elements in the vessel. By contrast, horizontally arranged separator elements become liquid saturated along their entire length, which can increase the potential for re-entrainment in areas of high gas velocities. Additionally, saturated elements in a horizontal configuration can drain liquids on to the elements below, resulting in super-saturation of the lower elements in the vessel.

Figure 4 – Transcend Solutions vertical residue gas coalescer (left foreground) and previous horizontal filter coalescer (right background). Scaffold tent to the left of the vertical coalescer is the enclosed shelter for the test apparatus.

The optimally designed vessels were delivered in January of 2022 and immediately placed in service. The operating performance of the residue gas coalescers on each train was monitored with the same test apparatus, configuration and flow conditions utilized to evaluate the operational performance of the previous horizontal filter coalescer. The ambient air temperature during the evaluation was between -22 °F and -5 °F, representing a "worst case" test period due to both oil viscosity and residue gas temperature (85 °F). Due to the extreme ambient temperatures, the test apparatus was placed inside an enclosed, field-erected scaffold tent and the test apparatus and tubing connections were fully insulated. The plant operated at full 200 MMSCFD gas volume with all three compressors in operation during the entirety of the evaluation (apart from a brief compressor trip, where only two compressors were available). The data from the evaluation of the Transcend coalescer is overlaid on the data from the previous evaluation of the horizontal filter coalescer in Figure 5.

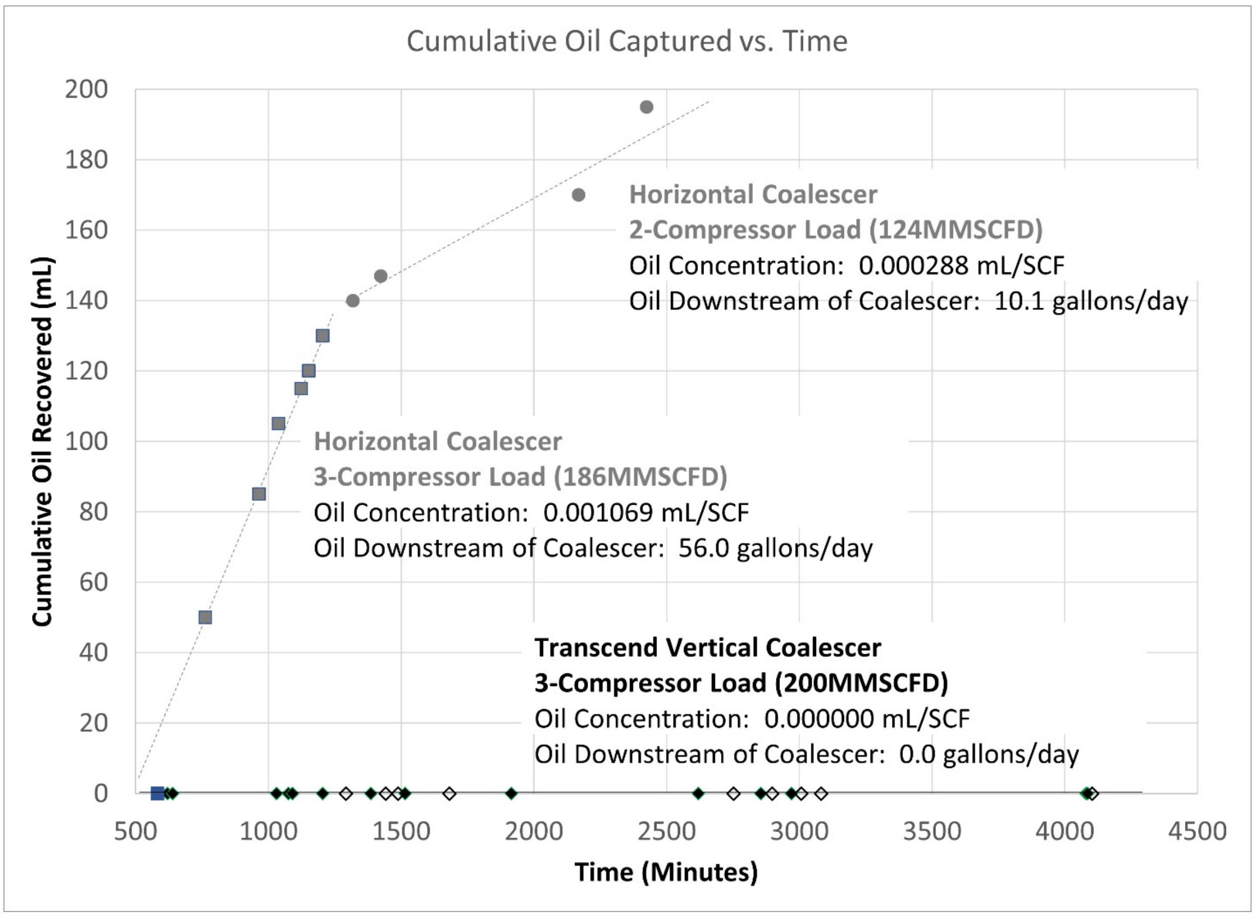

Figure 5 – Measured oil content in residue gas downstream of residue gas coalescer vessel. Horizontal filter coalescer (July 2021) at full load (Solid gray square data points; 3-compressors; 186 MMSCFD) and partial load (Solid gray circle data points; 2-compressors; 124 MMSCFD). Data for Transcend Solutions vertical coalescer is overlaid in solid black diamonds (Train 1; 3-compressors; 200 MMSCFD) and open black diamonds (Train 2; 3-compressors; 200 MMSCFD).

No measurable oil was collected in the test apparatus at the outlet of the new vertical residue gas coalescing vessel. The test apparatus was operated continuously for ~68 hours for the new residue gas coalescing vessels on both Train 1 and Train 2.

Once the initial performance validation period for the new, vertical gas coalescing vessels was complete, and the absence of lube oil downstream of the residue gas coalescers was confirmed, the plant re-activated the RSV reflux loop. While operating without the RSV reflux loop, propane recovery was limited to 89% - 90%. Once the RSV reflux loop was re-activated, propane recovery increased to 99+%. The added value of the recovered propane is estimated to be more than $5 million per year per train. The payback of the capital investment for the coalescers was in a matter of 1-2 months. Both process trains have been operating for nearly one year without an appreciable accumulation of differential pressure across the RSV reflux loop exchangers.

Impact of Residue Gas Coalescing Efficiency on RSV Facilities

The presence of entrained lube oil, even at the ppm level can have substantial adverse effects on the operation of RSV cryogenic gas plants. This is true as well for other applications where compression occurs upstream of cryogenic exchangers in cold boxes (e.g., nitrogen rejection units [NRU]) or upstream of other sensitive equipment (e.g., gas membrane systems). Lube oil aerosols will rapidly accumulate in cryogenic exchangers, where the low operating temperature solidifies the lube oil, generating excessive differential pressure and rendering the exchanger inoperable. Similarly with membrane systems, the oil accumulates on the membranes destroying the mass transfer properties of the membrane.

In RSV gas plant designs, inoperability of the RSV reflux loop due to excessive exchanger pressure differentials deprives the demethanizer of adequate reflux and diminishes liquids recovery. As noted in the above example, this can lead to excessive opportunity costs related to diminished recovery of valuable hydrocarbon liquids.

Some RSV facilities utilize both a residue gas coalescer and a separate, dedicated coalescer on the RSV reflux loop. This is an acknowledgement that many coalescers and coalescing elements used in residue gas coalescing applications have been inadequately designed for the application and multiple coalescers in series are required to operate the RSV reflux effectively. Rarely do multiple inadequate separators in series provide performance equivalent to a single effectively designed coalescing separator. It should be noted that the plant highlighted here now utilizes a single, adequately designed high-performance gas coalescing separator in lieu of multiple residue gas separators and does not experience any downstream oil carryover.

The example highlights the utility of online liquid aerosol quantification in troubleshooting plant operational issues. The analytical testing methods outlined here are applicable to any process gas stream to both quantify free liquid content in the gas and to isolate and identify the liquids present. Often plant operational issues are difficult to identify and where the entrained liquids are only present as aerosols, there may be no other indication that liquid entrainment is present in the gas. The online analytical methods outlined here can be used to provide a complete system survey by sampling various locations within the process to determine the contaminants present and how they propagate through the process. The data generated then provides a clear basis for well-informed solutions.

The on-line analytical measurement of entrained aerosols can augment operational monitoring by plant personnel. Suggested monitoring should include the differential pressure across the RSV pass relative to flow rate. An increase of differential pressure across the RSV exchangers at a given flow rate over time might signal fouling of the exchanger pass. Additionally, one could monitor the approach temperature between the RSV pass outlet and the residue gas inlet. In theory, this value should increase over time as fouling occurs. Likewise, monitoring the temperature difference between the RSV pass outlet and the GSP pass outlet should also reflect a widening gap as the RSV pass becomes fouled.

Alternate Oil-Free Solutions for Reciprocating Gas Compressors

A high-performing gas coalescing system should be capable of delivering gas with an entrained oil concentration of <50 ppb at inlet oil concentrations typical of a reciprocating gas compressor. When truly oil free gas is required, such as in high-purity industrial gas applications, an additional oil adsorption system may be employed to remove residual oil and oil vapor. A representative process flow for such a system is illustrated in Figure 6. An oil free adsorption system typically employs a high efficiency coalescer followed by a carbon bed which has sufficient capacity to adsorb the ppb level of aerosolized residual oil and oil vapor. A dry gas filter is placed downstream of the oil adsorbing carbon bed to prevent the possibility of carbon migration downstream of the bed. Generally, an adsorption system is applied where cost effective and driven by gas purity requirements.

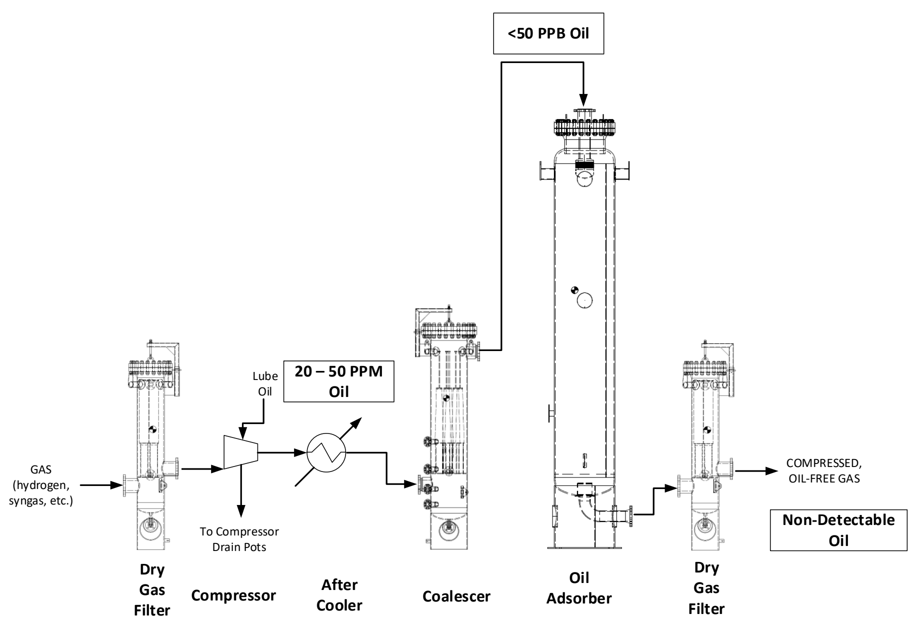

Figure 6 – Oil adsorption system utilized in high-purity industrial gas applications to provide "oil free" gas.

While truly oil free gas is possible with an oil adsorption system, this approach is generally cost prohibitive for a cryogenic gas processing plant. At the scale of a 200 MMSCFD gas plant, the oil adsorber required would be a high-pressure design on the order of 8’ diameter x 30’ tall w/ 3.5”-4” wall thickness. The total installed cost for the additional oil adsorber and dust filter equipment would likely be $3M - $5M. Even more challenging is defining end-of-run on the carbon bed, since the carbon bed capacity for compressor oil can vary widely based on whether the compressor oil is only present in a vapor form, compared to capacity in the presence of liquid oil carryover. An effective, well-designed coalescing system, as shown in this paper, can deliver gas suitable for protection of cryogenic exchangers in an RSV gas plant, making the added expense of the oil adsorbing carbon bed and after filter difficult to justify with little added performance benefit.

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