Separation of Compressor Oil from Helium

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An oil-sealed rotary screw compressor used to compress helium for cryogenic applications can entrain as much as 4000 ppm by weight of oil impurities. Efficient oil-separation filters will reduce total impurities in the gas to below 0.1 ppm.

This paper describes how filtration of helium differs from filtration of other gases, and offers recommendations for removing liquid oil in compressed helium.

SEPARATION OF COMPRESSOR OIL FROM HELIUM

Compression of helium by an oil-sealed rotary screw compressor entrains as much as 4000 parts per million by weight (ppm) of liquid and vapor oil impurities in the gas. For cryogenic applications, helium impurities must be reduced below 0.1 ppm. In principle, the methods used for removing oil from compressed air can also be used for removing oil from helium. However, extensive experience with compressed helium has shown that oil separation equipment designed for compressed air must be modified significantly to produce the desired results with helium.

The main differences between air and helium filtration are:

1. The purity requirement for helium refrigeration systems is far more stringent than normal air filtration requirements. For most applications, filtration of oil in air to 1 ppm is satisfactory, while in cryogenic helium applications 0.1 ppm is often considered the maximum tolerable level, and even lower concentrations are preferred.
2. The output oil content in helium from a rotary screw compressor is much higher than the output oil content in air from the same compressor. One reason for the high oil concentration by weight in helium is that the compressor is a volume-handling device, and a given weight of oil per unit volume of gas results in 7.25 times the weight of oil per unit weight of helium, compared with weight of oil per unit weight of air. In addition, helium is commonly compressed to 200 psig or higher, while compressed air is usually compressed to 125 psig or less. The higher output pressure results in higher volumetric oil loading.

REMOVAL OF LIQUID OIL FROM HELIUM

Description of Coalescers
At least 99.99% of the oil in helium is in the form of liquid droplets. Coalescers remove virtually all the liquid oil contaminants.

All commercial filters for high efficiency separation of liquid oil from gas are continuous coalescing filters. The typical coalescing filter element is composed of a 1/16” to 1/4” thick mat of borosilicate glass fibers, formed into a cylinder and structurally bonded by resin or by internal and external perforated supports. With proper design, filter elements of this construction can readily achieve initial retention efficiencies of 99.99% or higher for 0.3 to 0.6 micron particles and droplets.

If the filtered contaminant is a solid particle, it remains attached to the surface of the filter fiber against which it has impacted, held by Vander Waals forces. However, liquid droplets captured on the fibers can migrate down the length of a fiber to fiber crossover points. There the liquid droplets grow into large drops, which eventually are forced through the depth of the filter to the downstream surface by the flow of gas through the filter. By the time they reach the downstream surface, the droplets have grown so large that - at least in theory - they are too heavy to be resuspended in the gas stream. Therefore, the large drops drain down the vertical filter tube, while clean gas exits the filter housing. If gas flow direction through the filter tube is inside-to-outside (as in the case with all commercial coalescing filters), the coalesced liquid drains from the outer surface of the filter tube into the sump of the filter (see Fig. 1), from which it may be removed continuously by an automatic drain. The net effect of the process is to coalesce submicron oil droplets into large drops, which are continuously drained from the system. Since the liquid is removed as rapidly as it enters the filter, the filter has an infinite life in liquid removal applications, and the efficiency of the filter remains constant indefinitely.

The theoretical picture of a coalescing filter presented above applies quite well in practice to most compressed air filtration. However, some problems arise in helium filtration. A potential difficulty with any continuous coalescing filter results from the fact that the filtered gas and coalesced liquid both exit from the downstream side of the filter element. Any re-entrainment of the coalesced liquid will contaminate the clean gas. Most manufacturers fabricate their coalescing filter elements with an outer layer of coarse glass fiber or polyurethane foam to act as an entrainment separator. While the entrainment separator layers are undoubtedly beneficial, they are never 100% efficient. In a particularly wet system, such as any helium system, there invariably is significant liquid carryover from the first coalescing filter. Therefore, more than one stage of coalescing filtration is always needed in helium filtration.

A second practical difficulty with the picture of the theoretical coalescing filter is that coalesced oil drains more slowly from a higher efficiency filter than from a lower efficiency filter. If oil enters the filter more rapidly than it can drain from the filter, the excess will be re-entrained in the exit gas, regardless of the efficiency rating of the filter. For this reason, a very high efficiency filter used as a first stage coalescer in a helium system is likely to give much poorer coalescing results than a lower efficiency filter.

RECOMMENDATIONS FOR REMOVING LIQUID OIL FROM HELIUM

Based on operating experience with a wide range of helium systems, Parker Hannifin has empirically developed recommendations for removing liquid oil from helium (see Table 1). Systems designed with these criteria consistently have reduced liquid oil content in helium from several thousand ppm to less than 0.1 ppm. The specific recommendations apply only to the particular construction and geometry of the Parker Balston filter elements and filter housings, but the general principles of multiple stage and graded efficiency filtration are believed to be applicable to any manufacturer's coalescing filters.
OIL VAPOR IN HELIUM

Typical Compressor Oils
While helium producers and users have frequently installed carbon adsorption equipment to remove compressor oil vapor from helium, historically the adsorbers have been designed without benefit of quantitative information on oil vapor concentration or the effectiveness of adsorbents for removing the vapor. Parker Hannifin has recently made quantitative determinations of organic volatiles in two compressor oils frequently used with helium: Union Carbide UCON LB-170X and LB-300X.

The UCON fluids are reportedly to have the composition \( \text{C}_4\text{H}_{10}(\text{OC}_3\text{H}_6)_{n-\text{OH}} \). The different members of the family have different average molecular weights, and therefore different viscosities. The numerical designations are equal to the viscosity in SUS at 100°F. The “X” designation signifies the presence of an aromatic amine antioxidant. Union Carbide has stated that the product is not distilled or stripped, and therefore any low molecular weight materials produced in manufacture remain in the fluid as delivered. In addition, the Union Carbide specification permits up to 3000 ppm of water in the product, and a typical water content is 1500 to 2000 ppm.

Experimental Procedure for Measuring Oil Vapor Concentration
The apparatus consists of a source of ultra zero compressed air, a heated oil reservoir, an adsorbent cartridge housing with bypass, a flowmeter, and a Beckman Model 400 hydrocarbon analyzer (see Fig. 2). All lines are kept at constant temperature with heating tapes. The system is first flushed with ultra zero air, and the hydrocarbon analyzer is calibrated at the test flow rate of 2.5 liters per minute. About 25 grams of oil is then added to the reservoir and heated to the test temperature. Ultra zero air is then passed across the surface of the hot oil, through the bypass line, to the analyzer. To test the efficiency of an adsorbent, the procedure is repeated with the adsorbent cartridge installed and the air passing through the filter holder rather than the bypass.

Measured Volatile Hydrocarbons in the Lubricants
Figures 3 and 4 show the concentration of hydrocarbon vapors generated by the LB oils in ultra zero air at two different temperatures, expressed as ppm of methane by weight in air. By summing the area under the higher temperature curve for LB-170X, Parker estimates that our sample of LB-170X contained initially about 600 ppm of volatile organics by weight of oil. As noted above, the oil as received probably will contain an additional 1500 to 2000 ppm of water (which was not measured in our tests).

Since the test apparatus is not intended as an efficient stripper of volatiles, it can be assumed that any reasonably

<table>
<thead>
<tr>
<th>Stage</th>
<th>Filter Grade</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>DX (93% efficiency at 0.01 micron)</td>
<td>Medium efficiency, fast draining coalescer</td>
</tr>
<tr>
<td>2nd</td>
<td>BX (99.99% efficiency at 0.01 micron)</td>
<td>High efficiency, slow</td>
</tr>
<tr>
<td>3rd</td>
<td>BX (99.99% efficiency at 0.01 micron)</td>
<td>Draining coalescer</td>
</tr>
</tbody>
</table>

2.) Maximum Allowable Linear Flow Rate
Flow through second and third stages should not exceed 15 ACFM per 2 inch diameter x 18 3/4 inch long filter tube.
efficient method of pre-treating the oil by the user will produce, at worse, the same percentage removal of volatiles as the test apparatus. The desorption curve for LB-170X at 200°F (see Fig. 3) shows that approximately 90% of the organic volatiles can be removed easily, since the first 60 minutes accounts for about 90% of the area under the desorption curve.

The remaining 10% of volatiles in the oil evolved at a much slower rate, as is evident from the curve. If we assume that user pretreatment will remove that fraction of the volatiles in the oil which is readily desorbed, then pretreatment will reduce the volatile hydrocarbon content by 90%, from 600 ppm to 60 ppm by weight in the oil as received. Union Carbide believes that it is unlikely that additional volatiles would be generated by chemical degradation in helium compression service. Benefits of adsorption do not warrant undertaking the possible problems.

**CONCLUSIONS**

1) Liquid oil contamination in helium gas can be well below 0.1 ppm by a properly designed multiple coalescing filter system containing graded efficiency elements.
2) The oil vapor problem is best attacked by efficiently treating the oil to remove most of the volatiles before charging the compressor.