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NOTES ON HELIUM LEAK-DETECTION PRACTICE FOR HRT

INTRODUCTION

The following discussion is intended as a guide to the equipment and methods usable for leak-testing HRT components and the assembled plant. The discussion is necessarily brief; it is not expected that it will adequately answer all questions arising during operation. To a great extent, Helium leak detection is an art, and can be most successfully learned in actual practice. However, a knowledge of the mechanism and limitations involved will aid the operator's judgment in utilizing his equipment with maximum speed and effectiveness.

VACUUM EQUIPMENT AND TECHNIQUES

Mechanical Pumps

Mechanical vacuum pumps vary in internal detail but most use a positive-displacement principle in which the air is removed by a vane or cam sweeping along the inner periphery of a machined cylinder. Flapper or poppet valves are used for the exhaust seals, and internal sealing is accomplished by an oil film between the moving parts. For testing large components at the HRT, the mechanical pumps most used will be Kinney Model DVD-8810, single-stage pumps, rated at 110 cfm. free air displacement (atm.), with a nominal limiting pressure of 5 microns absolute. The balance of this section will deal with this type of pump.

The heart of all Kinney pumps consists of a wide cam with a keyhole-shaped cross-section (see Fig. 1) which is swept around the inner surface of a hollow cylindrical casing by an eccentric crankshaft. The rectangular extension is hollow, and this internal passage connects with the interior of the casing, forming the intake passage. Air is trapped between the cam and the casing, and swept out through the exhaust passage which is sealed with feather valves.

Fig. 1
Kinney
Mechanical
Pump

The DVD-8810 will operate satisfactorily on any good grade of non-emulsifying medium-weight turbine oil such as Gulf Harmony C. As with most mechanical vacuum pumps, operation is noisy and attended by considerable vibration and oil vapor exhaust when the pump inlet pressure is near atmospheric. As the inlet

pressure drops, however, the smoothness of operation improves and vapor emission will cease. To avoid creeping and transmission of excessive vibration to the vacuum piping, pumps should be well anchored, and if possible should be connected to the system by a flexible tube or bellows. Valves are provided in the bearing lubrication lines for controlling the oil flow. Initially the bearings should be well supplied with oil; however, as the suction pressure drops to around 0.1 mm Hg, the supply should be throttled (approximately 1/2 turn open) to attain maximum efficiency from the pump. Excess oil in the pump, by liberating dissolved gases into the pumping space, adversely affects the suction pressure attainable. When stopping the pump, the suction side should be vented if the pump is to be left off for more than a few minutes; otherwise, oil will seep into the pump cavity through the bearings. If in doubt, turning the pump over by hand one or two revolutions will purge it and prevent damage from the cam hammering against an oil slug. While most of the water which may condense in a mechanical pump can be drained from the oil reservoir, that which remains in suspension is sufficient to limit the attainable vacuum. For best results the oil should be replaced before pumping on a dry system.

Even large mechanical pumps require very little cooling. One-half gallon per minute should be adequate for the DVD-8810 in normal operation.

Diffusion Pumps

Diffusion pumps utilize either oil or mercury vapor to entrain gas molecules and sweep them by molecular collision from the inlet to the exhaust port of the pump (Fig. 2).

A heater section in the base of the pump boils the liquid, causing vapor to rise up the center chimney and spray downward through the nozzle toward the walls. Incoming gas molecules collide with this vapor jet and are driven toward the pump exhaust, from which they are swept away by a mechanical forepump. Since there are no check valves and no internal seal, except the curtain of vapor, a forepump is required to prevent the accumulation of gas molecules at the pump exhaust, which would soon stop the pumping action. Diffusion pumps require a pressure of 100 to 200 microns to be maintained at the discharge end, and care should be taken to provide a forepump with adequate capacity to assure this condition. Large sizes, such as those used in leak detection, use oil as the pumping medium. The ultimate vacuum which such a pump can produce depends on the vapor pressure of the cold oil thrown out above the nozzle. A commercial diffusion pump oil such as Narcoil-10 can produce an ultimate pressure of 0.02 microns.

Cooling

Cooling of large diffusion pumps is done by external coils through which water is circulated. These should cool the pump shell to a temperature near the pour point of the oil, if possible, where the vapor stream first impinges on the shell, and should maintain the lower portion of the shell at a low enough temperature to prevent the oil from reboiling before it gets to the heater section. Too much cooling will lower the boiling rate in the heater section, however, decreasing the pumping rate.

Precautions

To avoid decomposition of the hot oil by oxidation, the diffusion pump should not be turned on until it has been first evacuated with a mechanical pump. Likewise, before it is opened to atmospheric pressure after shutdown, the pump should be allowed to stand evacuated until cool enough to be touched with the hand.

Cold Traps

Vacuum cold traps are commonly made in the form of a long metal bulb enclosed in a cylindrical can. The inner bulb is open to the atmosphere at the top and is filled with liquid nitrogen or other refrigerating medium. The space between bulb and can is tied into the vacuum system so that the incoming stream impinges on the cold bulb. In removing condensible vapors, cold traps act like selective vacuum pumps for these vapors, and greatly increase the overall pumping rate during the early stages of evacuation when the moisture content is high. The main drawback to using a cold trap during preliminary evacuation is that the bulb may become heavily frosted. When this occurs, the frost surface may be well above the refrigerant temperature, and the limiting system pressure will be governed by the vapor pressure at the frost surface.

Pressure-Measuring Devices

McLeod Gauge

The McLeod gauge consists of a mercury reservoir connected to an arrangement of glass tubes, which is connected to the vacuum system. The gauge is so arranged that a measured amount of the air or gas in the vacuum system can be compressed into a blind capillary by a column of mercury when the gauge is inverted. The degree to which the calibrated mercury column will compress the gas volume is dependent on the gas pressure prior to compression, and this pressure can be read from a calibrated scale on the capillary. Its useful range is from about 1 mm Hg to 0.5 μ absolute.

The McLeod gauge has the advantage that for non-condensable gases, it will give a true pressure reading irrespective of the physical properties of the gas provided it obeys Boyle's law since the reading is a function only of the length and bore of the capillary and the height of the mercury column. While excellent as a laboratory standard, however, it is inconvenient for leak-detection work for several reasons: It does not give a continuous reading

and takes about 1 minute to come to equilibrium; it emits no measurable signal, so it cannot be read remotely; and it is fragile and subject to mercury contamination by air or water vapor. It should be connected to a vacuum system through a drying tube, to prevent moisture from entering the gauge or mercury being introduced into the system.

Thermocouple Gauge

The thermocouple gauge consists of an electric heater with a thermocouple attached, which is enclosed in a vacuum-tight container attached to the vacuum system. For pressures between approximately 1 mm. and 1 μ , the thermal conductivity of a gas mixture is proportional to the pressure, and the heat conducted away from the heater will vary accordingly and be detected by the thermocouple. The sensing unit is sealed into a small metal case resembling a radio tube and is attached to the system through a 1/8-in. threaded pipe socket. The electrical leads are connected to a measuring instrument which supplies a regulated power output to the heater and reads the thermocouple response directly in pressure units.

The thermocouple gauge is dependent upon the characteristics of the gas being measured; for example, a Helium atmosphere will give a pressure reading 40% higher than air under the same conditions. The gauges are normally calibrated for air. Each sensing element varies slightly in its output characteristics, and bears the proper heater input current marked on its case. The output is non-linear, with greatest sensitivity between 50 and 150 microns. For maximum accuracy, the element should be calibrated against a laboratory standard over its working range; however, for most leak-detection work a check at 1 micron is usually sufficient.

The usefulness of the thermocouple gauge derives from its small size, remote-reading characteristics, continuous indication, and the fact that it responds within a few seconds to pressure changes. The units are more rugged than a McLeod gauge, but should be handled as one would a metal-cased radio tube. At least two types of thermocouple elements are commercially available, and are not interchangeable due to differences in power requirements and pin connections. A General Electric element will work with either General Electric or Consolidated gauges; however, a Hastings gauge requires a Hastings element.

Ion Gauge

This instrument is commonly found on leak detectors and other vacuum equipment operating in the range of 1 to 0.0001 microns. There are several different types of ionization gauges but common to all are a means of ionizing the gas molecules, a means of accelerating the ions, and a means of collecting these ions. The number of ions collected is a function of the concentration of molecules present in the vicinity of the gauge, which is a measure of the pressure.

Because of the bulky and complex electrical circuitry associated with these gauges, they are built into permanent vacuum equipment. The elements can be easily contaminated by operation at pressures above 0.2 micron, and should not be energized for more than a few seconds above this pressure.

Vacuum Vessels and Piping

Joints and Valves

Vacuum system joints should be welded wherever possible. Soldered joints may be made vacuum-tight, with sufficient care, but are easily damaged in the smaller sizes. Where joints must be breakable, flanges using neoprene or resilient non-porous plastic O-rings are most satisfactory. Flat neoprene gaskets may also be used if expedient. Rubber is subject to outgassing, and should be avoided. Valves should be of the packless (metal diaphragm or bellows-sealed) type, preferably designed for vacuum service. Saunders type rubber diaphragm valves are difficult to open against vacuum, particularly in large sizes.

Piping

Piping should be of as large a diameter as possible to secure maximum pumping speed. At pressures approaching 1 micron, the characteristics of gas flow are no longer viscous; the flow rate becomes proportional to the cube of the diameter and inversely proportional to the pipe length. Aside from the added time required to evacuate a large system through small lines, another disadvantage arises: Helium leak detection is dependent upon the ability to recognize that a burst of Helium detected was admitted at the spot being blanketed externally at a known time. If the travel time for the inleaking gas to the detector becomes long, leak testing must proceed slowly to insure that the leak can be located. Where the entire system is of small volume but the lines are long (i.e., no intervening large reservoirs between pumps and leak) the problem is less serious. K-25 experience indicates that in lines on the order of 3/4-in. pipe, 50-ft. long, leaks can be picked up in roughly 30 sec. to 1 min.

Producing a Vacuum

The major obstacles in attaining the required vacuum for Helium leak detection are outgassing and vapor evolution in the system, and the leaks themselves, if these are large enough. Liquid water held in the system will boil at about 17 mm. Hg, at room temperature, and prevent a good vacuum from occurring until all the water vapor is removed. Oil, solvents, or other liquids will similarly evolve large volumes of vapor until exhausted. Air and gas molecules are readily adsorbed on the surface of most materials, particularly organics such as rubber, and prolonged outgassing from this source may result. However, such outgassing will commonly not interfere until the system pressure reaches the vicinity of 10-50 microns. Prolonged stationary pressures of 100 microns or more probably mean that large leaks into the system are present, or the gauges are reading incorrectly; usually the former.

Leaks in the external vacuum lines--i.e., that part of the assembly connecting the test system to the pumps--may be sealed with vacuum wax or Glyptal varnish. The Glyptal is more permanent, but will release solvent vapors into the system for 2-3 hours; also, in the case of leaks big enough to see with the naked eye, Glyptal will be sucked into the system before it can set firmly. A continuously reading vacuum gauge is valuable for finding large leaks as the improvement in vacuum can be directly observed when a leak is covered.

For leaks in the test system a step-by-step retightening of all joints should always be the first resort. If this fails, it is often possible to use the leak detector, as will be discussed later.

HELIUM LEAK DETECTION

Terminology

Leakage Units

To avoid the ambiguity which arises when speaking of volume inleakage at a variety of system pressures, leakage is usually expressed either in units of volume flow at a reference temperature and pressure, or in composite units such as micron cubic feet per hour (MCFH) or micron-cc. per second. A micron cubic foot per hour is the amount of inleakage which will increase the pressure in a volume of one cubic foot by one micron in an hour. This is equivalent to $\frac{1}{760000} \text{ ft}^3$ per hour at normal temperature and pressure, or 0.89 cc/day (NTP).

The leakage specification which has been set up for HRT process equipment is 0.1 cc/day (NTP) of Helium for any one component, or 1.0 cc/day for the complete fuel and blanket system.

Helium Leak Detector

Principles

The Helium Leak Detector is essentially a mass spectrograph, adjusted to sense the presence of Helium ions in a gas stream. A sample of the gas is drawn into the machine by a small vacuum system, and ionized by a stream of electrons. The ions are then accelerated in an electric field and bent through a curved path by a magnetic field. The strengths of these fields are so adjusted that Helium ions will pass through a slit at the end of the path and hit a target, while heavier gas ions will be deflected. The detector system is so arranged that the Helium indication will vary directly with the concentration of the Helium present. A hundredfold range of sensitivity for the instrument is permitted by means of a range selector switch. The maximum sensitivity of the average commercial model is about 1 part of Helium in 200000 parts of air, while special models may detect a tenth of this quantity.

Operation

Shown below is a schematic diagram for the Consolidated Model 24-101A Leak Detector, the type used for HRT work:

1. Flanged connection to vacuum system or probe
2. Throttle Valve
3. Cold Trap
4. Ion Gauge
5. Helium Detector
6. Pump Shutoff Valve
7. Diffusion Pump
8. Ballast Space
9. Mechanical Pump

Operation of the leak detector is subject to the same precautions listed above for vacuum pumps and the ion gauge. A set of instructions for startup and shutdown of the unit is attached to the top of the case. Since the filament of the leak detector tube is easily damaged by operation at pressures above 0.15 micron, a relay is provided in the machine which automatically shuts off the filament power if the pressure is above this value.

Two general methods of leak detection are commonly employed, depending upon the characteristics of the system under test. Depending upon the characteristics of the system, one method or the other may be more effective:

Evacuation Method

This method employs a vacuum pumping system to evacuate the unit under test, and the leak detector is connected into the evacuation line.* The method can be used for large, spread-out systems where moving the leak detector around for probing would be inconvenient or impossible. It is also a fast production method for small vessels, where the entire outside surface can be blanketed with a Helium-filled envelope.

The difficulties associated with this method are principally those associated with obtaining the required vacuum, and the response time required for detecting leakage in widely spread-out systems. Wherever possible, a small portion of the system at a time should be isolated and tested.

Sensitivity

During preliminary checking for gross leakage, the pressure in the system is often not low enough to permit leak-detector operation with the connecting line fully open. By throttling the input to the machine, however, the pressure in the leak detector can be brought low enough to permit it to operate. The throttling will reduce the fraction of the evacuation stream sampled by the machine; however, the quantity of Helium which will enter through a leak large enough to affect the system pressure will be sufficient to give an indication on the detector.

From the above remarks it will be seen that any means of increasing the fraction of gas sampled by the detector will increase the sensitivity of the arrangement. For large single vessels, or for small complex systems of a few liters capacity, the leak detector alone can be used to maintain the vacuum. While this method insures 100% sampling, thus providing maximum sensitivity,

*The suspected points in the system are then blanketed externally with Helium. The Helium will penetrate any leaks to the interior and be drawn into the detector where its presence is indicated. Under ideal conditions, leaks can be pinpointed within less than an inch.

the rate of evacuation by this means is on the order of 1 cfm. or less at 1 micron. Consequently, the size and complexity of a system where this applies is limited by the length of response time which can be tolerated.

Another means of increasing the fraction sampled involves connecting the leak detector to the space between the diffusion and mechanical pumps, where the pressure is higher than in the region ahead of the diffusion pump. This method is useful when the forepressure is around 20 to 50 microns; at higher pressures, it is necessary to throttle the leak detector, thus defeating the purpose.

If the pump shutoff valve (not the throttling valve) on the leak detector is partially closed, the pressure in the detector space will increase, and the leakage indication will also increase. If the test system is well-evacuated, i.e., around 1 micron, the leak detector pressure may be as low as 0.01 micron. Throttling the pump shutoff valve to bring the detector space pressure to 0.1 micron will affect the sampling rate very little, since the flow to the leak detector is a function of the mean pressure in the sampling line. The leak indication would increase tenfold, however. Obviously, if the shutoff valve is fully closed, the pressure in the machine will eventually build up to system pressure, shutting off the filament. The pumping action of the cold trap will usually be sufficient to prevent this, however, if the valve is opened intermittently and the trap is kept filled with refrigerant.

Calibrated Leaks

To check the leak response time of a system under test, Helium is introduced at a remote point in the system through a calibrated leak, preferably of a size approximating the maximum permissible leak for the system. Such a device is also used as a comparison standard to determine the size of existing leaks, and to check the sensitivity of the leak detector.

Calibrated leaks are of two types: One consists of a glass bulb containing Helium at atmospheric pressure, which diffuses through the plug at a known rate. The rate of gas escape is slow enough so that the leak rate varies only a few percent per year. Such a leak is compact but fragile, and must be installed with a tee in the connecting line so that the volume between the system valve and the leakage plug can be evacuated before the leak is opened to the system.

The other type consists of a copper capillary tube about two feet long, rolled flat and coiled inside a metal casing which is then sealed with solder, except for the ends of the capillary. This type may be connected directly to the system and can be capped at its outer end. In use, the cap is removed and the open end surrounded with a blanket of 100% Helium at atmospheric pressure. A common method is to connect the leak with a short length of hose to a flask into which helium is flowing, with a vent to atmosphere to prevent pressure buildup in the flask.

Probe Method

This method of leak detection requires no vacuum system except that in the leak detector itself. The system under test is filled with Helium, preferably under pressure, and the external surface is inspected with a probe consisting

of a slender nozzle with a very fine needle valve, connected by flexible tubing to the leak detector. This method is very useful for vessels which cannot be satisfactorily evacuated, such as those containing highly adsorptive material, or having thin walls not braced for vacuum service. It is also convenient for units of a few liters capacity with a limited number of leak possibilities, and for long, small-bore lines. The probing speed should be on the order of 2-3 feet per minute, and drafts must be avoided. Large leaks will quickly contaminate the atmosphere around the test assembly, and prevent further probing. The presence of water, oil, etc., inside the vessel will prevent or reduce the leakage, depending on the Helium pressure used, so that care should be taken to make the vessel clean and dry before testing. The hose connecting the probe to the leak detector should be 1/2-in. to 3/4-in. I.D., and not over 5 to 6 ft. long for good sensitivity.

Sensitivity

The sensitivity of the leak detector in the probe method, other things being equal, is directly proportional to the Helium concentration of the gas inside the vessel, and increases roughly as the 1.6 power of the pressure in atmospheres. Thus a high internal Helium pressure is advantageous for this method. A small piece of rubber hose slipped over the probe tip and projecting about 1/4-in. will hood the tip and increase the sensitivity approximately tenfold. Under ideal conditions, a hooded probe moving at 1 foot/minute is capable of just detecting a leak of 0.1 cc/day, with the vessel filled with 100% Helium at atmospheric pressure.

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