INTRODUCTION TO GAS REMOVAL SYSTEMS AND LIQUID RING VACUUM PUMPS

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ABSTRACT

Next to ejectors, Liquid-Ring Vacuum Pumps (LRVP) are the most used vacuum-producing devices in industry. Integration of Liquid-Ring Vacuum Pumps with Steam Jet Ejectors, commonly referred to as a hybrid system, is one of the more efficient methods of producing process vacuum. The LRVP is a specific form of rotary positive-displacement pump utilizing liquid as the principal element in gas compression.

The compression is performed by a ring of liquid formed as a result of the relative eccentricity between the pump's casing and a rotating multi-bladed impeller. The eccentricity results in near complete filling then partial emptying of each rotor chamber during every revolution. The filing-and-emptying action creates a piston action within each set of rotor of impeller blades.

The pump's components are positioned in such a manner as to admit gas when the rotor chamber is emptying the liquid, and then to allow the gas to discharge once compression is completed. Sealing areas between the inlet and discharge ports are provided, to close the rotor areas, and to separate the inlet and discharge flows.

Key Words: *Gas removal, NCG, non-condensable, liquid ring vacuum pump, ejector, condenser*

1. APPLICATIONS

Liquid-Ring Vacuum Pumps are used in the refining industry for crude oil vacuum distillation, evaporation, filtering, and drying, and in the power industry to evacuate steam surface condensers. Other industries that rely extensively on vacuum pumps are food, chemicals, pharmaceuticals, hospitals, and pulp and paper.

2. LIQUID-RING VACUUM PUMPS BENEFITS

- Reliable, simple design which involves only one rotating part, which is not subject to much wear
- Can handle condensable vapors or even slugs of liquid entrained in the gas stream without damage to pump or affecting pump performance
- Produces a steady non-pulsating gas flow when it is used as either a vacuum pump or compressor
- Resistant to contaminants entering with the gas stream – these will be diluted and washed through the pump by the seal liquid

3. ADVANTAGES

Hybrid systems, made up of ejectors, condensers, and vacuum pumps, offer several advantages. For instance, some or all of the condensate can be gravity-drained into the vacuum pump. To accomplish this, the condensers and ejectors are mounted above the vacuum pump, allowing all equipment to drain into the vacuum pump. The equipment can also be drained with a barometric leg to a hotwell.

Mechanical stresses, however, are placed on the pump by mounting equipment above it. To minimize this, all mounted equipment must be independently supported. Another thing to look out for is the ejector position. Ejectors with steam jackets must be oriented such that condensate will not accumulate in the jackets.

Another advantage of hybrid systems is packaging. Generally, components are skid-mounted such that the package is a complete system that includes valves, interconnecting piping, instrumentation, and utility connections. The package or skid is designed to allow for the transfer of the forces and moments to the foundation supports without misalignment of the packaged components.

However, before making any decisions about designing a new vacuum system or upgrading an existing installation, proper selection of equipment should be considered. Two topics that play key roles in this assessment are steam limitation and costs.

With the existing availability of steam in a plant, additional use of steam may be economically prohibitive. Therefore, use of steam ejectors may not be profitable. In this case, a viable alternative is to replace the last stage or stages of the ejector system with liquid-ring vacuum pumps to achieve design vacuum and conserve steam. If steam use constraints are not a factor, higher vacuum and capacity can be achieved by adding steam jet ejectors and condensers upstream of the existing system.

For all installations, costs – including initial capital, installation, operating, maintenance, and service costs – are important in determining correct equipment selection. For example, systems with all ejectors have low initial capital costs. However, evaluation based on utility costs may prove hybrid systems to be more attractive over time.

4. TROUBLESHOOTING LIQUID-RING VACUUM PUMPS

Like the proper installing of vacuum pumps, troubleshooting them is critical to their continued operation and maintenance. As a result, it is important that only qualified personnel, using proper equipment, be authorized to perform testing.

There are many factors that can influence the performance of a vacuum system. First, it is always good practice to inspect the equipment when it arrives on-site, and then to make sure that the equipment is properly installed, and that all valves and flow switches are in the correct direction as per the installation drawings. Verify that the pump rotates freely and in the proper direction, and that the system is properly primed before start-up. All these preliminary checks make troubleshooting of the system easier.

Malfunction of the system could be due to utility or process conditions, or both, or the equipment, and it is important to determine the cause. A malfunction due to external influences can be determined as follows:

1. The first step is to compare the original design conditions, especially gas composition and cooling water temperature, to the existing conditions. Any change in the design conditions and the gas composition may have an effect on the vacuum system. For example, an increase in the condensable load will raise the effective seal-liquid temperature and affect the vacuum system. A change in the condensable or non-condensable gas composition may affect the seal-liquid composition and the vacuum. High seal-liquid temperatures will also affect the vacuum level.

2. Make sure that there is no excessive air leakage. Air leakage can be determined by a drop test per Heat Exchange Institute Standards for Steam Jet Vacuum Systems.

3. Back-pressure on the system should be as per design conditions. Excessive back-pressure increases the brake horsepower, and may have an effect on the capacity of the vacuum pump.

If it is determined that the malfunction is not due to external influences, troubleshooting of the equipment can be made as follows:

1. Check the seal liquid's temperature rise across the pump. This should be as per design. Even if cooling water temperature and gas composition meet design standards, a reduced seal could be due to a plugged strainer or partially closed valve in the recirculation line. Also, check the recirculating pump's performance (if furnished) and the recirculating heat exchanger for any fouling. Any of these factors could have an effect on the performance of the vacuum system.

2. Check pump speed with a tachometer to make sure it meets design specifications. If the vacuum pump is V-belt driven, check the tension to ensure that the belts are not slipping.

3. Test the vacuum pump per the Heat Exchange Institute's Performance Standards for Liquid Ring Vacuum Pumps, and compare with the manufacturer's performance curve. Internal clearances may have to be readjusted to meet the performance curve.

A regular maintenance program is important even if the desired vacuum is achieved. The following items should be checked:

1. If the vacuum pump is furnished with packing, it is supposed to drip. However, excessive leaking of packaging is due to improper adjustment. The packing should be re-adjusted, and the dripping checked to provide proper cooling. Pumps furnished with mechanical seals should not leak. Make sure that the seals are flushed with clean liquid that is compatible with material used.

2. Check for excessive bearing temperatures. The normal temperature is around 140ºF. Higher temperatures could be due to misaligned couplings, excessive piping stress, over-greasing, or contaminated lubricant.

3. Check for excessive noise and vibration of the vacuum pump. This could be caused by coupling misalignment, high seal-water flow, high discharge pressure, an improperly anchored pump, bearing failure, water-filled casing during startup, or a lack of air flow to the vacuum pump.

4. Check the motor's amperage. A high amperage could be due to high discharge pressure, excessive seal-liquid flow, or motor malfunction.

5. Ensure that the operating service-liquid temperature at the pump inlet and the temperature rise across the pump meet the design limits. If the shaft packing is overheating, check the shaft seal cooling-liquid supply for clogged lines or filters, closed valves, obstructed drain lines, fouled recirculation heat exchanger, or improperly adjusted packing. High temperature may result from a clogged strainer, or partially closed valve. For noise or vibration in the pump, look for an excess of service-liquid flow.

6. Check for misadjusted or malfunctioning flow controls or valves.

If the pump floods prior to startup, look for leaking shutoff valves, closed drain valves, or clogged drain lines. Check startup procedures for the proper order of steps.

5. EJECTOR STAGE

The typical performance curve for an ejector shows suction pressure versus capacity, usually represented as Dry Air Equivalent (DAE). The DAE is an absolute unit that defines the performance capacity of any ejector stage. Having the curves plotted in this unit allows the analysis to be made with equipment from any ejector manufacturer.

Because geothermal loads consist primarily of carbon dioxide and water vapor, the DAE must be converted into an NCG flow specific to conditions at a given plant site.

The methodology described here is derived from the standards of the Heat Exchange Institute, the governing body for all steam ejector applications. Information contained in the Heat Exchange Institute standards is accepted universally for this type of equipment. Conversions, which are relatively simple, are based on the conversion curves included in the standards. These curves enable conversion of gas at any molecular weight and temperature to an equivalent amount of air at 70ºF, which represents the basis of the DAE unit.

The Heat Exchange Institute also provides the equation (Equation 7 on Page 63 of the standards) to calculate water vapor saturation from the condensers, using pressure and temperature measurements.

Dry Air Equivalent (DAE):

The DAE is an absolute unit that defines the performance capacity of any ejector stage. The DAE is the equivalent mass flow of 70°° F dry air and is the industry standard for ejector capacity rating. The Heat Exchange Institute has published curves whereby the appropriate correction factors for molecular weight and temperature can be found to convert any gas stream to its DAE rating. The DAE is typically represented in terms of the flow capacity on the performance curve for an ejector showing suction pressure versus flow capacity.

6. DETERMINING NC GAS LOAD FROM EJECTOR PERFORMANCE CURVE AND "HEI" GRAPHS

A summary of the analytical methodology and a sample calculation are outlined below. The sample calculation uses data from the Ejector Performance curve of the 30x30 1st of 3 stage jet, and Figures 15 and 16 from the HEI.

The methodology is as follows:

1. Using measured ejector suction pressure, determine total DAE (Dry Air Equivalent) Flow

2. Using NCG molecular weight and measured suction temperature, establish the following:

   - Temperature Correction Factor for NC Gas and Water Vapor mixture using Figure 15
   - Molecular Weight Correction Factors for using Figure 16
   - DAE equation as follows:

$$DAE = \frac{WNCG}{(T_{corr} \times MW_{corr,\,NCG})} + \frac{W_{WV}}{(T_{corr} \times MW_{corr,\,WV})}$$

   Where NCG=NC Gas, WV= Water Vapor, W=Flow Rate, MW=Molecular Weight, T_{corr} = Temperature correction factor, and MW_{corr}=Mol. Wt. Correction factor

3. Using water vapor saturation formula, determine Water Vapor Flow Rate as a function of NC Gas Flow.

$$W_{WV} = \frac{WNCG \times MWWV \times PWV}{(MW_{NCG} \times [P - P_{WV}])}$$

   Where P= Suction Pressure and P_{WV} = Vapor Pressure from steam tables

4. Plug the result from step 3 into DAE equation of step 2. Solve for NC Gas first and once NC Gas flow is known, using result form step 3 determines Water Vapor flow.

The sample calculations follow this same four-step procedure and a selected suction pressure of 100 mbar for this example. NC Gas Mol. Wt. of 41.0 and a gas suction temperature of 40° C is assumed for this example.

1. From Ejector Performance curve of 30x30 jet, at a suction pressure of 100 mbar we can read off the chart that

   DAE = 8,150 kg/hr

2. From Figure 15, T_{corr} = 0.992 for 40 ° C gas suction temperature
   From Figure 16, $MW_{corr,\,NCG}$ = 1.16 for a MW of 41 for NC Gas and $MW_{corr,\,WV}$ = 0.82 for a MW of 18 for water vapor

   DAE=8,150kg/hr and from the DAE equation:

$$DAE = 8{,}150 = \frac{WNCG}{(0.992 \times 1.16)} + \frac{WWV}{(0.992 \times 0.82)}$$

3. From steam tables for T=40 ° C, P_{WV} = 7.375 kPa or 73.75 mbara

   From the water vapor saturation formula:

$$W_{WV} = \frac{WNCG \times 18 \times 73.75\ \text{mbara}}{(41 \times [100\text{mbara} - 73.75\ \text{mbara}])}$$

   Simplifying, we get W_{WV} = 1.233 x W_{NCG}

4. Plugging this into the DAE equation from step 2, above:

$$8{,}150 = \frac{WNCG}{(0.992 \times 1.16)} + \frac{1.233 \times WNCG}{(0.992 \times 0.82)}$$

   Solving this we get **W_{NCG} = 3,416.7 kg/hr**

   Knowing W_{NCG} = 3,416.7 kg/hr and plugging this into the simplified equation of step 3,

   W_{WV} = 4,214.3 kg/hr