VacAdemics

Issue 1

Applying Vacuum Technology

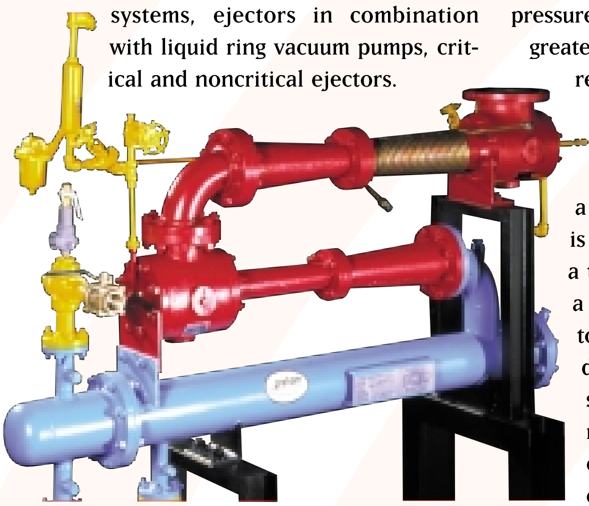
Fitting the Right Vacuum Equipment Into Your Plans

Engineering the right answer requires a full understanding of the options

Selecting the right technology is vital to achieving an efficient, productive process. There are many types of vacuum equipment available — ejector systems, liquid ring vacuum pumps, dry vacuum pumps and vacuum process condensers. These systems are not interchangeable as each type of service has different requirements. Characteristics, such as capital costs, utilities, environmental impact, installation and maintenance, must be considered. All options must be understood to choose the correct piece of equipment.

Ejector Systems

The simplest design and largest capacity vacuum producer is an ejector. There are single-stage ejectors, multistage noncondensing ejectors, ejectors with condensers, ejectors that use steam as the motive fluid, organic motivated ejector systems, ejectors in combination with liquid ring vacuum pumps, critical and noncritical ejectors.



An ejector produces vacuum by expanding high-pressure motive fluid across a converging/diverging nozzle, which converts pressure energy to high velocity. High-velocity motive then mixes and entrains the process gas in a mixing chamber. This mixed gas stream is subjected to a converging/diverging diffuser, which sets up a shock wave for a critical flow ejector, and the velocity energy is converted back to pressure energy. Because compression has occurred, the resultant absolute (discharge) pressure is higher than the pressure at the inlet. Critical flow occurs when the compression ratio (discharge pressure divided by suction pressure) is approximately 2:1 or greater.

An ejector system is normally set up to maintain a certain vacuum condition while discharging noncondensable gases to a pressure that is at atmospheric pressure or greater. The number of ejector stages required depends primarily on the vacuum conditions that must be maintained. Roughly, operating pressures of 150 torr and above is a single-stage system, 20 to 150 torr is a two-stage system, 5 to 20 torr is a three-stage system, 0.5 to 5 torr is a four-stage system, and below 0.5 torr is a five-stage system. Condensers are used between ejector stages to condense process and motive fluid vapors. This improves ejector systems operating efficiency by condensing vapors that no longer must be handled by a downstream ejector.

The ejector can use various motive fluids, but steam is the most common. Other types of motive fluids include, but are not limited to, ethylene glycol, methanol, cyclohexane, monochlorobenzene and phenol. By using a compatible motive fluid, the amount of contamination is minimized and/or the potential for product buildup inside an ejector is reduced.

The ejector should be used when the process load contains condensable and/or corrosive vapors, very low absolute pressures are desirable or the capacity required is very large. Ejectors also work well as boosters, in combination with a liquid ring pump.

Ejector System Advantages

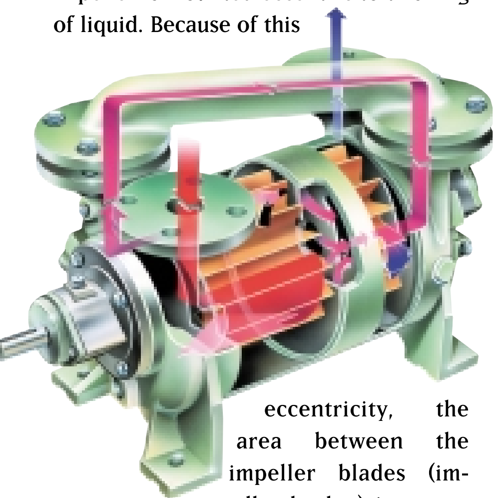
- ✔ Simple design, no moving parts and practically no wear
- ✔ Flexible mounting orientation
- ✔ Can be manufactured in any metal and various types of plastic
- ✔ Lowest capital cost
- ✔ Has the largest capacity of any vacuum-producing device
- ✔ No special startup or shutdown procedures required
- ✔ Can handle condensable loads
- ✔ Easy repair and maintenance
- ✔ Operating pressures down to 5 microns HgA

Other Considerations

- ✔ Requires a pressurized motive source
- ✔ Process gas may contaminate motive fluid
- ✔ May require discharge silencers or noise insulation
- ✔ Normally requires a cooling liquid source to condense vapors and motive fluid
- ✔ Motive fluid may back-stream into the process

Liquid Ring Vacuum Pumps

Liquid ring vacuum pumps use a sealant fluid to form a ring of liquid that is concentric with the casing. The liquid ring is formed by the centrifugal force caused by a rotating impeller. A multibladed impeller is mounted eccentric to this ring of liquid. Because of this



eccentricity, the area between the impeller blades (impeller bucket) increases in size at the inlet area and draws gas in. As the impeller blades rotate toward the discharge, the area decreases in size and the gas is compressed. The liquid ring also seals the clearances inside the pump and absorbs the heat generated by compression, friction and condensation.

Liquid ring pumps are available in single- or two-stage configurations. A single-stage pump efficiently operates at 100 torr or higher. A two-stage pump applies when the operating pressure is below 50 torr.

The lowest operating pressure for a liquid ring pump is a function of sealant fluid vapor pressure. For example, the lowest pressure with ethylene glycol as the seal fluid is 2 to 4 torr, but with water at 80°F it is approximately 30 torr.

There are three typical arrangements for liquid ring pump systems — a once-through sealant, partial and total sealant recirculation. The complexity and expense of the system increases as seal recirculation reduces sealant fluid contamination.

The liquid ring pump can use many different types of sealant fluids, such as ethylene glycol, oil, solvents, etc. If the process gas is compatible with the sealant fluid, then sealant fluid contamination is minimized and solvent recovery is possible.

The liquid ring pump should be used when the process load contains condensable vapors, if liquid carryover is possible or if cool running operation is required due to flammable or temperature-sensitive mixtures.

Liquid ring pumps may be constructed of numerous materials. Materials for the vacuum pump should be specified to include casing, impeller, shaft, seals (double, single or packed) and allowable seal elastomer materials. Some common materials used in liquid ring pumps are cast iron, cast carbon steel, bronze, titanium, Hastelloy (B/C), Alloy 20, 316SS, 317SS, Monel, Ni-Resist and nickel-aluminum-bronze.

Liquid Ring Vacuum Pump System Advantages

- ✔ **Simple design with only one rotating assembly**
- ✔ **Can be manufactured in any metal that can be cast**
- ✔ **Very low noise and vibration**
- ✔ **Very little increase in temperature of discharge gas, "cool running"**
- ✔ **Can handle condensable loads**
- ✔ **Liquid in the suction will not damage the pump**
- ✔ **Can handle small particulates without damage**
- ✔ **Easy maintenance, easy to re-build**
- ✔ **Slow speeds of 1,800 rpm or less for maximum life**
- ✔ **Can be started and stopped repeatedly**
- ✔ **Can use any type of liquid for the sealant fluid**

Other Considerations

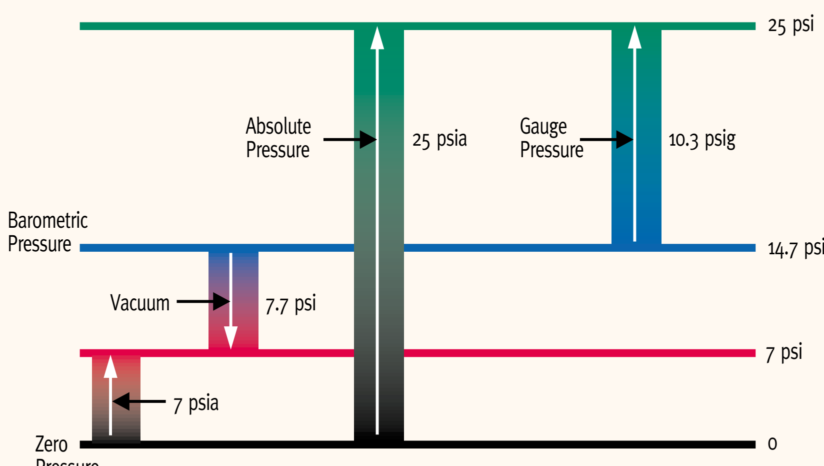
- ✔ **Process gas may contaminate sealant fluid**
- ✔ **Cavitation can occur; requires a noncondensable load**
- ✔ **Most of the operating hp is used to form the liquid ring, resulting in large motors**
- ✔ **Operating pressure depends upon sealant fluid's vapor pressure**

Required Basic Design Information for Liquid Ring Vacuum Pumps

1. **Operating pressure**
2. **Discharge pressure**
3. **Mass flowrate of each component***
4. **Molecular weight of components**
5. **Sealant fluid and properties**
6. **Cooling fluid information:**
   Type
   Temperature
7. **Power supply**
8. **Materials of construction**
9. **System type:**
   Once-through
   Total recirculation

** Or acfm at inlet pressure and temperature*

Useful Tools for Stating Vacuum and Pressure

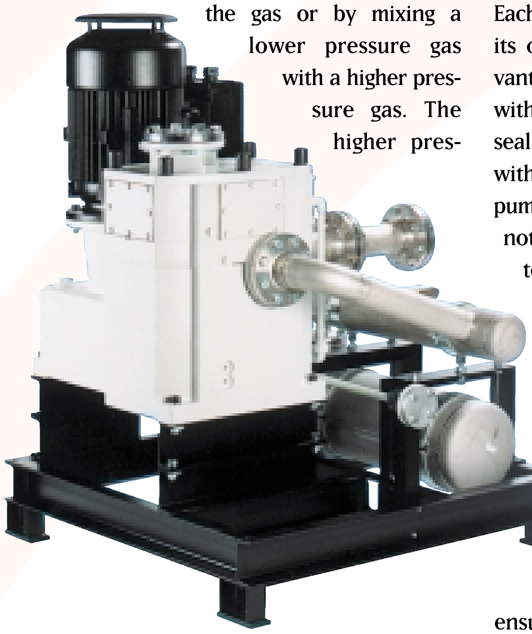


Common units of measure for pressure

1.0 psia = 2.03666 inches HgA = 51.7144 mmHgA = 6.8947 kPaA = 0.068947 barA = 0.0703 ATA = 2.3135 feet H_2O = 0.0703 Kg/cm2A

Dry Vacuum Pumps

Dry vacuum pumps do not require a working fluid, such as motive, service liquid or oil, to produce vacuum. These pumps can pull from a vacuum level in the micron range while discharging to atmospheric pressure. Dry pumps create vacuum one of two ways: through mechanical compression where a volumetric reduction takes place within the pump raising the pressure of the gas or by mixing a lower pressure gas with a higher pressure gas. The higher pressure gas is usually discharged process gas that is cooled and then reintroduced into the pump. Some pumps available use a combination of each mechanism.



Heat is produced during the compression cycle. In a liquid ring vacuum pump most of the heat generated by compression is absorbed by the service liquid. In a dry pump the service liquid is not present and the process gases must absorb this energy. As a result, dry pumps run relatively hot compared to other types of mechanical pumps. In general, dry pumps may operate at temperatures from 250 to 600°F (120 to 315°C) and the actual temperature will depend on the type of dry pump.

There are three basic types of dry pumps available today — the lobe type, the screw type and the hook-and-claw type pump. Each manufacturer or pump model offers its own distinctive advantages and disadvantages. Some pumps are available only with a lip seal, others have a mechancial seal, and others may utilize a labyrinth seal with a nitrogen purge. Some of these pumps are difficult to disassemble and cannot be disassembled in the field for maintenance or cleaning.

Because dry pumps run relatively hot they have a greater propensity for interior product buildup. There is no service liquid to help carry product buildup out of the vacuum pump. Because of the many different types of pumps available, as well as the wide range of differences between the units, great care should be taken to ensure the correct system is used for a specific application.

Dry pumps should be used when steam, water, or the working fluids contamination must be avoided, when solvent recovery is the main objective or when lower emissions are required. Employing a dry pump on a corrosive process also may yield a significant cost savings. If the process will have liquid carryover, then special precautions are required.

Important concepts about vacuum and pressure measurements:

- ✔ **Barometric pressure – The local atmospheric pressure.**
- ✔ **Absolute pressure – The pressure when measured from absolute zero.**
- ✔ **Gauge pressure – Absolute pressure minus barometric pressure or the pressure above barometric pressure.**
- ✔ **Vacuum – Barometric pressure minus absolute pressure or the pressure below barometric pressure.**

Dry Vacuum Pump Advantages

- ✔ **Dry running, no process gas contamination**
- ✔ **Can be used in multipurpose applications, as there is no cross contamination**
- ✔ **Solvent/product recovery is possible**
- ✔ **Pumps normally run hot, preventing condensation; standard cast iron can be used as corrosion normally occurs in the presence of moisture**
- ✔ **Cleaner running processes**

Other Considerations

- ✔ **Cannot handle particulates, especially if they are abrasive**
- ✔ **Cannot handle large slugs of liquid**
- ✔ **A silencer may be required**
- ✔ **Discharge gas temperature may be hot**
- ✔ **The Graham DRYFLO™ pump can be repaired on site in a matter of hours**
- ✔ **Some types require a gas purge for cooling or to protect the bearings and seals from the process**
- ✔ **Limited choice of materials of construction**
- ✔ **Polymerization of substances can occur due to high operating temperatures**

Required Basic Design Information for Dry Vacuum Pumps

1. **Operating pressure and temperature**
2. **Discharge pressure**
3. **Mass flowrate of each component***
4. **Molecular weight of components**
5. **Gas autoignition temperature**
6. **Possibility for polymerization**
7. **Process temperature limit**
8. **Cooling fluid information:**
   Type
   Temperature
9. **Possibility for liquid carryover**
10. **Power supply**
11. **Materials of construction**

** Or acfm at inlet pressure and temperature*

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Vacuum Process Condensers

According to *Process Vacuum System Design and Operation*,[1] "A vacuum condenser is the most energy-efficient, cost-effective vacuum pump ever developed." A vacuum process condenser is positioned between a process vacuum vessel and a vacuum system. Its main purpose is to reclaim fluids as condensate before they enter the vacuum system. That reduces the capital and operational cost of the vacuum system, reduces waste treatment cost and recovers valuable product for re-use.

A vacuum process condenser can be direct contact or surface type. Direct contact is when a cooling fluid directly contacts the process vapors to be condensed. Surface type, normally shell-and-tube, has condensation occurring on a heat transfer surface that separates the process vapors and condensate from the cooling fluid. Shell-and-tube type units may have condensation in the tubes or on the outer tube surfaces. Although referred to as the shell-and-tube type, they are by no means a typical process heat exchanger. Thermal and hydraulic design is complicated, and commercially available software does not accurately model pressure drop when operating pressure is below 40 torr.

A vacuum system, such as an ejector system, liquid ring pump or dry pump, must back up a vacuum process condenser to remove noncondensable gases. It is important to integrate a process vacuum condenser into the vacuum system design as they operate in unison. A properly optimized process sets up the vacuum condenser and vacuum system as a complete unit, ensuring maximum recovery of product, minimum utility consumption, limited pressure drop and minimal capital cost.

Required Basic Design Information

1. **Operating pressure and temperature**
2. **Discharge pressure**
3. **Cooling fluid type and temperature**
4. **Mass flowrate of each component in the process load and properties**
5. **Molecular weight of each component in the load**
6. **Fouling factor**
7. **Type of condenser (fixed tubesheet, U-tube, removable bundle style)**
8. **Materials of construction**

Reference

1. Ryans, J., and Roper, D., ***Process Vacuum System Design and Operation***, McGraw-Hill, 1986.

Summary

When evaluating a new process or potential revamping strategies, assess the vacuum equipment options. Consulting with vendors that have complete vacuum equipment product lines allows for a thorough analysis. There may be more than one technical answer for a given process requirement, but there is only one engineering answer that is completely optimized and factors in all relevent aspects important to your process. Be certain to assess the options based on:

✔ Operating cost ✔ Maintenance cost ✔ Cleanability ✔ Serviceability ✔ Solvent recovery ✔ Effect on process ✔ Handling of upsets ✔ Purchase price ✔ Materials of construction ✔ Waste generation ✔ Pollution abatement ✔ Emission reduction ✔ Operating range

This is the first in a series of six educational newsletters on vacuum equipment. Watch for the next issue of VacAdemics in March.

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