VacAdemics
Issue 2
Applying Vacuum Technology

# Pressure Control for Your Process

## Engineering the right answer requires a full understanding of the options

***The pressure of a process that operates under vacuum will vary if the vacuum system is left unrestrained. All processes do not require pressure control. In certain cases, the higher the vacuum, the better the process runs. In most cases, however, pressure control is necessary to satisfy process requirements or to avoid performance problems. A number of variables should be considered when defining pressure control options for your vacuum system. The type of control may vary based on the type of vacuum equipment. Applying the right technology to a process is important. Understanding the options is key to choosing the right technology.***

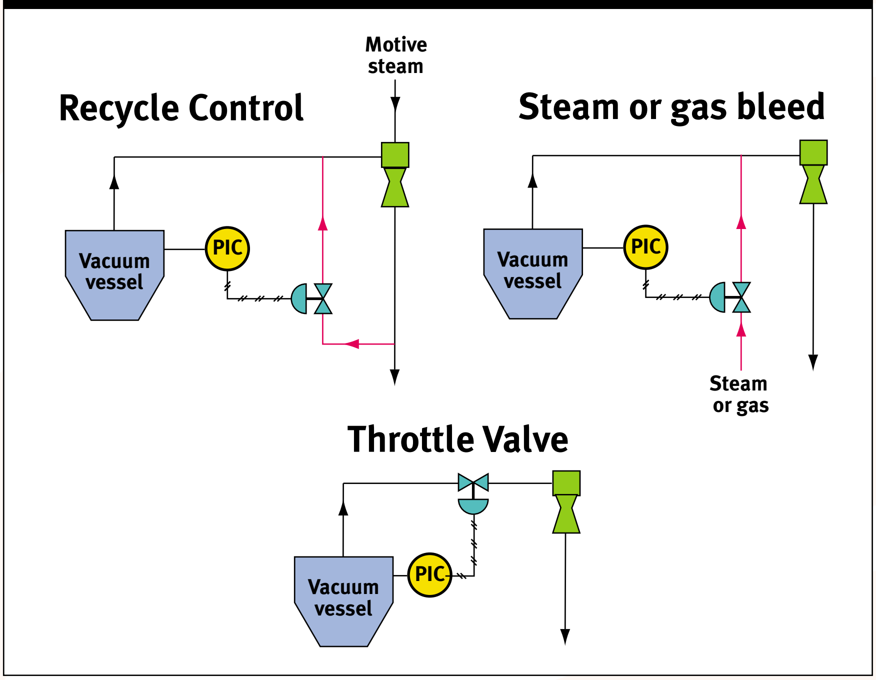
## Ejector Systems

The simplest ejector system is a single-stage ejector that maintains vacuum on its suction side and discharges to atmosphere. The ejector will have a performance curve to describe the suction pressure maintained by the ejector as a function of mass flowrate. The pressure maintained by the ejector will be lower when the mass flowrate is less than design capacity and higher when the flowrate is greater than design capacity.

If it is not desirable to operate at lower pressures when loading from the process vessel is below design capacity, then some form of pressure control is required. According to *Process Vacuum System Design and Operation,*[1] there are three different options for pressure control — a throttling valve between the vacuum vessel and ejector, introducing an artificial load into the suction line to the ejector and using a recycle control.

When using a throttling valve between the vacuum vessel and the ejector, the valve is a restriction between the two pieces of equipment. It creates a pressure drop between the two, thereby allowing the process to operate at a set pressure while the ejector suction pressure varies based on loading. Valve selection is critical if this type of control is to be practical because at low operating pressure slight changes in valve position may have a large effect on pressure drop.

### Single-Stage Ejector Control Options




Another means to control pressure when process loading is below design is to introduce an artificial load into the suction line to the ejector. The artificial load can be air, nitrogen, steam or some other gas. Any of these are appropriate for a single-stage ejector. If there is a condenser downstream from the ejector, confirm the condenser will operate with the selected artificial load before beginning.

The third technique to control system pressure is to use a recycle control. Recycle control is when a portion of the ejector discharge flow is recycled to the suction of the ejector. The recycled stream acts as an artificial load, providing additional loading needed to maintain suction pressure at the design capacity level. No additional flow is added to the system, process gas/vapor already in the system is re-used.

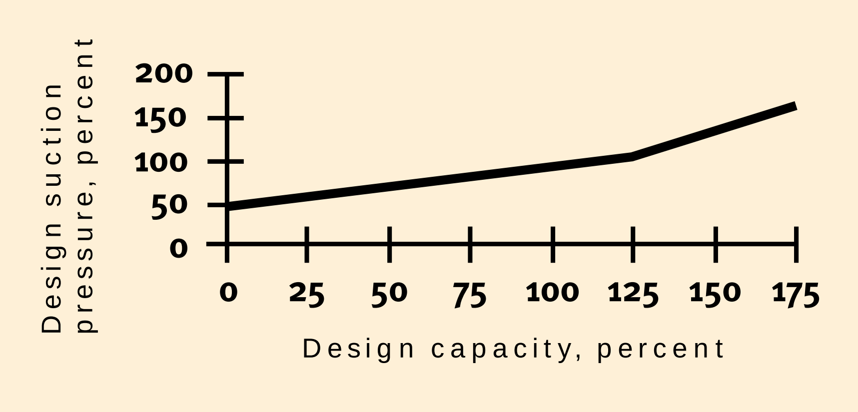
If using a multiple-stage ejector system

*continued from page 1*

with intercondensers, and pressure control is required when operating below design loading capacity, then the control options are limited. The most reliable technique is recycle control, but that recycle should be from the discharge of an ejector preceding the first intercondenser. Configuring the recycle in this way will ensure the recycle stream has a mole fraction of noncondensable gases that is less than the mole fraction of noncondensable gases in the design suction load. This is a critical consideration because if the recycle stream is rich in noncondensable gases and has a mole fraction of noncondensable gases greater than the process loading mole fraction of noncondensable gases, then the downstream ejectors may become overloaded, resulting in unstable operation.

Many times the first thought is to recycle the discharge of the last stage ejector to the suction of the first stage. When that is done the recycle valve and line are smaller and less costly. From an operations perspective, however, the discharge of the last stage ejector in a multiple-stage condensing ejector system may have a higher mole fraction of noncondensable gases than the normal process load. If that is the case, the recycle stream must be evaluated to ensure it does not cause an overload.

Typical Single-Ejector Performance Curve




When using recycle control, the operating pressure of the intercondenser may vary with cooling water flowrate and temperature. For example, the design operating pressure of the first intercondenser could be 80 torr during summer months when the cooling water is 90°F. During the winter, when cooling water is 60°F, that condenser may run at 65 torr. The recycle valve and line size must take these fluctuations into consideration to ensure recycle control is designed properly.

## Dry Vacuum Pumps

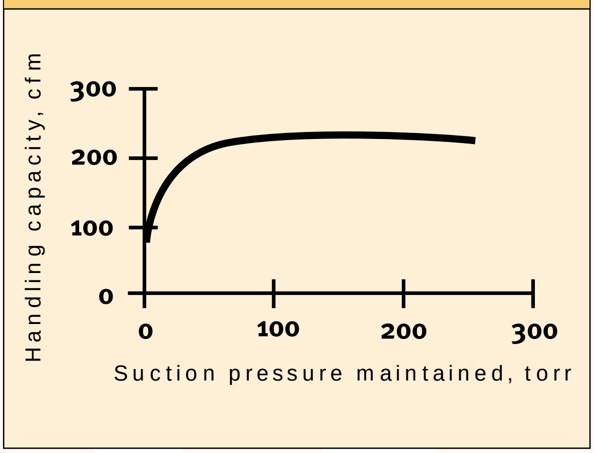
Dry vacuum pumps are similar to liquid ring pumps or ejectors in terms of the techniques that can be used to control operating pressure when operating below design capacity. The most reliable method is an inert gas bleed. A throttling valve can be difficult when operating in the typical range for dry pumps — 30 torr or below. Controlling operating pressure closely with a throttling valve is virtually impossible without a properly selected valve due to a low allowance for pressure drop across the valve.

A variable-frequency drive may be used, but there are considerations to bear in mind. As with a liquid ring pump, a variable-frequency drive slows a dry pump when operating below design capacity. That keeps suction pressure constant, but could cause a problem in the pump.

A slower running dry pump will result in cooler operating temperatures and that can lead to condensation within the pump. Dry vacuum pumps are intended to run relatively hot to keep process load in the vapor phase and to avoid condensation, which can cause corrosion. Also, the condensate may cause damage in dry vacuum pumps that use a mechanical compression. The liquid is incompressible and pump damage may occur.

The use of recycled gas from the discharge of a dry vacuum pump is possible. However, that discharge gas from a dry vacuum pump is relatively hot and a heat exchanger must be used to cool the gas before it may be used as additional load to the pump. Graham's DRYFLO type ALLex RGC has a recycle gas-cooled design that does permit the use of recycle gases for pressure control.

Dry Vacuum Pump Performance Curve

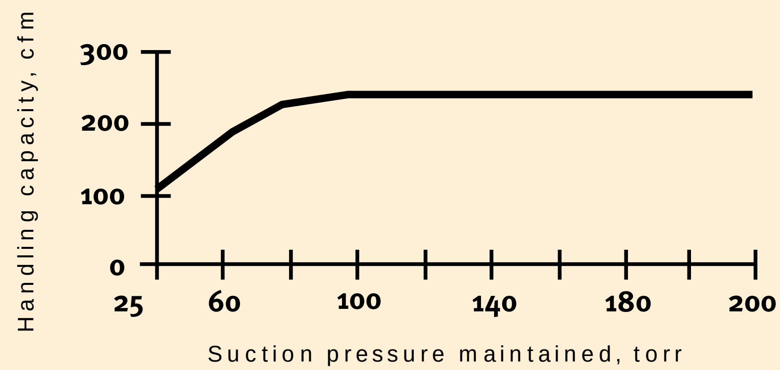


## Liquid Ring Vacuum Pumps

A liquid ring vacuum pump is similar to an ejector — it has a performance curve that describes pressure maintained by the pump as a function of loading. At loading below design capacity, a liquid ring pump will maintain a lower pressure and, conversely, above design loading capacity it maintains a higher pressure. An important point is that even if the process does not require pressure control, control may be needed to ensure reliable pump operation. If a vacuum pump is operating at no load, then the pump will pull down to a pressure that approximates the seal fluid vapor pressure. When that occurs there is the possibility of cavitation, which may cause pump failure.

Installing a bleed line from the discharge separator to connections on the pump casing may help avoid possible cavitation under no-load conditions. This lets noncondensable gases into the pump, which reduces the possibility of cavitation.

Liquid Ring Pump Performance Curve



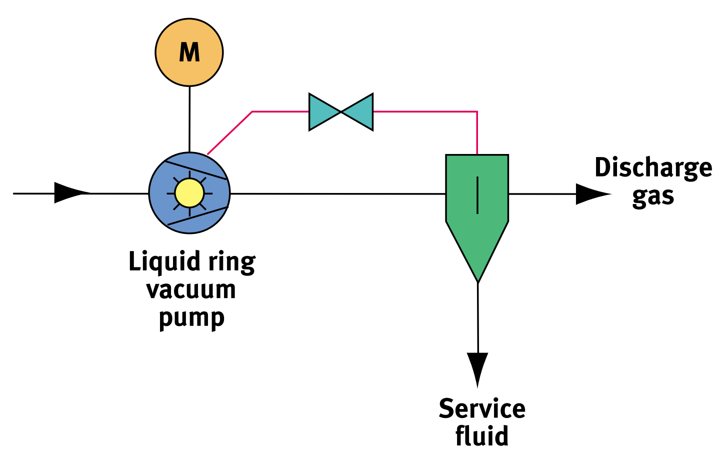

Options for pressure control are similar to those for ejectors. A throttling valve may be used between the vacuum vessel and pump. Again, the valve is a restriction in the line that induces a pressure drop. The pressure vessel operates at a constant pressure, while the liquid ring pump is at a lower pressure. The throttle valve is the barrier between the two pieces of equipment that allows each to operate at a different pressure.

Another possibility is an artificial load to the suction of the pump. This load must be a noncondensable vapor, such as air or nitrogen. Using condensable vapor, such as steam, as the artificial load will not work because it will condense in the pump.

Recycle control is a third possibility. Separator discharge vapors can be recycled to the suction of the pump and will act as artificial load, causing a constant operating pressure even though process loading is below design capacity. The recycle line should be run from the separator vent line to ensure the recycle flow is single-phase, noncondensable gas. Again, recycle control does not add additional vapors/gases to the system, making it an effective means of pressure control.

An article by K. Skelton[2] described the use of variable frequency drives to control operating pressure. As process loading falls below design capacity, liquid ring pump impeller rotation can be varied to reduce handling capacity. The capacity ratio is roughly proportional to rotational speed ratio, for example, if actual process loading is 70 percent of design, the rotation of the impeller may be reduced to approximately 70 percent. This is more efficient than other types of pressure control, but the initial cost is higher. If using this method, check with the liquid ring pump supplier, as there is a minimal impeller rotation rate necessary to prevent the liquid ring from collapsing and causing vacuum loss.

Cavitation Control Off Separator



## Vacuum Process Condensers

Pressure control is possible if a system has a vacuum condenser between the vacuum vessel and the vacuum system, but it must be suitable for the application. A vacuum process condenser will run at pressures below the design operating pressure when cooling fluid temperature is below design capacity, process load conditions are below design, or the condenser is operating below the design fouling margin. Cooling fluid temperature variation is the most common cause for changes in operating temperature.

There are several additional considerations if using recycle control with a vacuum condenser backed up by an ejector system. For example, if the vacuum condenser is handling steam from an evaporator, the condenser operating pressure will follow the cooling fluid temperature. Recycle control or a steam bleed will not work in this instance. The ejector will not see the recycle or steam bleed because the vacuum condenser has the capacity to condense either of those artificial loads. The recycle stream or steam bleed will go to the condenser and not to the ejector.

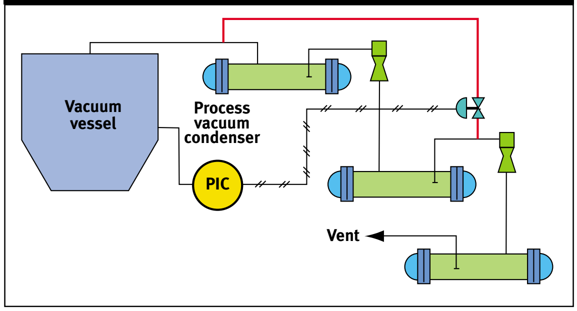
A noncondensable gas bleed into the condenser may be used, but it is important to understand the range of operation and control to determine the amount of noncondensable bleed needed. The ejector system capabilities require close inspection — ejector system must not be overloaded with noncondensables as performance will suffer. The vacuum condenser and backing vacuum system operate in unison and should be evaluated together. That ensures the two individual items work as a system throughout all anticipated ranges of operation.

Another possibility is to recycle the discharge of the first intercondenser to the vacuum process condenser inlet. This stream will be sufficiently rich in noncondensable gases that it can permit effective pressure control of the process condenser. Again, nothing gets added to the process stream. A throttling valve between the process vacuum condenser and first ejector will work as well.

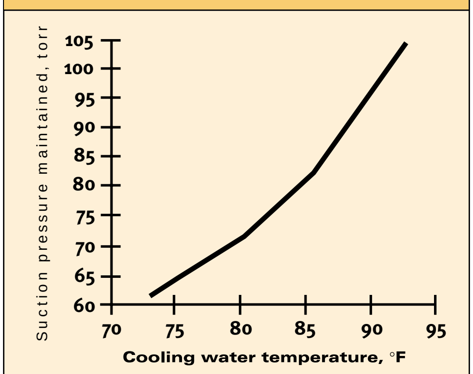
It is possible to throttle cooling fluid consumption to control vacuum condenser operating pressure. When a condenser is underloaded or cooling fluid temperature is colder than design capacity, a vacuum condenser will pull to a lower pressure. This can be avoided by reducing cooling fluid consumption.

The principle at work is two-fold: First, the lower flowrate of cooling fluid will result in a greater cooling fluid temperature rise. That, in turn, lowers the log mean temperature difference. Secondly, when the cooling fluid flowrate is reduced its heat transfer coefficient will be reduced as well. Both serve to reduce the handling capacity of the condenser and enable pressure control.

Recycle Control Around First Intercondenser




Vacuum Condenser Performance Curve




## Summary

Pressure control for your vacuum is possible. There are a number of techniques that may be used. When designing a pressure control system for your vacuum equipment, be certain to consult and involve a vacuum equipment supplier. That will ensure the appropriate analysis is done and the proper control technique is selected. Decide early on if pressure control is important for your process. The type of pressure control chosen may have an influence on vacuum equipment design. By doing the assessment early, costly design iterations and equipment changes may be avoided.

**References**

1. Ryans, J., and Roper, D., *Process Vacuum System Design and Operation*, McGraw-Hill Inc., 1986, pp. 326-327.
2. Skelton, K., "Variable Frequency Drives for a Vacuum Pump System," *Pumps and Systems*, January, 1998.

*This is the second in a series of six educational newsletters on vacuum equipment. Watch for the next issue of VacAdemics in May.*

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