VACUUM
Theory and Applications

Vacuum may be defined as the complete emptiness of a given volume. It is impossible to obtain a perfect vacuum, but it is possible to obtain a level of vacuum, defined as a pressure, in a system, below barometric pressure.

For convenience, in vacuum engineering design, the term absolute pressure is used. Absolute pressure is a pressure above absolute zero pressure (a perfect vacuum).

Another convenient term is gauge pressure, which is a pressure measured above barometric pressure.

The relationship between the various parameters is described in Figure 1.

Pressure Relationships

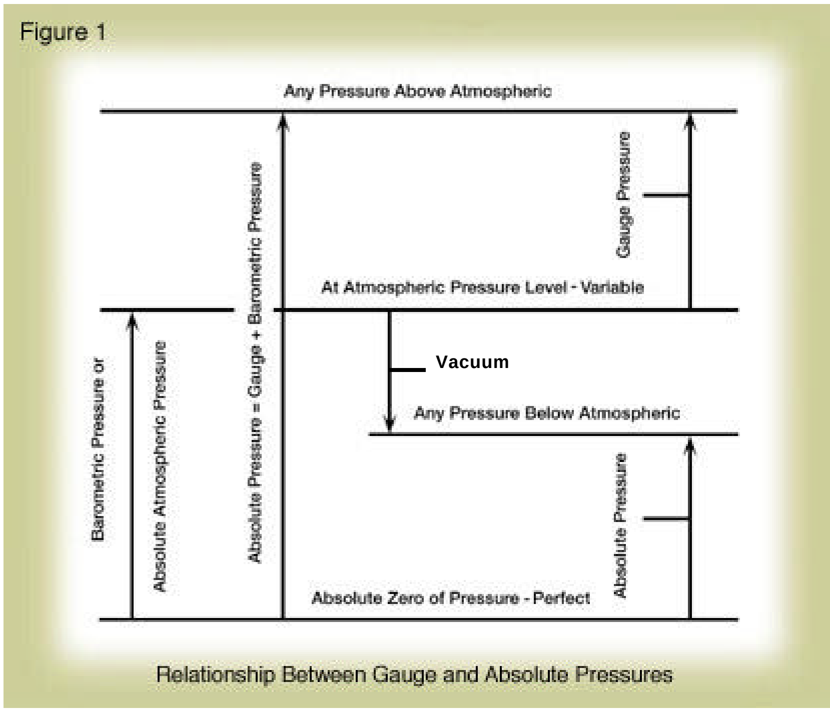
Figure 1 graphically illustrates the relationship between gauge and absolute pressures. Perfect vacuum cannot exist on the surface of the earth, but it nevertheless makes a convenient reference point for the measurement of pressure.

Barometric pressure is the level of the atmospheric pressure above perfect vacuum.

"Standard" atmospheric pressure is 14.7 pounds per square inch (psi), or 760 millimeters of mercury (mmHg).

Gauge pressure is measured above barometric pressure, while absolute pressure always refers to perfect vacuum as a reference point.

Vacuum is the depression of pressure below the barometric pressure. Reference to vacuum conditions is often made by expressing the absolute pressure in inches of mercury, millimeters of mercury, or microns.



In the prior discussion pressure in a system has been indicated. In order to fully understand what pressure means in the physical world, the following explanation is presented. Vacuum was defined as "complete emptiness". If any gas (or gases) is present in a system a perfect vacuum cannot exist; therefore, by definition, a pressure (no matter how low) will be exhibited.

The physical basis for measuring gas pressure is THE KINETIC THEORY OF GASES. The latter is based upon the elastic collisions of the existing gas molecules with the walls of the vessel.

For each impact the change in momentum is equal to:

$$(mv) - (-mv) = 2\,mv$$

Where:

m = mass of molecule
v = velocity of molecule

The pressure in the vessel may be defined as the rate of change of momentum of the gas molecules impacting upon the walls of the vessel, namely...

$$P_t = 2mv\,N$$

Where:

N = number of molecules impacting a unit surface per unit time

As is obvious from the above, if the number of molecules impacting upon the surface of a vessel is reduced the pressure will also be reduced. This is the basis of obtaining a vacuum (removing gas/gases from the vessel).

Note, the above will be valid if more than one gas is present in the vessel. Each gas will act independently and the resultant pressure will be determined by the LAW OF PARTIAL PRESSURES.

The latter (DALTON'S LAW) may be stated as follows:
In a given mixture of gases, or vapors, each gas, or vapor, exerts the same pressure it would exert if it occurred alone in the same space and at the same temperature as exists in the mixture, thus;

$$P_t = P_1 + P_2 + P_3 + ..$$

Where:

P_t = Total pressure
P_1 P_2 P_3.. = Partial pressure of component gases, or vapors

The partial pressure of each component may be expressed as follows:

$$P_x = n_x P_t$$
$$P_x = N_x P_t$$

Where:

P_x = Partial pressure of component x
N_x = Mole fraction of component x
P_t = total pressure

Measurement of Pressure

Vacuum may be measured by a variety of instruments depending upon application. A representative list is provided below:

1. *Mercury manometers*
Mercury manometers use mercury in a glass u-tube. An open (one side) manometer will measure pressure relative to local barometric pressure. A closed (one-side) manometer will measure absolute pressure.

2. *Bourdon Gauges*
Measure vacuum (relative to local barometric pressure) by means of a flexible tube sensor.

3. *Diaphragm Gauges*
Use a diaphragm that will deflect under pressure

4. *Electronic Gauges*
Convert pressure to an electrical signal that can be transmitted, recorded, or displayed.

The reading errors will depend upon the type of gage used and in ascending order of accuracy will be mechanical gages, manometers, and electronic gauges.

Vacuum Devices

Where, and why, is vacuum so important in power and process applications?

In many applications gases and/or vapors must be removed in order to obtain required performance, or product. The inclusion of a vacuum system is often the most efficient method for accomplishing this. For example, vacuum operations permit processes to operate at low temperatures and this is a decided advantage where heat sensitive materials are involved.

How is a vacuum achieved? As indicated previously, the pressure in a vessel is the sum of the partial pressures of component gases and vapors (DALTON'S LAW). In order to reduce the pressure (obtain a vacuum) the gases and vapors must be removed.

Two distinct devices used to produce and maintain vacuum will be discussed.

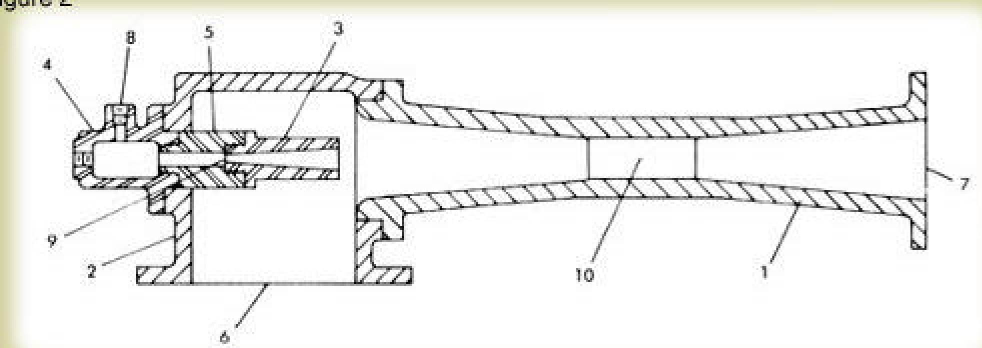
I. Steam Jet Ejectors

The first device to be described will be the steam jet ejector (the steam jet ejector is a mass flow device). A typical steam jet ejector assembly is shown in Figure 2. The assembly may be only one component in an overall steam jet ejector system design. Refer to the Heat Exchange Institute *Standards for Steam Jet Vacuum Systems* for nomenclature, design variations, and test procedures.

TYPICAL STEAM JET EJECTOR ASSEMBLY

1. Diffuser
2. Suction Chamber
3. Steam Nozzle
4. Steam Chest
5. Extension (if used)
6. Suction
7. Discharge
8. Steam Inlet
9. Nozzle Throat
10. Diffuser Throat

Figure 2



Typical Steam Jet Ejector Assembly

The following describes the basic design and operation of steam jet ejectors.

There are two separate fluid flows involved. The first is the high pressure motive steam (other motive fluids may be used). The steam is introduced into the nozzle (Item 3 of Figure 2) and by expansion in the diverging part of the nozzle, steam pressure is converted into velocity. This velocity will be in the supersonic range (3000 to 4000 ft/sec).

The second fluid involved is the load (from a vessel or process) and is introduced into the suction of the ejector (Item 6).

In the suction chamber (Item 2) the high velocity steam exiting from the nozzle entrains the load. The load is continually removed resulting in a reduced pressure at the suction. The resulting mixture, at the resulting velocity, enters the diffuser where this velocity energy is converted to pressure energy so that the pressure of the mixture at the ejector discharge is substantially higher than the pressure in the suction chamber.

II. Liquid Ring Vacuum Pumps (LRVP)

The second device to be discussed is called a Liquid Ring Vacuum Pump, which is a positive displacement machine. The LRVP uses a liquid compressant to compress entering gases and then discharges same to the atmosphere or process.

There are two types of LRVP but the basic theory of operation is the same, namely, a crescent shaped rotating liquid ring, formed by the offset of pump rotor, acting as a series of pistons in the rotor vanes.

One type of LRVP is called a flat port pump and is described in Figure 3.

Another type of LRVP pump uses a cone design to introduce and discharge the gases. Figure 4 describes the internal design for this unit.

The liquid ring vacuum pump is a specific form of rotary positive displacement pump utilizing liquid as the principal element in gas compression. The compression is performed by the liquid ring as a result of the relative eccentricity between the casing and a rotating multi-bladed impeller.

The eccentricity results in near complete filling then partial emptying of each rotor chamber during each revolution. The partial filling and emptying creates a piston action within each set of rotor or impeller blades. Parts are positioned in such a manner as to admit gas when the rotor chamber is emptying of the liquid and allow the gas to discharge once compression is completed. Sealing areas between the inlet and discharge ports are provided to close the rotor areas, separating the inlet and discharge flows.

A portion of the liquid in the casing is continuously discharged with the gas and the cooler service liquid is introduced to remove the heat generated during operation. Figures 3 and 4 provide typical examples of liquid ring vacuum pumps.

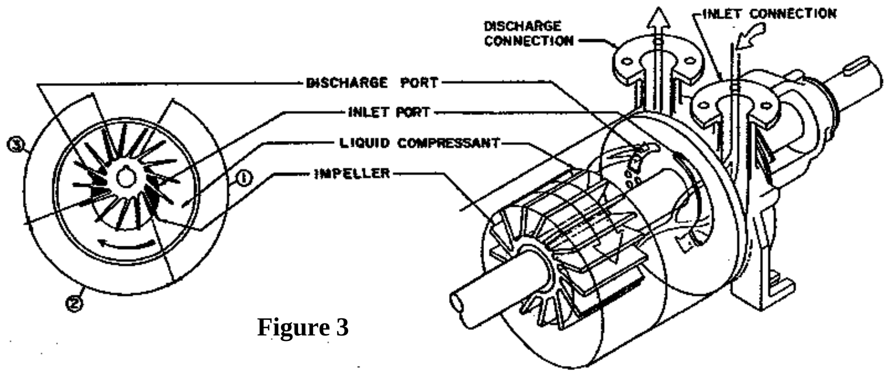


Figure 3

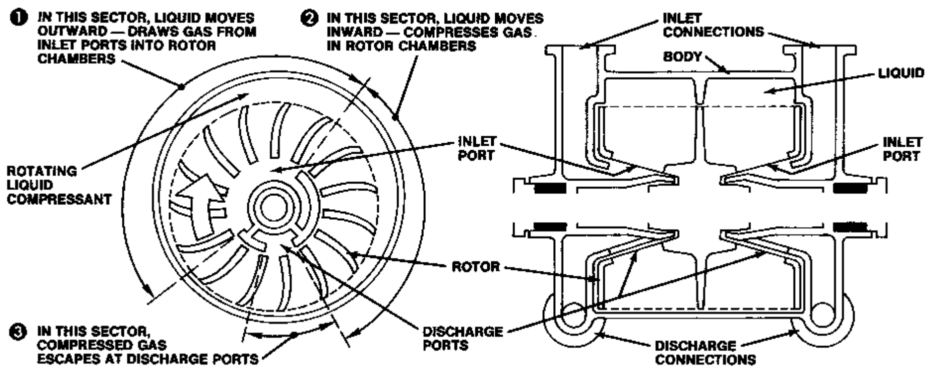


Figure 4

Applications of Vacuum Technology

A representative number of examples will indicate how vacuum technology is used to provide a broad range of operations in industry.

1. *Power cycles*
In order to maintain vacuum in a main condenser (RANKINE, or regenerative cycles), non-condensable gases must be continually removed. Steam jet ejectors or liquid ring vacuum pumps can be used depending upon system application and economics.

2. *Refrigeration and chilled water processes.*
Evaporation cooling of the liquid in a vessel is obtained by maintaining a high vacuum (low absolute pressure). Part of the water in the vessel will flash (evaporate) by using sensible heat thus reducing the temperature. Either a LRVP or steam jet ejector might be used for this service.

3. *Vacuum distillation*
Vacuum distillation is used in the petroleum industry in the production of fuels. Liquid ring vacuum pumps are normally used for this service.

4. *Freeze drying*
This is a complex procedure starting with a frozen product then removing water by means of vaporization. An example would be in the preparation of orange juice concentrate. Due to the low

pressure required, multistage ejectors would normally be used.

5. *Medical applications*
Liquid ring vacuum pumps are used to maintain vacuum in hospital rooms.

GLOSSARY

Critical Temperature & Pressure: At the critical point physical property differences between liquid and vapor will disappear and properties of both will become the same. Above the critical temperature no liquid phase can exist.

Non-condensable gas : A gas at a temperature higher than its critical temperature. A noncondensable gas is a gas that will not be liquified in the equipment supplied.

Standard Atmospheric Pressure: 760 torr or 29.92 inches of mercury

Torr: A unit of pressure equal to 1/760 of a standard atmosphere. One torr is equal to 1.0 mm of mercury.

Vapor Pressure: The pressure at which the liquid and vapor phases will be in equilibrium at a given temperature. The vapor pressure will vary with temperature.
