Bulletin E68A

VACUUM SYSTEMS

MULTI-STAGE EJECTOR SYSTEMS
YSTEMS ☐ THERMOCOMPRESSORS ☐
TER CHILLERS – CHILL-VACTOR®
AROMETRIC CONDENSERS ☐ LIQUI
MS – SCRUB-VACTOR ☐ MULTI-STA
UID RING VACUUM PUMPS ☐ JET B
☐ EDUCTORS ☐ **CROLL-REYNOLDS** ☐
☐ COMBINATION EJECTOR/LIQUID
YSTEMS ☐ DISTILLATE RECOVERY
E AND BAROMETRIC CONDENSE
POWERED VACUUM SYSTEMS ☐ CO
RING VACUUM PUMP SYSTEMS ☐

EJECTORS

The steam-jet ejector is a device designed to convert the pressure energy of a motivating fluid to velocity energy in order to entrain the suction fluid . . . and then recompress the mixed fluids by converting velocity energy back into pressure energy. It is based on the theory that a properly designed nozzle followed by a properly designed throat or venturi will economically make use of the high pressure fluid to compress from a low pressure region to a higher pressure. This change from pressure head to velocity head is the basis of the jet vacuum principle.

Ejectors are generally categorized into one of four basic types: single-stage, multi-stage non-condensing, multi-stage condensing and multi-stage with both condensing and non-condensing stages.

Single-stage ejectors are the simplest and most commonly used construction. They are generally recommended for pressures from atmospheric to 3" Hg. Abs. Single-stage units discharge at or near atmospheric pressure.

Multi-stage non-condensing ejectors are used where it is necessary to produce lower suction pressures. Steam consumption in these units is relatively high as each successive stage is required to handle the load and motive steam of the stage ahead of it. These designs are frequently used where a low first cost is more important than operating economy, for intermittent use or for applications where water is not available.

Multi-stage condensing ejectors are available in two or more stages. An inter-condenser of either the surface or direct-contact type is used between the stages to condense the steam from the preceding stage and reduce the load. This design is generally recommended for suction pressures from 4.0" Hg. Abs. to 0.5" Hg. Abs. in two-stage designs; from 25 mm Hg. Abs. to 2 mm Hg. Abs. in three-stage designs.

For handling large amounts of condensable vapors, the first stage "booster" is usually followed by a condenser which is in turn followed by a two-stage ejector to compress non-condensables to atmospheric pressure. When condensable loads are small or nonexistent, only one inter-condenser following the second stage may be used. Three-stage non-condensing units use relatively large quantities of motivating steam and are not generally recommended.

Some designs incorporate the use of an after-condenser to condense the atmospheric stage motive steam. Where surface type after-condensers are used the condensate for the main condenser can be pumped through the inter-condenser and after-condenser as cooling water. This permits returning heat of the ejector steam to the boiler.

For extremely low suction pressures, 4, 5 and 6-stage ejectors are utilized. Since the pressure between the first two stages of the four-stage ejector, the first three stages of a five-stage ejector and the first four stages of a six-stage ejector is too low to permit condensing the ejector steam, these stages are built non-condensing and the subsequent stages are condensing.

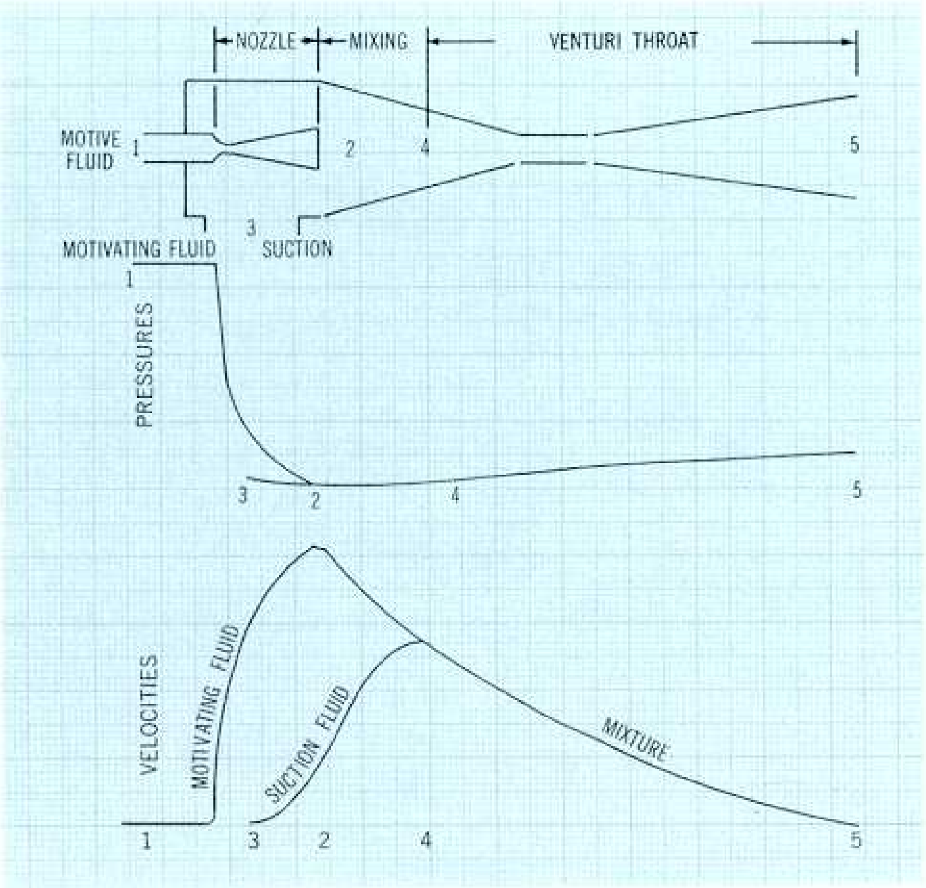


FIGURE 1

Basic Construction:

Ejectors are composed of three basic parts: nozzle, mixing chamber and diffuser. Figure 1 illustrates a typical ejector. A high pressure motivating fluid (M_a) enters at 1, expands through the converging-diverging nozzle to 2. The suction fluid (M_b) enters at 3, mixes with the motivating fluid in the mixing chamber 4. Both M_a and M_b are then recompressed through the diffuser to 5. The pressure and velocity changes are also shown graphically for the process directly below the ejector diagram. Figure 2 shows the thermal changes on a Mollier diagram for a typical ejector using high pressure steam as the motivating fluid and saturated vapor as the suction fluid.

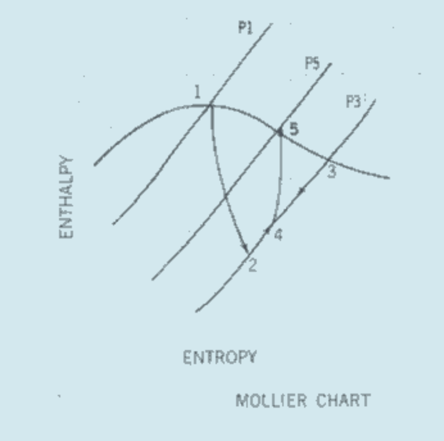
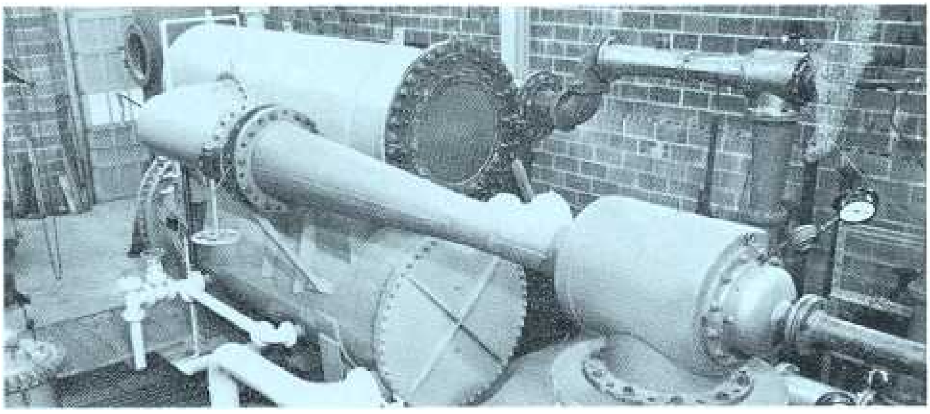


FIGURE 2



Steam Jet Equipment On Test In Croll-Reynolds Research and Test Center.

Ejector Efficiency

There are many published and accepted formulae to express ejector efficiency. The usual concept of efficiency involves a comparison of energy output to energy input. A ratio of this sort is of little value in the selection and design of ejectors. Since ejectors approach a theoretically isentropic process, it is convenient to express overall efficiency as a function on entrainment efficiency. The direct entrainment of the low velocity suction fluid by the motive fluid results in an unavoidable loss of kinetic energy owing to impact and turbulence so that the surviving kinetic energy of the mixture is but a fraction of that originally possessed by the motive fluid. This fraction that is successfully transmitted to the mixture through the exchange of momentum is called the entrainment efficiency.

That proportion of the motive fluid energy which is lost is transferred into heat and is absorbed by the mixture, producing therein a corresponding increase in enthalpy. The following formula is based on steam handling saturated vapor at the suction fluid.

$$EFF = E_e \times E_n \times E_d = \left[\frac{M_b}{M_a} + 1\right]\left[\frac{H_5 - H_4}{H_1 - H_2}\right]$$

Where: E_e = entrainment efficiency
E_n = nozzle efficiency
E_d = diffuser efficiency
M_b = suction fluid—lb./hr.
M_a = motive fluid—lb./hr.
H_1 = motive fluid enthalpy—btu./lb.
H_2 = enthalpy at nozzle discharge—btu./lb.
H_4 = mixture enthalpy before compression—btu./lb.
H_5 = enthalpy at discharge—btu./lb.

The capacity (#/Hr.) of an ejector handling other than saturated vapor is a function of the fluid's molecular weight and temperature. The higher the molecular weight of a fluid, the greater the ejector suction capacity, assuming equal motivating quantities. Conversely, the ejector will handle less of lower molecular weight fluids. For example, a steam ejector will handle approximately 23% more free dry air than it will saturated vapor. The reverse of this is true where suction fluid temperatures are concerned. The ejector will handle less fluid as the temperature of that fluid increases.

An ejector represents what is referred to as single point design. That is, its design will be optimum at a single set of conditions. Ejector designs can be classified either as critical or non-critical. Critical design means that the fluid velocity in the diffuser throat is sonic. In non-critical units the fluid velocity is subsonic. A steam ejector is of critical design when the suction pressure is lower than approximately 55% of the discharge pressure. Ejectors designed in the critical range are sensitive to operating conditions other than those the unit was designed for. The table below illustrates how these changes in operation can affect ejector performance:

In critical design units it is possible to decrease the motivating pressure without a resulting change in the suction pressure if the discharge pressure is also decreased. The relation of a change between the motivating pressure and discharge pressure depends on the characteristics of the ejector design. Since an ejector is a one point design unit, once a unit is designed and built to definite specifications of motivating pressure, discharge pressure and suction pressure, its suction capacity cannot be increased without changing the internal physical dimensions of the unit. The suction capacity is actually lowered by increasing the motivating pressure. Since the ejector nozzle is a fixed orifice metering device any change in the motivating pressure is accompanied by a proportionate change in the quantity of motive fluid.

In non-critical design units, changes in the motivating pressure and discharge pressure cause gradual changes in the suction pressure and capacity. It is still impossible, however, to increase the suction capacity in proportion to motivating pressure increases.

In an ejector whose motivating fluid is steam, the quality of the high pressure steam has an effect on the operation of the unit. Most units are designed to use dry and saturated high pressure steam as a motive fluid. If the quality of the steam decreases below 98%, a gradual decrease in the suction pressure and suction capacity is experienced. This phenomenon will be particularly noticed in units designed for high compression ratios

$$\frac{(\text{Discharge Pressure})}{(\text{Suction Pressure})} \quad \text{or} \quad \frac{P_d}{P_s}$$

and even more so in multi-stage units. Effective ejector compression ratios can be as high as 10:1 at design conditions and approximately 20:1 at close off (point of zero suction capacity) depending on the motivating fluid pressure. Excessive steam superheat (higher than 50°F.) can also adversely affect the suction capacity of any ejector. It not only decreases the energy level ratio, but also the increase in specific volume tends to choke the diffuser. If an ejector is designed to use superheated motivating steam the latter adversity can be overcome.

EFFECT OF OPERATIONAL CHANGES ON CRITICAL FLOW EJECTOR PERFORMANCE

MOTIVE PRESSURE	DISCHARGE PRESSURE	SUCTION PRESSURE	SUCTION CAPACITY
Decrease	Constant	Increase rapidly	Decrease rapidly
Constant	Increase	Increase rapidly	Decrease rapidly
Constant	Constant	Increase	Increase
Constant	Constant	Decrease	Decrease
Increase	Constant	Constant	Decrease gradually
Constant	Decrease	Constant	Unchanged

Ejector Efficiency

There are many published and accepted formulae to express ejector efficiency. The usual concept of efficiency involves a comparison of energy output to energy input. A ratio of this sort is of little value in the selection and design of ejectors. Since ejectors approach a theoretically isentropic process, it is convenient to express overall efficiency as a function on entrainment efficiency. The direct entrainment of the low velocity suction fluid by the motive fluid results in an unavoidable loss of kinetic energy owing to impact and turbulence so that the surviving kinetic energy of the mixture is but a fraction of that originally possessed by the motive fluid. This fraction that is successfully transmitted to the mixture through the exchange of momentum is called the entrainment efficiency.

That proportion of the motive fluid energy which is lost is transferred into heat and is absorbed by the mixture, producing therein a corresponding increase in enthalpy. The following formula is based on steam handling saturated vapor at the suction fluid.

$$\mathrm{EFF} = E_e \times E_n \times E_d = \left[\frac{M_b}{M_a} + 1\right]\left[\frac{H_5 - H_4}{H_1 - H_2}\right]$$

Where: E_e = entrainment efficiency
E_n = nozzle efficiency
E_d = diffuser efficiency
M_b = suction fluid—lb./hr.
M_a = motive fluid—lb./hr.
H_1 = motive fluid enthalpy—btu./lb.
H_2 = enthalpy at nozzle discharge—btu./lb.
H_4 = mixture enthalpy before compression—btu./lb.
H_5 = enthalpy at discharge—btu./lb.

The capacity (#/Hr.) of an ejector handling other than saturated vapor is a function of the fluid's molecular weight and temperature. The higher the molecular weight of a fluid, the greater the ejector suction capacity, assuming equal motivating quantities. Conversely, the ejector will handle less of lower molecular weight fluids. For example, a steam ejector will handle approximately 23% more free dry air than it will saturated vapor. The reverse of this is true where suction fluid temperatures are concerned. The ejector will handle less fluid as the temperature of that fluid increases.

An ejector represents what is referred to as single point design. That is, its design will be optimum at a single set of conditions. Ejector designs can be classified either as critical or non-critical. Critical design means that the fluid velocity in the diffuser throat is sonic. In non-critical units the fluid velocity is subsonic. A steam ejector is of critical design when the suction pressure is lower than approximately 55% of the discharge pressure. Ejectors designed in the critical range are sensitive to operating conditions other than those the unit was designed for. The table below illustrates how these changes in operation can affect ejector performance:

In critical design units it is possible to decrease the motivating pressure without a resulting change in the suction pressure if the discharge pressure is also decreased. The relation of a change between the motivating pressure and discharge pressure depends on the characteristics of the ejector design. Since an ejector is a one point design unit, once a unit is designed and built to definite specifications of motivating pressure, discharge pressure and suction pressure, its suction capacity cannot be increased without changing the internal physical dimensions of the unit. The suction capacity is actually lowered by increasing the motivating pressure. Since the ejector nozzle is a fixed orifice metering device any change in the motivating pressure is accompanied by a proportionate change in the quantity of motive fluid.

In non-critical design units, changes in the motivating pressure and discharge pressure cause gradual changes in the suction pressure and capacity. It is still impossible, however, to increase the suction capacity in proportion to motivating pressure increases.

In an ejector whose motivating fluid is steam, the quality of the high pressure steam has an effect on the operation of the unit. Most units are designed to use dry and saturated high pressure steam as a motive fluid. If the quality of the steam decreases below 98%, a gradual decrease in the suction pressure and suction capacity is experienced. This phenomenon will be particularly noticed in units designed for high compression ratios

$$\frac{\text{(Discharge Pressure)}}{\text{(Suction Pressure)}} \quad \text{or} \quad \frac{P_d}{P_s}$$

and even more so in multi-stage units. Effective ejector compression ratios can be as high as 10:1 at design conditions and approximately 20:1 at close off (point of zero suction capacity) depending on the motivating fluid pressure. Excessive steam superheat (higher than 50°F.) can also adversely affect the suction capacity of any ejector. It not only decreases the energy level ratio, but also the increase in specific volume tends to choke the diffuser. If an ejector is designed to use superheated motivating steam the latter adversity can be overcome.

EFFECT OF OPERATIONAL CHANGES ON CRITICAL FLOW EJECTOR PERFORMANCE

MOTIVE PRESSURE	DISCHARGE PRESSURE	SUCTION PRESSURE	SUCTION CAPACITY
Decrease	Constant	Increase rapidly	Decrease rapidly
Constant	Increase	Increase rapidly	Decrease rapidly
Constant	Constant	Increase	Increase
Constant	Constant	Decrease	Decrease
Increase	Constant	Constant	Decrease gradually
Constant	Decrease	Constant	Unchanged

Staging Ejectors

Lower suction pressures are obtained by staging of the jets. Figure 3 illustrates the design compression ratios and relative steam consumption for various stages.

Ejector staging can be divided into condensing units and non-condensing units. The usual method of staging is to use a vapor condenser between the stages. Condensers are used to condense out all of the motivating steam plus the suction vapor from the first stage, allowing only saturated non-condensables to pass on to the following stages. The size and type of condenser used is a function of the air-vapor ratios, cooling water temperatures available, steam and water costs, and contaminants in the first stage suction vapor.

The term non-condensing is used where a stage discharges directly into the following stage. As explained before, steam consumption in this type of unit is higher because the second stage must handle all of the motivating steam plus the suction capacity from the first stage. Non-condensing units are used where the interstage pressure is lower than could be obtained with the temperature of cooling water available, such as in four, five and six stage units.

Two and three stage non-condensing units are used where first cost and installation cost out-weigh consideration of steam consumption. Two-stage non-condensing units used as primers are more efficient than when used for single point operation. A two-stage non-condensing unit uses approximately 100% more steam than a two-stage condensing unit, but when used as an evacuator its priming time is only approximately 20% longer. This is due to the oversizing of the final or atmospheric stage.

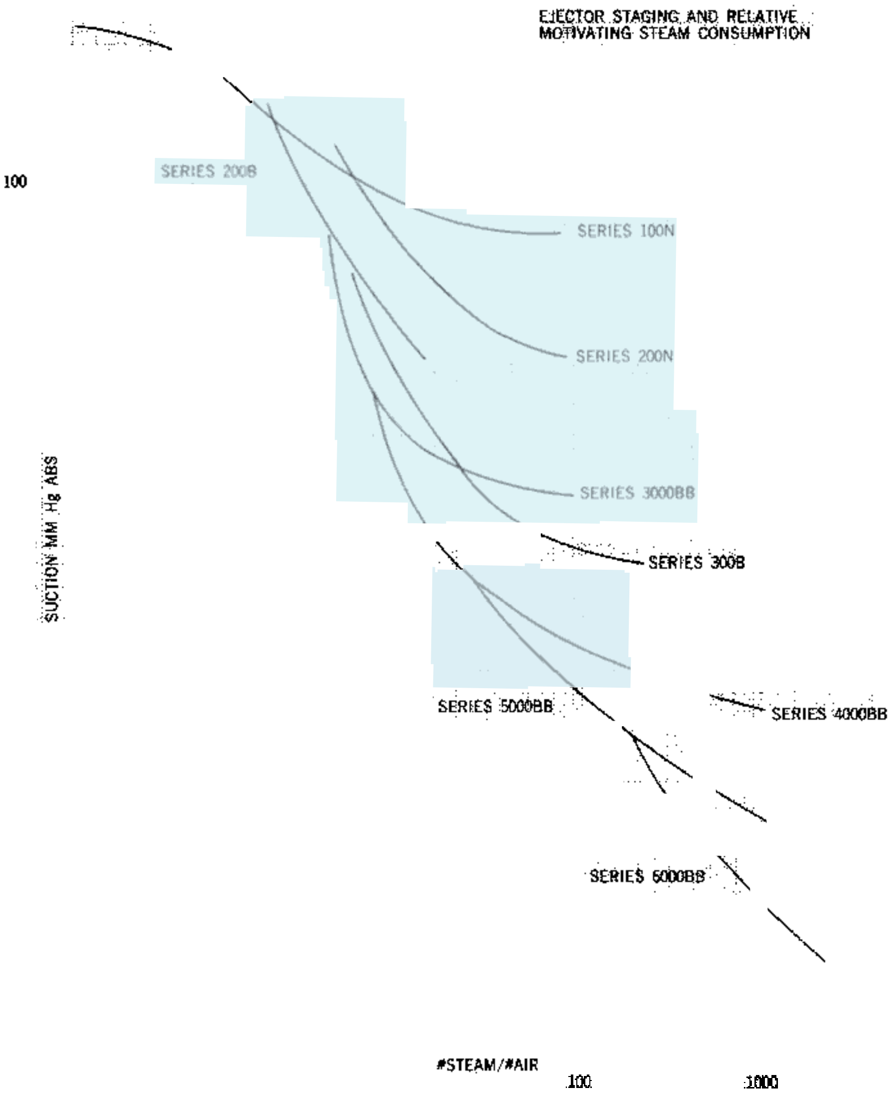


FIGURE 3

Ejector Materials of Construction

Steam-jet ejectors are generally furnished in cast iron or steel with a nozzle of stainless steel. Due to the broad range of applications for steam jet vacuum equipment, the units are frequently specified in special alloys and plastics. At Croll-Reynolds, we have designed steam jet EVACTORS utilizing carbon, stainless steel, Monel, Hastelloy, Ni-resist, Haveg, Teflon, titanium, ceramics, and other materials.

NOTE: EVACTOR, CHILL-VACTOR, SCRUB-VACTOR, AQUA-VACTOR are trademarks of Croll-Reynolds Company, Inc.

Combinations of EVACTOR stages are identified according to the number and arrangement of stages, using a series of numbers. In each series the first digit is the number of stages in the combination. Figure 4 shows the basic series.

The different types of condensing equipment used with the various EVACTOR series are identified by the following letters:

B—Barometric Counter-Flow Condenser, Intercondenser and Aftercondenser.

S—Surface Type Condenser, Intercondenser and Aftercondenser.

J—Atmospheric Jet Condenser, Intercondenser and Aftercondenser.

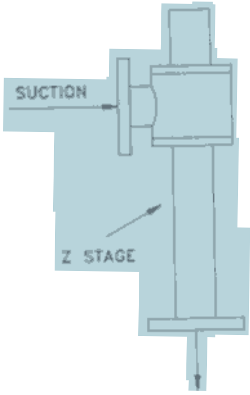
C—Surface Coil Type Condenser, Intercondenser and Aftercondenser.

N—Signifies no condenser in the series.

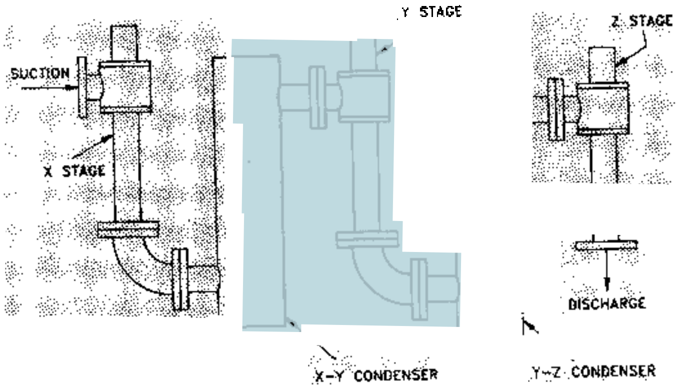
The operating range of the condensing equipment determines the nomenclature. Here are the basic divisions.

Condenser	1.5"	Hg. - 4" Hg. Abs.
Intercondenser	4"	Hg. - 10" Hg. Abs.
Aftercondenser	30"	Hg. - 32" Hg. Abs.

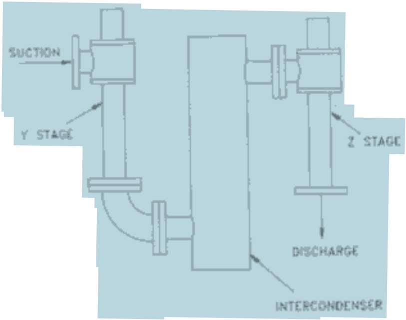
Letter No.	Position in Series	Normal Range of Suction Pressures (Hg. Abs.)	Normal Range of Disch. Pressures (Hg. Abs.)
Z	Atmospheric Stages	3" - 12"	30" - 32"
Y	1st of Two Stages	.5" - 4"	4" - 10"
X	1st of Three Stages	.1" - 1"	1" - 3"
W	1st of Four Stages	.2 mm - 4 mm	2 mm - 20 mm
V	1st of Five Stages	.02 mm - .4 mm	.4 mm - 3 mm
U	1st of Six Stages	.01 mm - .08 mm	.08 mm - .4 mm



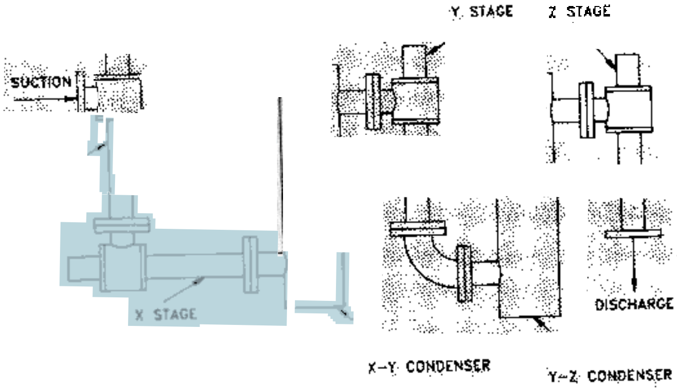
SERIES 100



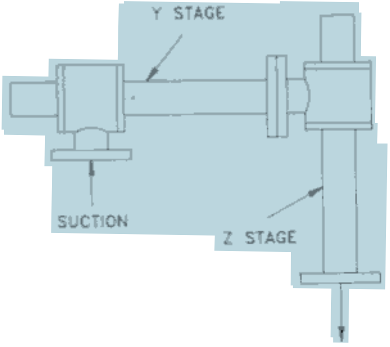
SERIES 3000



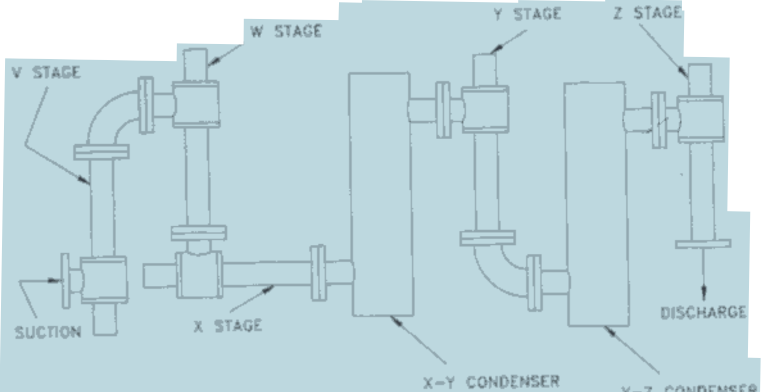
SERIES 200



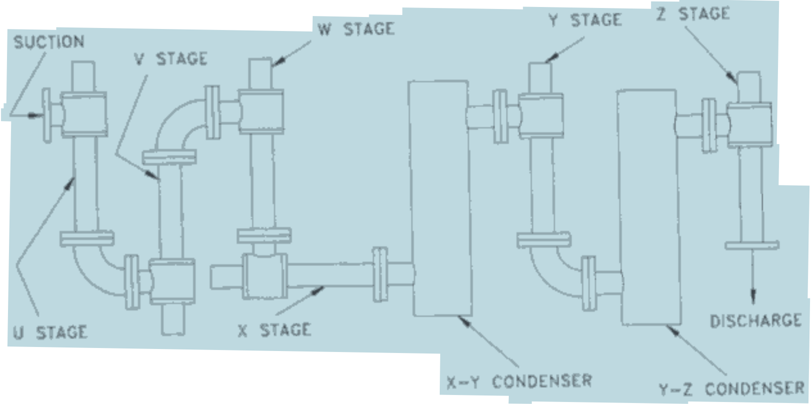
SERIES 4000



SERIES 200-N



SERIES 5000



SERIES 300

FIGURE 4

Condensers

A condenser is an apparatus used to reduce a vapor to its liquid state by removal of latent heat from the vapor. Its function as part of the steam jet vacuum system is basically the removal of condensable vapor ahead of a given ejector stage, thus reducing the size of the ejector and the amount of steam required. Condenser function may be defined as follows:

1. Precondenser: Used for direct condensing of vapors from the process. Non-condensables are removed from the precondenser by one or more ejector stages. The absolute pressure of process must be sufficiently high to allow condensation with the available water supply.
2. Condenser or booster condenser: Used to condense process vapor and motive steam from one or more preceding booster ejectors which compress process vapors from required low absolute pressure to the higher absolute pressure necessary for condensation by the available condenser water.
3. Intercondenser: Used between ejector stages where two or more stages are required to compress non-condensables from process or condenser pressure to atmospheric pressure, eliminating the handling of motive steam from a preceding stage.
4. Aftercondenser: Used to condense steam discharging from a "Z" or last stage ejector at atmospheric pressure. Non-condensables are vented into atmosphere.

There are two basic types of condensers: Direct Contact and Surface. Here are the advantages and chief characteristics of each type.

A. Direct Contact
(countercurrent, barometric design)

1. Lower first cost
2. Lower installation cost
3. Less water needed for a given vacuum condition
4. Smaller terminal difference allows operating at lower absolute pressure
5. Less floor area required
6. Scale or solids build-up has little effect on condenser performance, therefore little or no maintenance is generally required
7. Can be fabricated readily with corrosion resistant materials or supplied economically with rubber lining
8. Open barometric discharge provides safe operation without an atmospheric relief valve

B. Surface Condenser

1. Steam condensate may be recovered
2. Process product may be recovered as condensate, or gas at a higher pressure
3. No contamination of condenser water can occur
4. Vacuum surges will be less likely to carry water back to the process
5. Less head room required

In addition to the counter-current barometric direct contact condensers described above other direct contact condensers, although less efficient, are used because of certain specific advantages in special applications. Basically these are parallel flow type condensers. They are available in two designs:

1. Spray Condenser: Suitable for condensing large quantities of steam with a minimum of non-condensables. Water must be furnished free of debris and at 5 PSI minimum pressure to give intimate contact and good condensing action. Generally not used where close approach of operating pressure to water temperature is required.
2. Aqua-Vactor: This is a tradename for Croll Reynolds parallel flow condenser which serves as a combined condenser and air pump. The AQUA-VACTOR is particularly useful where high pressure (40 psig or greater) steam is not available and where small non-condensable loads are involved. It can be designed to discharge direct to atmosphere through a sealed discharge. When used for large vapor loads, it is more economical to use it in conjunction with a barometric discharge leg. The AQUA-VACTOR requires a relatively large amount of clean water, preferably at 20 psig or higher.

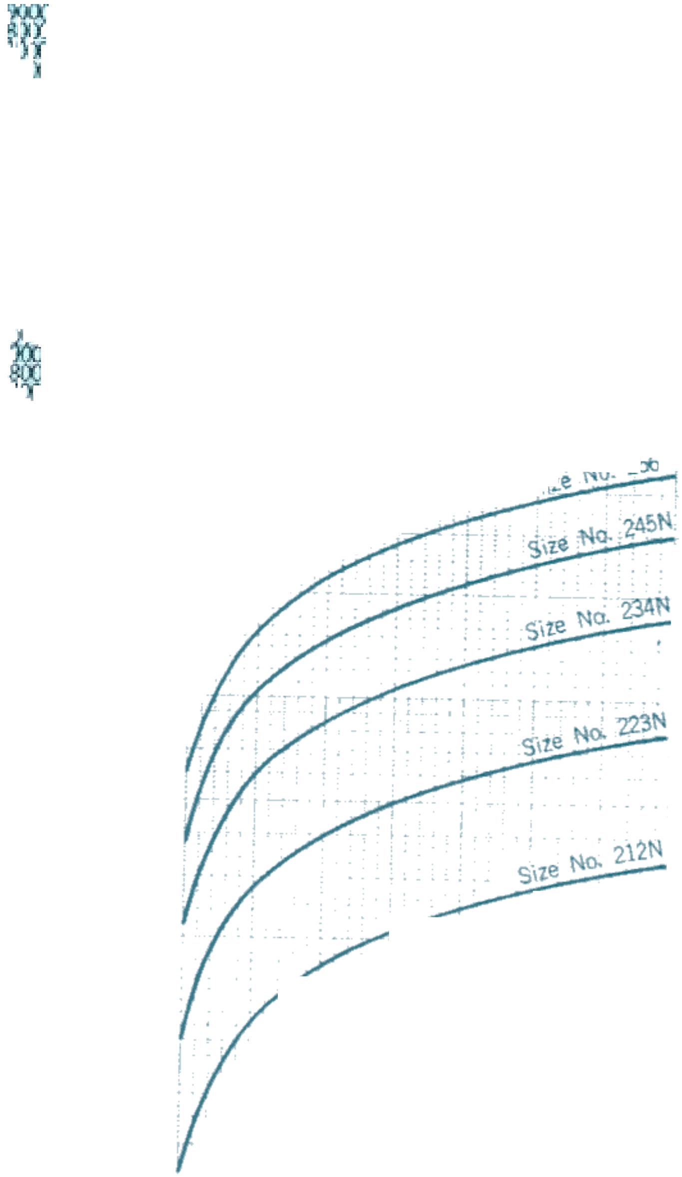
Condenser Selection And Sizing

1. Specify direct contact or surface type condenser and indicate for direct contact condenser whether it is to be a barometric or low level installation.
2. Give the vapor load, including nature of the vapor if other than water vapor. (BTU per hour or pounds per hour of saturated water vapor)
3. Provide information on the non-condensable load. Include estimated air leakage and average molecular weight if other than air (pounds per hour or Mols. per hour)
4. Operating pressure in inches of mercury absolute.
5. Maximum temperature of condenser water.
6. Material required, if other than steel.
7. Limitations of water quantity or temperature rise, if any.
8. Any other factors which could affect performance such as unusual amounts of dissolved gas in the condenser water or large fouling factors to be considered for surface condensers.
9. Allowable pressure drop (psi) and maximum pressure (psig) of surface condenser water.
10. Design water pressure of AQUA-VACTOR (psig).

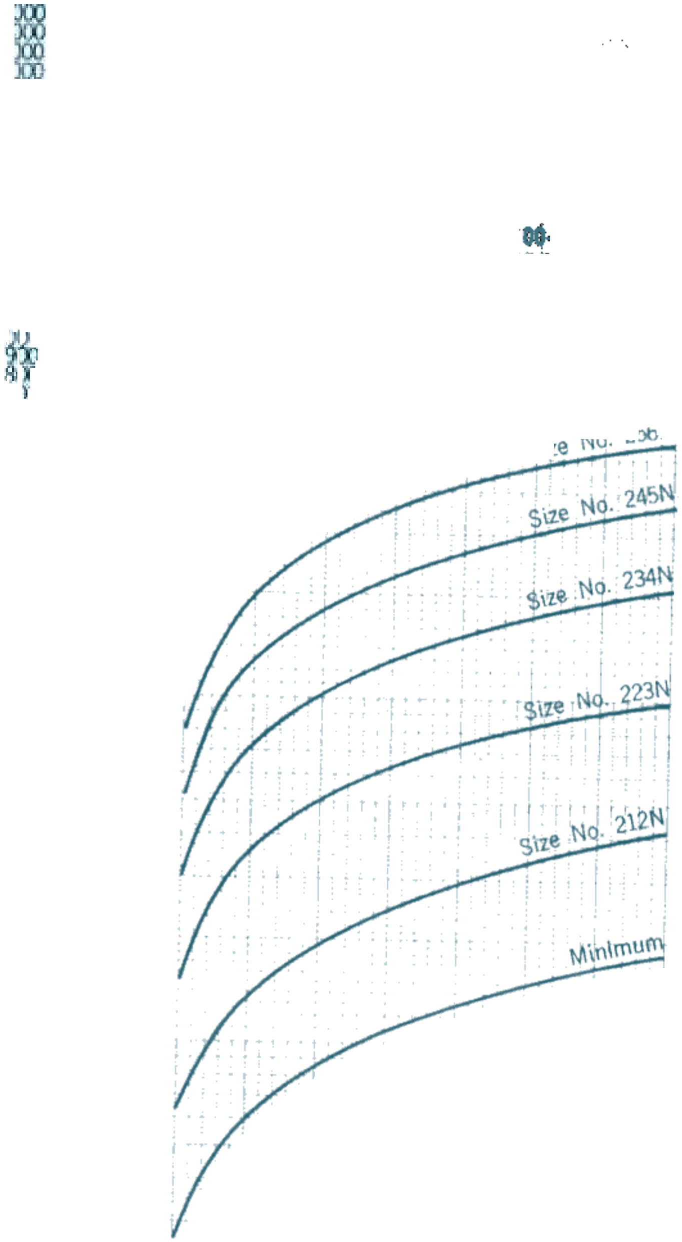
APPLICATIONS

Croll-Reynolds steam jet ejectors may be used wherever sub-atmospheric pressures are necessary. This includes the broad chemical field, including heavy chemicals, pharmaceuticals, food industry, vegetable oil refining, essential oils and flavorings, fertilizers and an infinite variety of products. It involves the complete range of processing: crystallization, evaporation, deodorization, deaeration, drying of solids, cooling of liquids and solids, high vacuum distallation, vacuum metallurgy, filtration and even high altitude simulation and the testing of rocket engines.

TWO TAG CR



TWO TAG CR

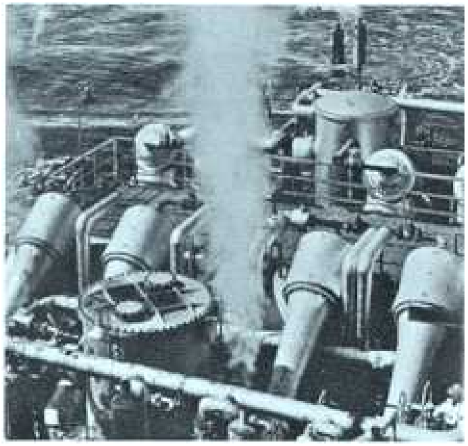


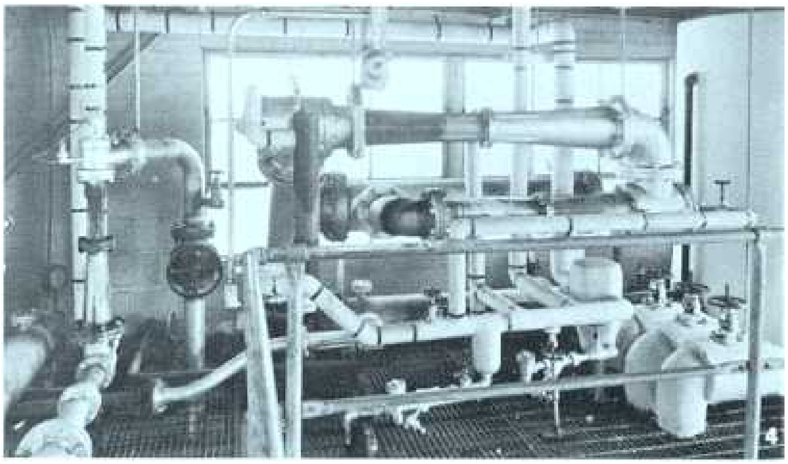
Vacuum Processing

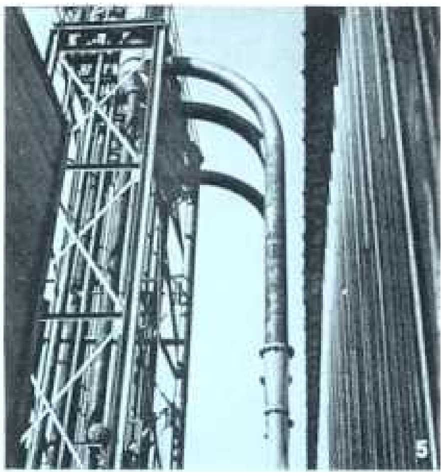
Evaporation is the one process which probably uses more single and two-stage ejectors than any other. There are many thousands of evaporators in the food, chemical and other process industries, and the majority of them operate under vacuum. Some products require very high vacuum in order to remove moisture at very low temperatures. For this service, multi-stage units are used. As many as six stages are now being used commercially. This permits evaporation of water vapor or other vapors from the solid phase direct to the vapor phase at extremely low temperatures.

Other important vacuum processes include crystallizing, drying, deaeration, filtration, vacuum impregnation, deodorizing, etc. Croll-Reynolds three-stage EVACTORS are used on both batch and continuous vegetable oil deodorizers in more than one hundred installations in the United States, with scores of others in foreign countries. These units are similar to the vacuum equipment used for vacuum refrigeration. A substantial quantity of water vapor is compressed from an absolute pressure in the range of 0.25" Hg. to 2.0" Hg. or some other pressure where it can be condensed along with the motivating steam, by water available from any convenient industrial water supply.

In this connection, Croll-Reynolds has developed a highly successful vacuum scrubbing device for removing organic vapors from the scrubbing steam used in deodorizers. The organic material is recovered in a surprisingly pure form, entirely free from emulsification, and has a market value sufficient to pay for its installation in a year or two. Another big advantage is the elimination of condenser water pollution by the organic materials. This unique scrubbing device is known as the Croll-Reynolds SCRUB-VACTOR.







2. Four and five stage C-R EVACTORS used for low temperature evaporation of heat-sensitive pharmaceuticals at Hoffmann-La Roche.

3. Part of a 4,500 ton C-R CHILL-VACTOR installation cooling 12,000 gpm process water for large antibiotic plant.

4. Two, three and four stage C-R EVACTORS help International Flavors and Fragrances, Inc. produce quality products economically.

5. C-R vacuum equipment used for cooling leafy vegetables, fruit and berries for large produce operation in Arizona.

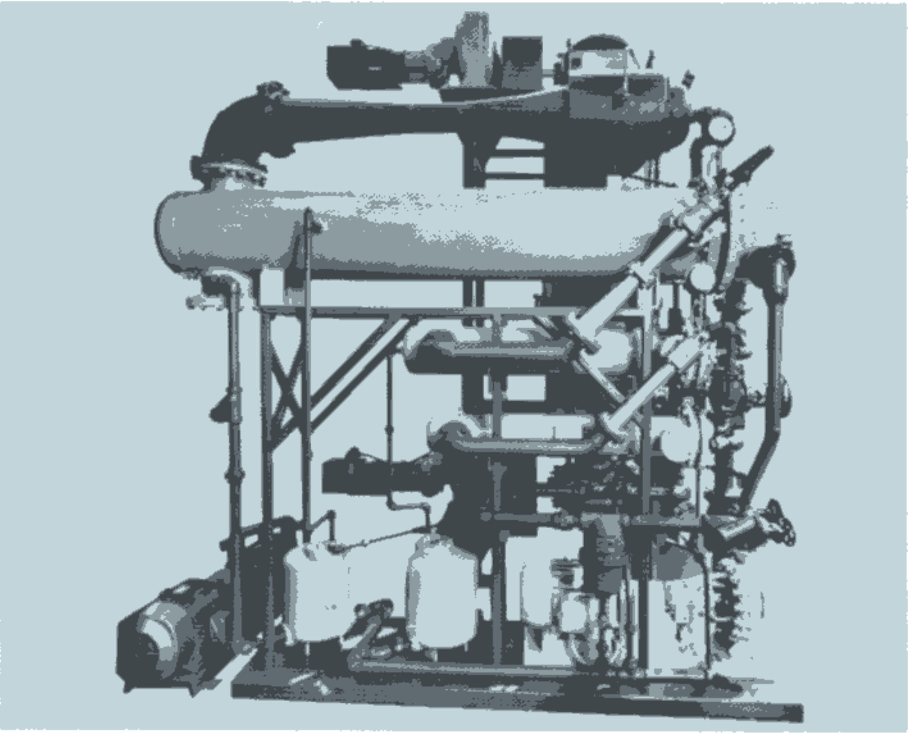
6. C-R four stage Scrub-Vactor installation for recovery of edible oils, eliminates contamination of condensing water and cooling tower.

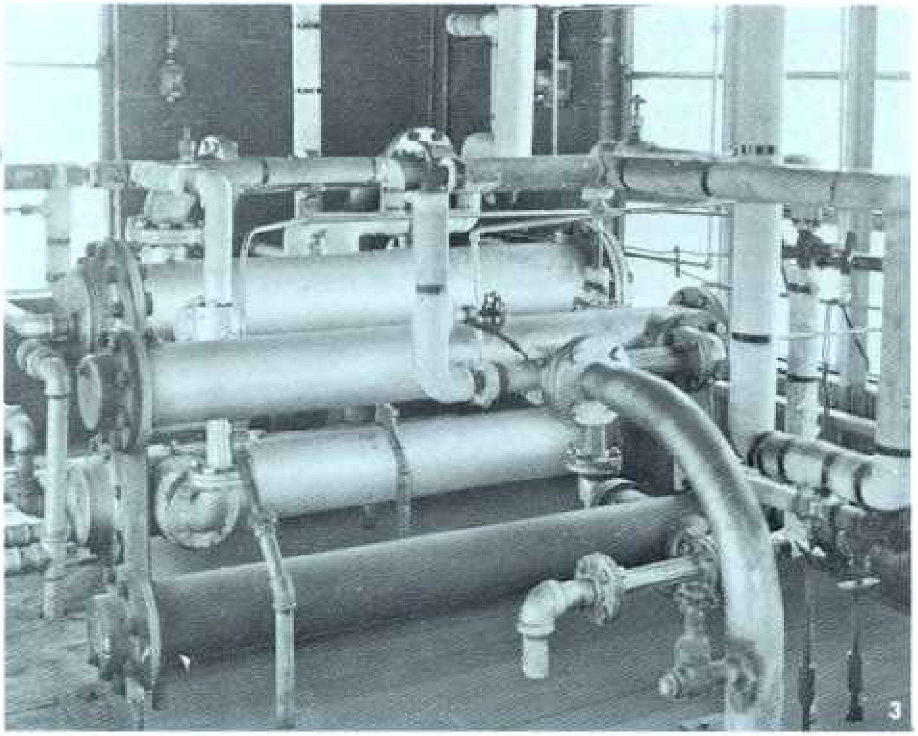
Recompression

Instead of flowing vapor directly to a condenser or a heater, it can be compressed in an ejector and permit higher discharge temperatures. Such ejectors are usually called thermocompressors, although this term overlaps the term booster ejector. In general, an ejector used to handle vapor at pressure corresponding to sub-ambient temperatures is called a booster and one at higher temperatures is called a thermocompressor. They are used for discharge pressures up to 15 psig and more, but efficiencies are better at lower discharge pressures.

One very important application of thermocompressors is on milk evaporators. Other applications include miscellaneous evaporators, dryers, heaters and supply of almost any low pressure steam requirement.

Croll-Reynolds makes an actual operating test under customers' specified conditions of every thermocompressor. These tests are limited only by test station boiler capacity. If any adjustments are indicated for maximum efficiency and dependability, they are made without extra charge and the unit is retested.





2. Three stage EVACTOR with Surface Condensers used in the continuous cooling of grain.

3. Three-stage and four-stage ejectors provide vacuum required in the distillation of natural and synthetic aromatic materials.

4. One of the world's largest steam jet ejectors, engineered and built by Croll-Reynolds for the LEM (Lunar Excursion Module) "Man on the Moon" project.

OPERATION AND MAINTENANCE

Since steam jet ejectors have no moving parts, operation and maintenance problems should be negligible.

Assuming the equipment has been specified correctly, satisfactory operation of an ejector system will depend upon, (1) correct installation, (2) correct utilities, and (3) periodic inspection.

Installation

A single stage, or multi-stage non-condensing ejector system can be installed in any convenient location. A condensing system will either require a barometric leg or a pump or trap for condensate removal. When using barometric condensers, it is common practice to use a barometric leg. A barometric leg necessarily requires that the vacuum equipment be located above ground level. The height required depends upon the absolute pressure at the condenser. High vacuum systems will usually require a minimum height of 34 feet. The barometric leg should discharge to a properly designed hotwell. There must be enough volume of water above the discharge of the barometric leg to keep the discharge submerged during start-up. The required volume can easily be calculated, if the diameter of the barometric leg is known.

If a pump is used to remove condensate, or a combination of condensate and condensing water, the pump manufacturer must be advised of the absolute pressure condition at the suction of the pump, and the discharge head required.

In many cases vacuum traps or receivers can be used to remove condensate. Traps and receivers may be considered, if the system is small and utilizes surface type condensers.

Once the ejector system has been located, consideration must be given to three or four connections: suction connection, discharge connection, steam connections, and in most cases water connections.

The suction line should be the same diameter as the suction connection of the ejector system and should be as short and as straight as practical.

The discharge line should be the same diameter as the discharge of the ejector system. Ejector systems are normally designed to discharge at 0.5 psig. If this pressure is exceeded, the system will not operate properly. Therefore, it is important to design the discharge line to keep pressure below 0.5 psig, or to inform the manufacturers of an anticipated higher discharge pressure. Many ejectors discharge to the atmosphere directly. Others discharge to condenser hotwells or after-condensers. In all cases discharge pressures should be carefully considered.

Since dry steam is a basic requirement for good performance and maintenance, installation of steam lines is extremely important. Steam mains should be well trapped. The steam piping to the ejector system should come off the top of the main line. In most cases a steam separator and steam strainer are recommended. Steam lines and separators should be completely insulated. A steam pressure gauge (compound type is recommended) should be located as close to the ejector system as possible.

Since precondensers and intercondensers operate under vacuum, water pressure at the inlet of barometric condensers is not critical. Sufficient pressure differential should be available for control of water flow. A pressure of 5 psig is normally considered sufficient. Water pressure should remain fairly constant, since wide fluctuations will cause changes in water flow with resultant changes in condenser pressures. If surface condensers are used, sufficient pressure must be available to overcome pressure drop through the condensers. Maximum allowable pressure drop through surface condensers is usually specified by the customer before design.

Utilities

The basic utilities with which we are involved, are steam and water. For efficient design, it is necessary to know minimum steam pressure at the steam inlet to the ejector system and maximum condensing water temperature.

Under critical flow design lowering of steam pressure below design pressure will cause the system to break down completely. Under noncritical flow conditions steam pressure below design will result in a loss of capacity and a resultant loss of vacuum. The use of steam pressure above design will not improve performance and, if the steam pressure is considerably higher than design, performance will be adversely affected, due to the throats of the system being overloaded. The steam supply to an ejector system must be dry. Wet steam will cause poor performance and, in addition, will erode the internals of the system, causing further loss of performance. A well designed steam separator and trap assembly will correct a wet steam condition. If the steam supply is superheated, this condition should be considered before final design. Significant superheat will change the design of nozzles and throats. If a significant superheat condition is not known by Croll-Reynolds before design, steam nozzles and throats will be undersized.

Maximum water temperature must be given before design of the condensing type ejector system. The absolute pressure at the condensers is dependent on the water temperature rise and water flow. The capacity of the stage following the condenser is dependent upon temperature of saturated air which, in turn, is dependent upon incoming water temperature. In order to maintain proper condenser pressures, design water temperature should not be exceeded. The quality of water used is not extremely important in the design of barometric condensers. Croll-Reynolds barometric condensers are non-plugging and are not affected by sludge. Any solid large enough to clog the inlet or outlet would naturally cause severe problems. Surface condensers' water quality must be considered before design. Fouling factors are normally determined and specified by the customer.

Inspection

Periodic inspection of the internals of ejector systems is highly recommended. The frequency of inspection will depend upon the type of service and quality of steam supply. A unit used on corrosive or erosive service will certainly be inspected more often than a unit in non-corrosive service. A good rule of thumb is to inspect the ejector system whenever related equipment is inspected.

Critical dimensions of an ejector system can be obtained from Croll-Reynolds. A visual check, however, is all that is normally required. If steam nozzles and diffusers are smooth and round, and erosion or corrosion is not indicated, replacement of parts is not required. Pitting, etching, or wire drawing, if noticed by the naked eye, will affect performance and call for replacement. Spare steam nozzles and diffusers should be kept in stock for small systems up to 6" suction. Above this size, we recommend steam nozzles be kept as spares.

Trouble-Shooting

Croll-Reynolds steam jet vacuum equipment is highly efficient and trouble-free. As with any equipment in erosive or corrosive service, breakdowns beyond control may occur. Knowledge of correct procedures for locating trouble will save time and valuable product.

Unsatisfactory performance of an ejector system can be caused by external or internal causes. Unsatisfactory performance can also be classified as sudden or gradual. The gradual loss of vacuum will normally suggest internal erosion or corrosion, whereas a sudden loss of vacuum will normally suggest external causes. Since it is easier to check external causes of trouble, all possible external causes should be checked first.

External Causes of Trouble

1. Low steam pressure
2. Wet steam
3. High water temperature or insufficient water flow
4. Entrained air in condenser water.
5. High discharge pressure
6. Fluctuating water pressure
7. Change in load—excessive air leakage

Let us assume that a multi-stage system has lost vacuum. The possible external causes are quickly checked and are found trouble-free. We must now look for internal causes of trouble.

Internal Causes of Trouble

1. Eroded or corroded parts, particularly nozzles and diffusers
2. Clogged nozzles, diffusers and strainers
3. Leaks in steam chests
4. Clogged or fouled water supply
5. Clogged water discharge
6. Excessive leakage—cracked or worn parts
7. Intercondenser water nozzle eroded

In order to reduce the amount of disassembly we will check by stages. Since stages ahead of the Z (or final) stage will not work unless the Z stage is working properly, we must check the Z stage first.

The discharge of the Z stage should be checked visually and audibly. Is water coming out of the discharge? If so, the condenser ahead of the Z stage is flooding. Can a popping noise be heard? If so, the Z stage is not performing properly. Since the majority of ejector problems are found in the Z stage, a simple performance check should be made. The suction flange should be blanked off, and the pressure read at the suction of the Z stage with a mercury absolute gauge. If the suction pressure is above design no load pressure, the Z stage should be disassembled and inspected carefully for clogged or eroded nozzles and diffusers. The steam chest should be carefully checked for indications of steam leakage, particularly around the steam nozzle connection. If erosion or corrosion is in evidence, it is quite likely that the diffusers and nozzles of preceding stages are in poor condition. The preceding stages, therefore, should be checked and parts replaced, if needed. If the Z stage checks out properly, preceding condensers and stages should be checked in reverse order, i.e., Y stage, X stage, W stage . . . Correct interstage pressures can be found in the Croll-Reynolds Instruction Book, or can be obtained from the Croll-Reynolds engineering department through your local representative.

It is, of course, necessary that accurate instruments be used in checking an ejector system. Steam pressure gauges should be calibrated periodically. Compound steam pressure gauges are recommended, since they are not damaged when subject to vacuum. Thermometers must be accurate, since interstage condenser pressures are dependent upon inlet and discharge water temperatures. The type of vacuum gauges used depends upon degree of vacuum. A mercury absolute gauge is usually satisfactory for single, two-stage and three-stage systems. More sophisticated gauges are required for four, five and six-stage systems.

If the customer is operating with four, five and six-stage systems, the proper type gauge will normally be available for trouble-shooting.

If plant personnel cannot quickly locate causes of trouble, Croll-Reynolds engineers are available on short notice. In many instances the trouble can be solved with a phone call.

condensing water temperature.

Under critical flow design lowering of steam pressure below design pressure will cause the system to break down completely. Under noncritical flow conditions steam pressure below design will result in a loss of capacity and a resultant loss of vacuum. The use of steam pressure above design will not improve performance and, if the steam pressure is considerably higher than design, performance will be adversely affected, due to the throats of the system being overloaded. The steam supply to an ejector system must be dry. Wet steam will cause poor performance and, in addition, will erode the internals of the system, causing further loss of performance. A well designed steam separator and trap assembly will correct a wet steam condition. If the steam supply is superheated, this condition should be considered before final design. Significant superheat will change the design of nozzles and throats. If a significant superheat condition is not known by Croll-Reynolds before design, steam nozzles and throats will be undersized.

Maximum water temperature must be given before design of the condensing type ejector system. The absolute pressure at the condensers is dependent on the water temperature rise and water flow. The capacity of the stage following the condenser is dependent upon temperature of saturated air which, in turn, is dependent upon incoming water temperature. In order to maintain proper condenser pressures, design water temperature should not be exceeded. The quality of water used is not extremely important in the design of barometric condensers. Croll-Reynolds barometric condensers are non-plugging and are not affected by sludge. Any solid large enough to clog the inlet or outlet would naturally cause severe problems. Surface condensers' water quality must be considered before design. Fouling factors are normally determined and specified by the customer.

Inspection

Periodic inspection of the internals of ejector systems is highly recommended. The frequency of inspection will depend upon the type of service and quality of steam supply. A unit used on corrosive or erosive service will certainly be inspected more often than a unit in non-corrosive service. A good rule of thumb is to inspect the ejector system whenever related equipment is inspected.

Critical dimensions of an ejector system can be obtained from Croll-Reynolds. A visual check, however, is all that is normally required. If steam nozzles and diffusers are smooth and round, and erosion or corrosion is not indicated, replacement of parts is not required. Pitting, etching, or wire drawing, if noticed by the naked eye, will affect performance and call for replacement. Spare steam nozzles and diffusers should be kept in stock for small systems up to 6" suction. Above this size, we recommend steam nozzles be kept as spares.

Trouble-Shooting

Croll-Reynolds steam jet vacuum equipment is highly efficient and trouble-free. As with any equipment in erosive or corrosive service, breakdowns beyond control may occur. Knowledge of correct procedures for locating trouble will save time and valuable product.

Unsatisfactory performance of an ejector system can be caused by external or internal causes. Unsatisfactory performance can also be classified as sudden or gradual. The gradual loss of vacuum will normally suggest internal erosion or corrosion, whereas a sudden loss of vacuum will normally suggest external causes. Since it is easier to check external causes of trouble, all possible external causes should be checked first.

External Causes of Trouble

1. Low steam pressure
2. Wet steam
3. High water temperature or insufficient water flow
4. Entrained air in condenser water.
5. High discharge pressure
6. Fluctuating water pressure
7. Change in load—excessive air leakage

Let us assume that a multi-stage system has lost vacuum. The possible external causes are quickly checked and are found trouble-free. We must now look for internal causes of trouble.

Internal Causes of Trouble

1. Eroded or corroded parts, particularly nozzles and diffusers
2. Clogged nozzles, diffusers and strainers
3. Leaks in steam chests
4. Clogged or fouled water supply
5. Clogged water discharge
6. Excessive leakage—cracked or worn parts
7. Intercondenser water nozzle eroded

In order to reduce the amount of disassembly we will check by stages. Since stages ahead of the Z (or final) stage will not work unless the Z stage is working properly, we must check the Z stage first.

The discharge of the Z stage should be checked visually and audibly. Is water coming out of the discharge? If so, the condenser ahead of the Z stage is flooding. Can a popping noise be heard? If so, the Z stage is not performing properly. Since the majority of ejector problems are found in the Z stage, a simple performance check should be made. The suction flange should be blanked off, and the pressure read at the suction of the Z stage with a mercury absolute gauge. If the suction pressure is above design no load pressure, the Z stage should be disassembled and inspected carefully for clogged or eroded nozzles and diffusers. The steam chest should be carefully checked for indications of steam leakage, particularly around the steam nozzle connection. If erosion or corrosion is in evidence, it is quite likely that the diffusers and nozzles of preceding stages are in poor condition. The preceding stages, therefore, should be checked and parts replaced, if needed. If the Z stage checks out properly, preceding condensers and stages should be checked in reverse order, i.e., Y stage, X stage, W stage . . . Correct interstage pressures can be found in the Croll-Reynolds Instruction Book, or can be obtained from the Croll-Reynolds engineering department through your local representative.

It is, of course, necessary that accurate instruments be used in checking an ejector system. Steam pressure gauges should be calibrated periodically. Compound steam pressure gauges are recommended, since they are not damaged when subject to vacuum. Thermometers must be accurate, since interstage condenser pressures are dependent upon inlet and discharge water temperatures. The type of vacuum gauges used depends upon degree of vacuum. A mercury absolute gauge is usually satisfactory for single, two-stage and three-stage systems. More sophisticated gauges are required for four, five and six-stage systems.

If the customer is operating with four, five and six-stage systems, the proper type gauge will normally be available for trouble-shooting.

If plant personnel cannot quickly locate causes of trouble, Croll-Reynolds engineers are available on short notice. In many instances the trouble can be solved with a phone call.