Ejectors Have a Wide Range of Uses

This introduction to ejectors will show you some of their many uses, and the handy check list will help you get the right one for the job

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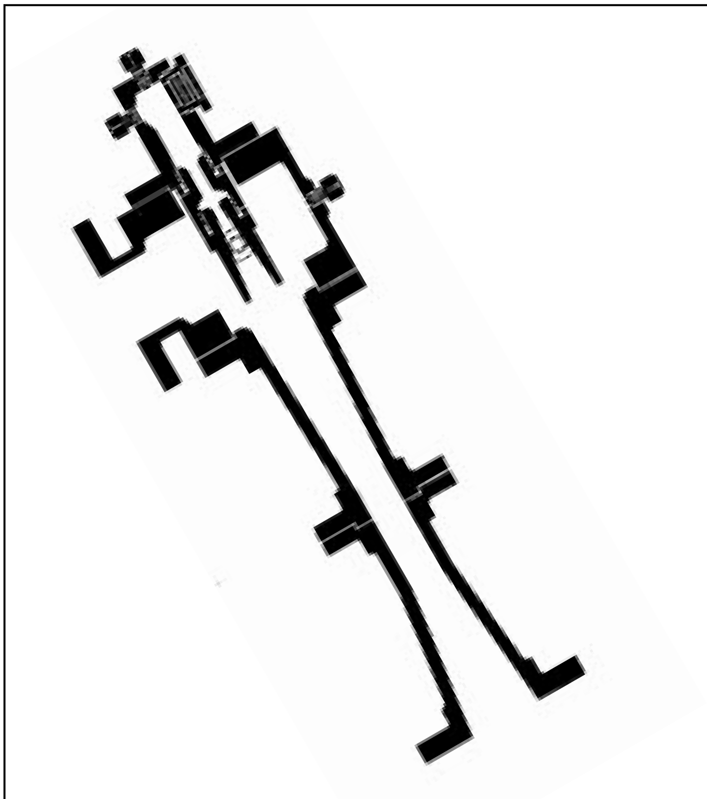

EJECTORS

Ejectors are simple pieces of equipment. Nevertheless, many of their possible services are overlooked. They often are used to pump gases and vapors from a system to create a vacuum. However, they can be used for a great number of other pumping situations.

Here are three articles which will help you answer questions about this type of equipment. The first, "Ejectors Have Wide Range of Uses," suggests ways to harness this equipment to an advantage. It gives a check list of information needed by the vendor.

If you can then use the typical steam jet ejector, the second article tells points to consider when you "Figure What an Ejector Will Cost." The third article, suggesting "How To Get The Most From Ejectors," gives tips on trouble-shooting and choosing materials of construction.

Harold L. Hoffman
Process and Construction Editor

Ejectors are employed in the industry in numerous, unique and even sometimes bizarre ways. They can be used singly or in stages to create a wide range of vacuum conditions, or they can be operated as transfer and mixing pumps. The ejectors have the following advantages over other kinds of pumps:

- Rugged and simple construction
- Capability of handling enormous volumes of gases in relatively small sizes of equipment
- Less maintenance requirements
- Simple operation

WHAT MAKES THEM WORK

All ejectors operate on a common principle. The single stage ejector, in its simplest form, consists of an actuating nozzle, suction chamber and a diffuser. The actuating fluid, which may be a gas, vapor or liquid, is expanded from its initial pressure to a pressure equal to that of the secondary fluid. In the process of being expanded, the actuating fluid is accelerated from its initial entrance velocity, which is negligibly small, to a high velocity. In the suction chamber, the actuating fluid induces a region of low pressure-high velocity flow which causes the secondary fluid to become entrained and mixed with the actuating fluid. During the mixing process, the actuating fluid is retarded and the secondary fluid is accelerated. As the mixture enters the diffuser, it is compressed to the exit pressure by rapid deceleration. The purpose of the ejector is to transport and compress a weight of induced fluid from the suction pressure to the exit pressure. By staging ejectors it is possible to obtain a very large range of suction pressures from atmospheric down to as low as one micron of mercury absolute.

In multistage ejectors, it is usually advantageous to condense the steam from each stage in a water-cooled intercondenser so as to reduce the load to the succeeding stage. This reduces the size and steam consumption of the succeeding stages and results in a

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much more efficient ejector system. Of course, the steam condensing must take place at a pressure above that corresponding to the saturation pressure of the cooling water.

An intercondenser, however, increases the initial cost of an ejector. It must be determined, therefore, whether or not the additional expense of an intercondenser is worth the savings that will be forthcoming in steam economy. Small ejectors for pilot plants, laboratory use or intermittent service may not warrant intercondensing. As many as 4 or 5 non-condensing stages may be justified under some circumstances.

Wherever it is desired to reclaim condensate, it is good practice to use a condenser on the final stage of an ejector system which discharges to atmospheric pressure. An aftercondenser. as it is commonly called, will serve to silence any noise that may issue from the discharge of the final stage. An aftercondenser also eliminates the nuisance or objection of discharging steam in a confined area. Aftercondensing does not increase the efficiency of an ejector, but it may increase the efficiency of the steam generating cycle by reclaiming condensate or preheating boiler feed water.

Condensers for ejectors are available in either surface type or direct contact type (barometric or jet condensers). Direct contact condensers have the following advantages.

- They cost less than a surface type designed for equal service.
- They seldom or may never require cleaning.
- The problems with corrosion are usually minimized in a direct contact condenser since the corrosive media from the ejector is diluted by the condensing water.
- Condensable vapors of relatively high vapor pressure which are partially soluble in water, such as ammonia, can be more effectively condensed in direct contact condensers because of the diluting effect of the cooling water.

Surface condensers, on the other hand, are advantageous for the following reasons:

- They do not mix the cooling water with the condensate thus permitting recovery of the condensate which may be suitable for boiler feed water.
- If height limitations require the use of a condensate pump only a relatively small pump is required as compared to a low level direct contact condenser where the pump must handle both the condensate and the cooling water.
- If the condensate contains a corrosive, poisonous or radioactive substance, special provisions may be necessary for disposing of the condensate which can be kept to a minimum by the use of a surface type condenser.

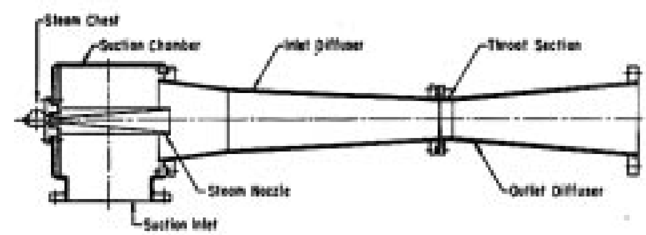
HOW THEY OPERATE

Most ejectors have a fixed capacity curve as shown in Figure 1. In this type of ejector the capacity is a function of the absolute pressure at the suction inlet. Increasing the steam pressure above the design pressure will not increase the capacity of the ejector: as a matter of fact, it will actually decrease the capacity because of the choking effect of the excess steam in the diffuser throat.

In contrast to the fixed capacity curve of Figure 1, some ejectors have a family of capacity curves, as shown in Figure 2, where the capacity is also a function of the steam pressure. These designs are referred to as *throttling type* ejectors because the capacity can be decreased by decreasing the steam pressure. In these designs, the ratio of discharge pressure to suction pressure is relatively low as compared to fixed capacity designs.

Ejectors are most sensitive to changes in discharge pressure. If the discharge pressure on an ejector exceeds its maximum stable discharge pressure, the operation will become unstable and the capacity will no longer be a function of the absolute pressure. Stabile operation can be attained either by increasing the steam flow or by decreasing the discharge pressure.

For stable operation, the steam pressure for most ejectors must be above a certain level. This lower boundary will have two magnitudes depending upon whether the steam pressure is approaching the transition point from the unstable side or from the stable side.



THESE PARTS MAKE AN EJECTOR

STEAM CHEST. This is the connection through which the high pressure motive steam supply is introduced.

SUCTION CHAMBER. This provides a plenum chamber with the appropriate connections for the suction inlet, diffuser and steam nozzle. This part can sometimes be eliminated by incorporating the diffuser connection and steam nozzle connection in the vessel which is to be evacuated. Frequently more compact designs and savings in cost can result from such designs.

STEAM NOZZLE. This is the heart of an ejector since it converts the energy of pressure to velocity and directs the flow of motive steam into the diffuser.

INLET DIFFUSER. This provides a correctly shaped introductory section and converging diffuser section to handle the high velocity flow of fluids. It is in this section that entrainment and mixing of the motive and load fluids is completed and the energy of supersonic velocity is converted to pressure.

THROAT SECTION. This is the transition piece between the converging supersonic inlet diffuser and the diverging subsonic outlet diffuser.

OUTLET DIFFUSER. This provides a correctly shaped diverging diffuser section for completing the conversion of velocity to pressure. After the fluid flow has passed through the throat of the diffuser, the flow is essentially subsonic. The outlet diffuser section further reduces the fluid velocity to a reasonable level so as to convert practically all the velocity energy to pressure energy.

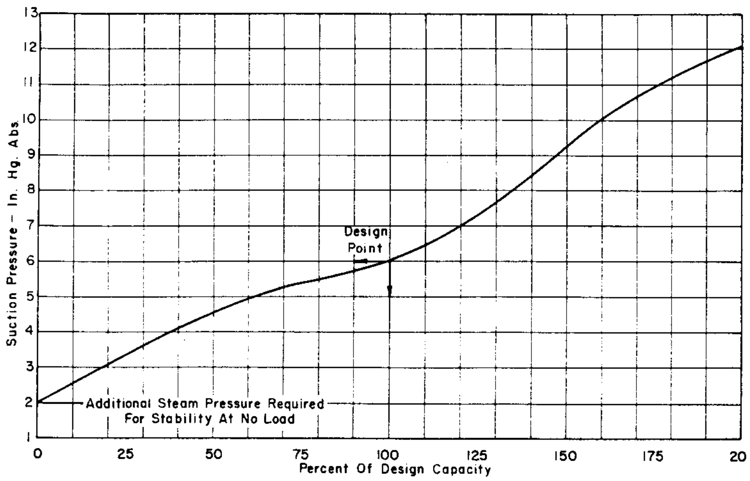


FIGURE 1—*For a fixed-capacity ejector, increasing the steam pressure will not increase the capacity.*

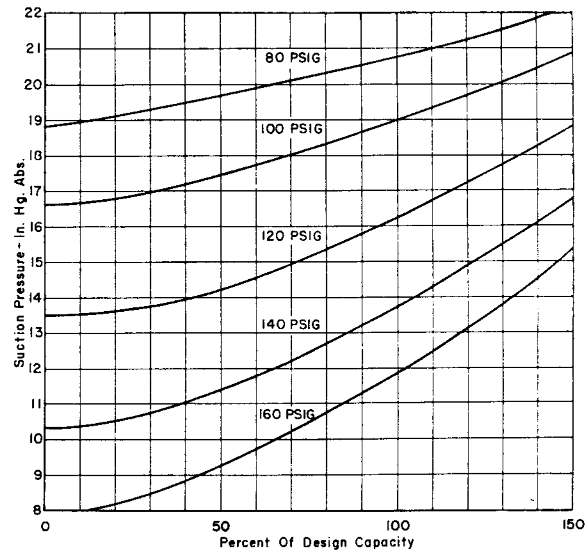


FIGURE 2—*The capacity of a throttling ejector is a function of both the suction pressure and the motive ste pressure. Basic design here is 100 psig.*

If the steam pressure is being increased from a region of unstabile operation, the point at which the ejector first becomes stable is called the *motive steam pickup pressure.* The pickup pressure is a direct function of the discharge pressure. At the higher discharge pressure, the ejector will regain its stability once the motive steam pressure is increased to the pickup pressure; but the absolute pressure for a particular load may be increased slightly from what it was at the lower discharge pressure.

For every discharge pressure in an ejector there is also a minimum steam flow below which the operation will be unstable.

If the steam pressure is being decreased from a region of stabile operation, the point at which the ejector becomes unstable is called its *motive steam break pressure*. The motive steam break pressure is below the motive steam pickup pressure for any given discharge pressure and load. For this reason, the ejector operating with steam pressure between the break and pickup points may be stable or unstable depending on the direction of the steam pressure change.

The terms "break" and "pickup" pressures are also used in reference to the discharge pressure of an ejector for the pressures at which ejector operation becomes unstable and stable, respectively. These critical discharge pressures are a function of the steam pressure and load.

Some ejector stages have no motive steam break and pickup pressures because of the low ratio of discharge pressure to suction pressure over which they operate, or because they are designed to eliminate this characteristic. In these ejectors the capacity varies directly with steam pressure over certain operating limits.

Single-Point Design. If only one load and vacuum are required for a particular application, single and multistage ejectors can be designed specifically for one condition. This saves steam.

Occasionally, however, single-point design ejectors are not always stable at very light loads or at loads slightly in excess of design. An ejector of this design is not necessarily undesirable if the ejector always operates at the exact design conditions. This, of course, depends on whether or not it's possible to determine accurately the load on the ejector before hand.

Close designs can often result in substantial steam and water savings in large systems. However, it is usually not possible to determine exact operating conditions prior to design. For this reason single-point designs are not in general use.

Multipoint Design. Occasionally an ejector must operate alternately at two or more conditions of load and vacuum. In this instance the ejector must be designed for the most difficult conditions (or the conditions that call for the largest ejector). The other conditions will then fall within the performance curve of the larger ejector.

An ejector of this type is sometimes considerably oversized for some of the required conditions in order to achieve the most economical design from the standpoint of initial cost. If operational economy is important at each of the conditions, it may be desirable to use two separate ejectors to achieve efficiency at both operating points.

It is possible in some applications to provide an ejector for two or more different operating conditions—with maximum efficiency at each point—by providing a steam nozzle or diffuser designed for each condition. In changing operations from one condition to the other, it is necessary to shut down the system long enough to change the nozzle or the diffuser. Often, substantial steam savings

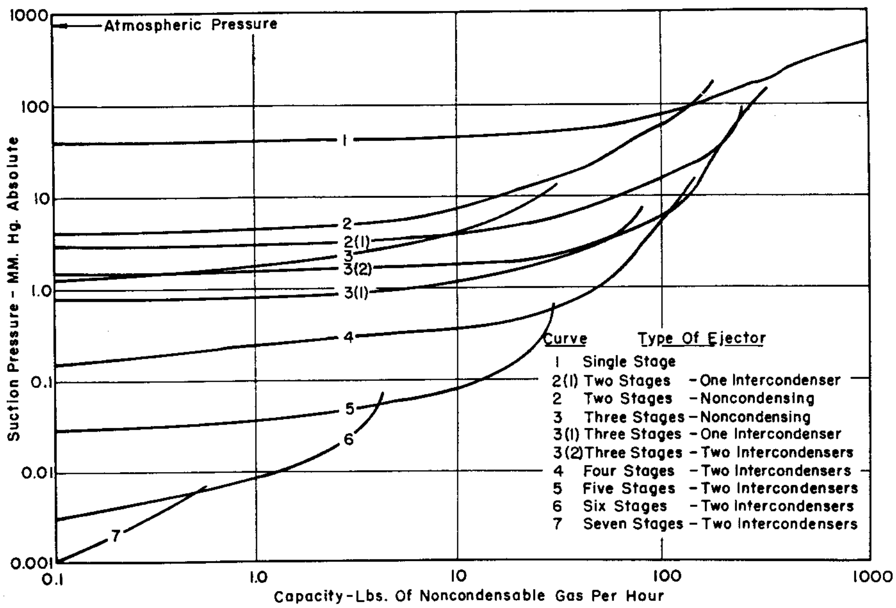


FIGURE 3—A wide range of pressures can be achieved by using various combinations of ejectors and condensers. The same steam consumption is used for each design here.

can be realized in this way, thus avoiding the cost of two ejector systems. Designs of this kind have found applications in the recompression boosters for evaporators and large ejectors for high-altitude wind tunnels.

In certain applications an ejector is required to meet a specific design curve. Then sometimes considerably more steam is used than for a single-point design to produce the desired characteristic curve. At some point in the curve the ejector is, of course, relatively efficient and at either side of this high-efficiency point the ejector is relatively inefficient.

Stages Give Versatility. It is possible to meet a large variety of operating conditions economically with multistage ejectors by operating only some of the stages at a time.

All ejectors have at least as many different performance curves as they have stages. For a particular stage to operate, all the succeeding stages must, of course, be operating. Practically all points within the envelope formed by these curves can be reached by the ejector. Thus, the ejector can cover an entire area of possible operating conditions.

Six and seven stages of compression have lengthened the range of operation of steam ejectors down to absolute pressures as low as 1 micron of Hg (0.001 mm. Hg. Commercial designs are available and should often be used in place of other kinds of vacuum pumps.

TO GET VACUUM

In the field of vacuum processing, steam jet ejectors have been most widely used. Steam jet ejectors are ideal for use on all kinds of stills, vacuum deaerators, evaporators, crystallizers, oil deodorizers, steam vacuum refrigeration, flash coolers, condensers, vacuum pan dryers, dehydrators, vacuum impregnators, freeze dryers, vacuum filters and more recently on stream degassing of metals and vacuum melting of metals. Steam jet ejectors offer operational and economical advantages over a very large range of pumping capacities. Corrosive applications are easily handled providing a suitable material is available that can withstand the corrosive medium in question with reasonable structural strength at the temperatures to be encountered by the ejector system.

Figure 3 is a comparison of capacity and operating range for most of the common designs of steam jet ejectors handling any non-condensable gas such as air. This graph is based on each of the designs using the same amount of motive steam at 100 psi pressure. Each point on the curve represents a point of maximum efficiency, therefore, it should be borne in mind that an ejector cannot necessarily operate over the entire range of suction pressures indicated for a particular design. A reasonable range of operation for good efficiency would be from 50 percent to 115 percent of the design capacity. An ejector may operate well in excess of these figures; however, the efficiency will usually decrease at points beyond these limits.

Water temperature affects the load which may be handled by an ejector. If condensing water colder than 85 F. were used for our comparison in Figure 3, all of the curves representing the performance of ejectors that require water would be shifted to the right, indicating an increase in capacity for these designs.

If water warmer than 85 F. were used, the shift in these curves would be to the left. And if the water temperature were high enough, some of the curves would move far enough to the left to disappear from the graph entirely.

The effect of water temperature is more critical on ejectors designed for low absolute pressures. For example; in a 4-stage ejector, the increase in capacity for 65 F. water over 85 F. water for a particular steam consumption will be greater at 1 mm. Hg. Abs. than at 4 mm.

Steam pressures higher than 100 psig will permit designing for a larger capacity for a particular steam consumption. A greater benefit from high steam pressures can be realized in 1- and 2-stage ejectors than in other designs.

The benefit from high-steam pressures becomes less as the absolute pressure for which the ejector is designed decreases. Single-stage ejectors designed for absolute pressures lower than 200 mm. Hg Abs. cannot operate efficiently on steam pressures below 25 psig. However, initial stages of multistage ejectors can often be designed to operate efficiently on steam pressures below 1 psig.

It is not uncommon to use an extra stage for an ejector designed to operate on steam pressures as low as 15 psig.

USE THESE SPECIFICATION CHECK LISTS

STEAM JET EJECTOR

Application________
Absolute pressure to be maintained by the ejector________
Fluids to be handled by the ejector________
Noncondensables gases, #/hr.________ M.W.________
Water vapor, #/hr.________
Condensable vapors other than water vapor: #/hr.________ M.W.________
Temperature of load fluid, F.________
Steam pressure available at the ejector, psig________
Steam temperature at the ejector, F.________
Cost of steam (if known), $/1,000 lbs.________
Is cooling water available for intercondensing?________
Cooling water source? Cooling Tower ☐ City supply ☐ Well ☐
Cooling water temperature at the ejector, F.________
Cooling pressure at the ejector, psig________
Cost of cooling water (if known), $/1,000 gal.________
Is cooling water relatively clean?________
Turbidity (if known)________
If evacuation time to establish the required absolute pressure in the system is important, then state net volume to be evacuated—cu. ft.________
Time allowed for evacuation, minutes________
Will system to be evacuated be wet or dry?________
If wet, state liquid present and quantity to be removed by evaporation.
Altitude at installation if abnormally high________
Discharge pressure final stage________
Type of intercondenser preferred?
Surface ☐ Direct Contact ☐
Is an aftercondenser required?
Type: Surface ☐ Direct Contact ☐
Is economy of operation to be stressed?________
Is low initial cost of ejector to be stressed?________
Any limitation on steam supply available that might affect ejector design?________
Any limitation on water supply available that might affect ejector design?________
Is installation to be inside or outside?________
Is A.S.M.E. Code construction required on inter and after-condensers?________
Are there any other construction codes required?________
Is there any special painting required?________
Is there any special orientation of components to be considered?________
Is there any space limitation to be considered?________
Is there any weight limitation to be considered?________
Size of suction connection from system to ejector.________
Is there any special supporting structure to be furnished?
____
Accessory equipment to be furnished with ejector:________
Steam valves, strainers and interconnecting steam piping________
Condensate pumps________
Discharge head required________
Electric power available: cycles________
volts________ phase________
Electric motors to be: Drip proof ☐ Splash proof ☐ TEFC ☐ Explosion proof ☐
Steam purifier________
Liquid level controls for intercondenser hotwell________
Traps________
Spare parts________
Other equipment________
Material: Diffuser and suction chamber:
Standard________ Special________
Steam nozzle: Standard________ Special________
Inter and after condenser-shell:
Standard________ Special________
(If shell & tube) Tubes: Adm.________ Special________
(If shell & tube) Tube sheet: Steel________ Special________
Standard materials are chosen to resist ordinary corrosion of steam and water. If corrosive vapors or liquids are involved, state under special material customer has found best for his operation. Is export packing required?

WATER OR LIQUID JET EJECTOR

Suction Pressure to be maintained________
Discharge Pressure________
Total load fluid #/hr.________ Temp. F.________
Load Fluid: Liquid #/hr.________ M.W.________
Non-condensables #/hr.________ M.W.________
Condensable Vapor #/hr.________ M.W.________
Propelling Liquid________
Propelling Liquid Pressure, psig________
Propelling Liquid Temperature (Maximum), F.________
Properties of propelling liquid (if other than water)________
____
Specific Gravity________
Specific Heat, Btu/#—F.________
Vapor Pressure at inlet Temperature, psia________
Materials of Construction
Suction Chamber________ Diffuser________
Steam Nozzle________ Steam Chest________
Accessories
Propelling liquid valve________
Propelling liquid strainer________
Other equipment (if any)________
____
____

It is very important that the steam used to motivate ejectors be at least dry-saturated steam. Small amounts of moisture can be removed successfully by using a good, properly sized steam separator which will remove 98 to 99 percent of the moisture entering the separator.

Water jet ejectors are available that can economically handle a nominal amount of air leakage in vacuum equipment along with a large condensable vapor load. Water pressures as low as 10 to 20 psig will sustain a moderate vacuum while water pressures of 40 psig and higher will efficiently sustain a vacuum in the range of 4.0 inches to 1.0 inch Hg. Abs. pressure with a single stage ejector depending on the load to the ejector and the temperature of the motivating water.

The water operated ejector combined with a steam jet ejector can yield a very compact, efficient and relatively inexpensive vacuum pumping system. The water jet ejector serves both as an intercondenser and a final stage to the ejector system. In instances where the non-condensables entering the ejector system are small compared to the condensable vapors, say 10 percent by weight non-condensables or less, the water jet ejector can take the place of a two stage ejector in maintaining a suction pressure of 3 inches to 2 inches Hg. Abs. to which the steam jet ejector can discharge. The result is a low priced and efficient vacuum pumping system. In Europe, an interesting equivalent to the water ejector is a centrifugal water jet ejector which combines a centrifugal pump with the ejector principle and which recirculates the motive water handling air and vapor loads in a single piece of equipment. It is likely, however, that the combination of a separate centrifugal pump and a separate water jet ejector would be a more competitive pumping system than the European centrifugal ejector pump.

STEAM VACUUM REFRIGERATION

In recent years steam vacuum refrigeration systems have become more popular than ever. They produce chilled water in the range of 40 F to 60 F for cooling process heat exchangers, air conditioning and the multitude of other applications where chilled water is required. The booster steam jet ejector draws off flash vapors and discharges them to the barometric condenser. The non-condensed materials are drawn from the barometric condenser by two more stages of steam ejectors and an inter condenser.

Another type of refrigeration system uses a surface condenser to replace the barometric condenser. Since the latter system does not mix the condensate with the cooling water, the condensate may be pumped from a condenser draw-off leg.

In addition to cooling water, flash cooling and concentrating of liquid solutions are two other applications for the steam vacuum refrigeration system. These systems are extremely simple in operation and rugged in construction. With simple automatic controls, they can function at excellent efficiency at all times of the year at all loads. Over-loading the system does not harm the equipment. The system will produce more refrigeration capacity at over-loads. but at a higher temperature than that for which it was designed. Most large capacity steam vacuum refrigeration units are installed outside and require no protection from the weather other than a protective coat of weather resistant paint. When indoor installations are required, the component parts can be arranged in almost any fashion to suit the particular space requirements. Steam vacuum refrigeration efficiently utilizes steam at pressures as low as 2 psig and sometimes lower.

FOR PUMPING AND MIXING

Steam jet ejectors can be designed to pump liquids and even finely divided solids for pneumatic conveying systems. In the latter service, they are becoming widely used to transfer fluidized catalyst with ease and a minimum of loss.

Liquid jet ejectors can also pump liquids with good efficiencies as can steam jet ejectors. In any case, the motive liquid pressure must be sufficiently higher than the suction and discharge pressures of the ejector to yield an economical flow ratio of motive liquid to load liquid. In addition to liquid pumping, liquid operated ejectors can be used to agitate, mix or meter liquid solutions.

Water operated ejectors are popularly used for fume scrubbing. A large volume of gas and vapor can be entrained at drafts from a fraction of an inch of water to about 10 inches of water and higher with good water economy. In these applications, obnoxious, corrosive or poisonous fumes can be sucked out of an enclosed area by means of a simple water jet ejector.

In addition to vacuum pumping, ejectors have found many applications for compressing fluids to pressures above atmospheric. Steam jet thermocompressors are a very efficient means of boosting low-pressure waste steam to a pressure where it can serve a useful purpose. High-pressure motive steam which might otherwise be throttled for use in an evaporator or heat exchanger can be used to actuate a steam jet thermocompressor. The thermocompressor can serves two purposes: (1) it throttles the high-pressure steam to the desired pressure and (2) it compresses low-pressure waste steam to a pressure where it is again useful.

Steam jet air compressors are useful for supplying compressed air in an explosion hazardous area where electrical equipment would have to be of explosion proof construction and relatively expensive. Compressed air at 20 psig for pneumatic controls is a typical application for steam jet air compressors.

It is often essential that an ejector be actuated by a gas or vapor other than steam. Excellent examples of this are the gas actuated ejectors used to compress low pressure manufactured gas from atmospheric pressure to the 15 or 20 psig pressure required for distribution mains. High pressure natural gas at about 100 psig or higher is used to actuate the ejector. The ejector serves to (1) compress the manufactured gas, (2) throttle the high pressure natural gas and (3) blend the two gases to the correct proportion.

HOW TO SPECIFY

When considering ejector equipment for an application. one should include all possible information relating to the performance required by the equipment. It is important, therefore, to mention here the type of information required by the manufacturers of ejector equipment. If the manufacturer has knowledge of the application, many design considerations will be evident and so it is advantageous and sometimes very important to reveal the application when writing specifications. The sample questionnaires accompanying this article will serve as a check list to anyone who must write ejector specifications. In many applications there may be additional information required; however, these questionnaires concern the essential data needed.

ABOUT THE AUTHOR

F. Duncan Berkeley is a design and development engineer for Graham Manufacturing Co., Batavia NY. He handles design, development and testing of steam jet ejectors. condensers, heat exchangers and related equipment. A graduate of Rensselaer Polytechnic Institute with a B.M.E. degree, he joined Graham in 1950. He worked in the Heat Exchanger division, Ejector Test department and Ejector Engineering division. The author of several published articles on ejectors and related equipment, Berkeley spent several weeks in Europe recently, observing progress on ejectors and heat exchangers.