Optimizing vacuum systems for energy-efficient operation

Ejector, liquid-ring pump combination boosts energy savings

LOREN E. WETZEL, ASSISTANT MANAGER OF CONTRACT ENGINEERING

The economic factor must be taken into consideration in the design and manufacture of equipment that utilizes utilities such as steam, cooling tower water and electricity.

Evaluating operating costs can make or break the profit of a commodity, and can dictate whether an expansion should take place.

Using a combination of liquid-ring pumps and steam jet ejectors in vacuum system design provides cost savings to a chemical plant by reducing energy requirements, maintenance and downtime.

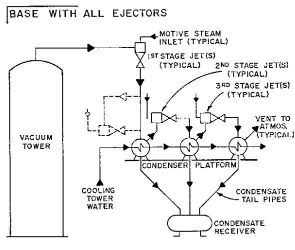
EJECTOR OPERATION

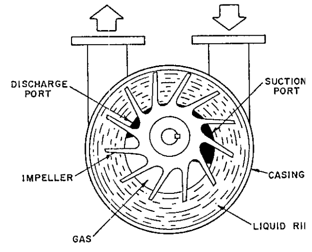
Steam jet ejectors have long been used as a means of transporting gases, liquids or solids from one pressure level to a higher pressure level, particularly in subatmospheric applications.

The ejector has no moving parts, making it easy to operate and durable.

In operation, atmospheric- to high-pressure fluid passes through a motive nozzle where its pressure is dissipated, accelerating the fluid to high velocity as it exits the mouth of the nozzle.

This high-velocity fluid stream (usually steam) issuing from the nozzle mouth entrains the suction fluid. These two streams mix as they pass into a diffuser. The velocity profile constantly changes and the pressure inside the venturi of the ejector continues to rise as the discharge of the venturi is reached.





Left: Fig. 1. Typical schematic of a chemical process ejector system.

Right: Fig. 2. Liquid-ring pump operating principle.

A single-stage ejector can compress gases, liquids or solids over a range of 12:1 or more, depending on the actual suction and discharge pressures.

To produce various vacuum levels, ejectors are staged together in two, three, four or more stages.

Ejectors can be designed as single-element or multielement systems, allowing for flexibility in the process load condition. Along with the steam jet ejectors, shell-and-tube vacuum condensers can be utilized in the system design to condense steam and organic vapors and cool the non-condensible gases to the optimum interstage pressures.

Ejector systems for applications in the chemical industry typically have a primary jet mounted at or near the top of the process evaporator pointing vertically down or located at the same elevation as the intercondensers, approximately 45 ft minimum above the condensate receiver liquid level (Fig. 1).

A variation of this configuration is to eliminate the primary jet, and the load from the process evaporator goes directly to the condenser.

The atmospheric-stage jets and the stage directly upstream of the next condenser handle all non-condensible gases. This results in relatively large ejector sizes and, thus, high steam consumption.

STEAM CONSUMPTION

While the use of steam jet ejectors is an economical method of transporting product between pressure levels, to obtain optimum energy efficiency a design that reduces steam consumption should be considered.

Energy costs for the operation of an ejector-condenser unit vary widely. With steam, the cost depends on the generation method (i.e., oil, gas, coal and electricity). For example, steam costs vary from $1.00 to $15.00 per 1,000 lb; while the cost of cooling water varies from $0.30 to $2.50 per 1,000 gal; and electricity costs vary from $0.02 to $0.10 per kw per hr.

The spiraling increase of fuel costs for generating steam forces designers to consider vacuum system configurations that use a combination of steam and electricity. The use of liquid-ring pumps reduces steam consumption while maintaining reliable operation.

PUMP OPERATION

A mechanical liquid-ring pump can operate singly, or can be paralleled with any combination of ejectors. The pump uses a seal liquid (usually water), which is thrown to the periphery of the casing to form a liquid ring (Fig. 2).

The liquid ring seals the space between the impeller blades and the casing, and the chambers at the top-most part of the impeller hub are filled with liquid.

As the pump's impeller rotates, the liquid ring moves away from the hub. This movement increases the space in the pumping chamber and draws gas into the chambers. As the impeller rotates, any gas in the impeller chambers is compressed by the liquid ring and expelled through the discharge port. This sequence is repeated with each revolution. The seal liquid absorbs the heat created by compression, friction and condensation.

The pump is driven by an electric motor at standard speeds from 400 rpm to 1,750 rpm and in some cases, at speeds to 3,600 rpm. Routine inspection, maintenance and repairs usually are accomplished during scheduled turnarounds, reducing equipment downtime.

For water conservation, a complete recirculation-type system or partial recirculation system can be purchased.

Based on the pumping capacity shown in Fig. 3, a single-stage pump has a higher capacity than a two-stage pump at pressures of approximately 225 mm Hg absolute and higher; whereas a two-stage pump has a higher capacity at pressures less than 225 mm Hg. The single-stage ejector consumes 432 lb per hr of 100-psig steam.

To accomplish the same performance, a single-stage or two-stage liquid-ring pump would require a motor utilizing 13 brake horsepower (BHP). (Refer to the figure in the sidebar for estimating the costs of steam and electricity in specific cases.)

SYSTEM BENEFITS

In addition to energy optimization, the use of a system utilizing a combination of liquid-ring pumps and steam jet ejectors (Fig. 4) reduces noise and maintenance hazards.

Sound pressure levels measured on the dBa scale at 1 m are considerably lower for a single- or two-stage liquid-ring pump compared to a single-stage ejector discharging to a shell-and-tube aftercondenser. An ejector often has to be insulated with a noise and thermal barrier material, which is cumbersome during system maintenance.

COST CONSIDERATIONS IN VACUUM SYSTEM DESIGN

To assess the utility costs of combination liquid-ring pump and ejector systems, a three-stage ejector system is designed in which the third-stage ejector consumes 1,830 lb per hr of 100-psig steam. The three-stage system typically would be arranged with a first-stage ejector discharging into a vacuum condenser, a second-stage ejector discharging into a second vacuum condenser, and a third-stage ejector discharging into an aftercondenser.

For this example, the third-stage ejector is replaced with a liquid-ring vacuum pump, creating a system with a two-stage ejector, one vacuum intercondenser and a liquid-ring vacuum pump.

The single-stage liquid-ring pump absorbs 50 brake horsepower (BHP) and has the same performance capabilities as the third-stage ejector.

Arbitrarily selecting a steam cost of $5.00 per 1,000 lb and an electrical cost of $0.10 per kw per hr results in a steam cost of $80,000.

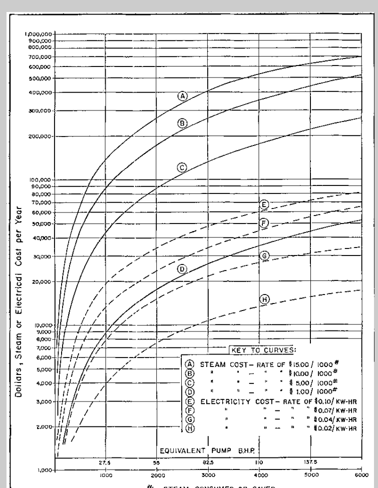
To operate the liquid-ring pump, the electrical cost is $32,000, providing a utility savings of $48,000.

In addition to energy savings, capital cost for associated equipment also must be considered to find the actual payback period. The third-stage ejector utilizes a shell-and-tube aftercondenser, which is not required in the liquid-ring pump design.

The capital cost of the ejector and shell-and-tube aftercondenser is approximately $12,000; while the liquid-ring pump and its associated equipment is approximately $14,000.

Thus, the use of the liquid-ring pump provides a total cost savings of $46,000 in the first year, without considering savings that can be gained from the use of a smaller platform, and the elimination of energy required to extract Btus from the cooling tower water used in the shell-and-tube aftercondenser.

This example looks at replacement of only the third-stage ejector. Other design considerations include replacement of the intercondenser and aftercondenser for potential energy savings.



A comparison of approximate costs of steam and electricity. Using these rates, an individual can analyze the cost savings based on the rates that are applicable for his/her locality.

The horizontal axis is labeled in pounds of steam (consumed or saved) and the approximate equivalent pump BHP, and the vertical axis is the steam or electrical cost per year.

Additionally, the liquid ring's scrubbing action reduces emissions as compared to the discharge from the atmospheric-stage ejector, even with a shell-and-tube aftercondenser. However, this reduction depends on the molecular weight and vapor pressure of the organic vapors.

DESIGN CONSIDERATIONS

While energy conservation is a key factor in the design of a vacuum system, there are several other specifics that should be taken into consideration. Among these are:

- System performance and flexibility;
- Optimum interstage pressures;
- Approach temperature;
- Percent non-condensibles;
- Liquid-ring pump size limits;
- Seal liquid fluid choices;
- Seal liquid temperature and rise;
- Single- or two-stage pump;
- Sealing methods (packing or mechanical seals);
- Selection of pump materials for process conditions;
- Packaging by manufacturer to minimize installation time;
- Use of condensate hotwell(s) to separate hydrocarbons or organics from recirculated seal water;
- Existing system revamp, including properly matching up existing ejectors with new pumps.

The design of a vacuum system requires careful planning and analysis. Energy savings must be a primary consideration in this process.

Installations that utilize a combination of steam ejectors and liquid-ring pumps can reduce energy consumption dramatically, providing chemical facilities with increased profits and reducing the cost of product for their customers.

To receive additional information on liquid-ring pumps, Bulletin P-86-D "Liquid-ring pumps for vacuum and compressor service" — Graham Manufacturing Co. Inc., Batavia, NY.

Loren E. Wetzel is assistant manager of contract engineering at Graham Manufacturing Co. Inc., Batavia, NY. He has a B.S. in mechanical engineering.

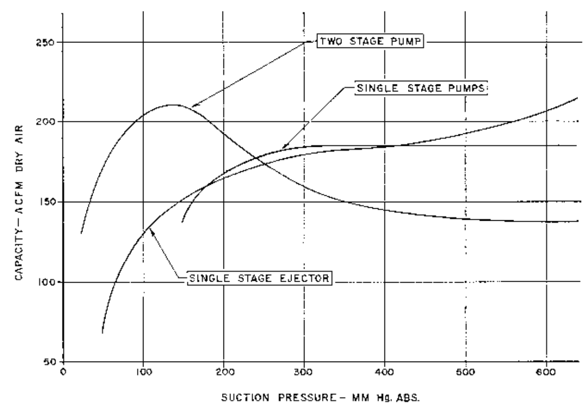
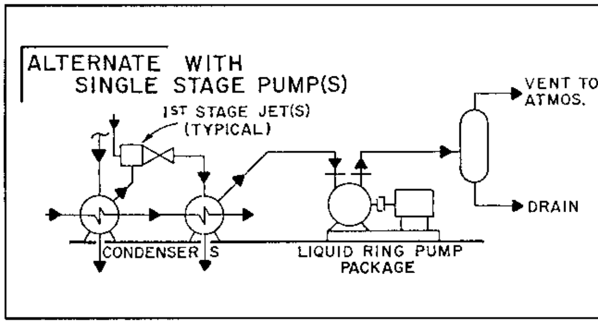


Fig. 5 Dry Air Performance Comparison of a Single Steam Jet Ejector Versus Single & Two Stage Liquid Ring Pumps



Top: Fig. 3. A dry air performance comparison of a single-stage steam jet ejector discharging to atmospheric pressure, a single-stage liquid-ring pump, and a two-stage liquid-ring pump.

Bottom: Fig. 4. Typical schematic of a combination liquid-ring pump and ejector system for a single-stage pump.