CHARACTERISTICS AND APPLICATIONS OF EJECTOR SYSTEMS

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Abstract

The paper presents an introduction to the principle of the operation of ejectors and deals with the three broad types encountered in industry, namely steam, air and water motivated units. The reasons for multi-staging ejector systems is discussed and examples given of typical applications. Methods of trouble-shooting vacuum systems are dealt with in detail. The interesting combination system of an ejector and liquid ring pump is presented with reference to possible applications in the sugar industry. The advantages and disadvantages of ejectors to create vacuum in comparison with mechanical pumping systems are also discussed.

Introduction

The ejector is a device for creating vacuum. It operates by converting pressure into kinetic energy in a jet steam, entraining and mixing with the suction fluid and regaining pressure by the reverse process of velocity reduction.

The device consists of three basic parts:

(1) The motive nozzle, which creates the jet stream from the upstream high pressure fluid. This may be steam, compressed air or gases, water or other liquids.

(2) A tee in which the nozzle is centrally located and having a branch for connection to the vessel or equipment to be evacuated.

(3) A combining tube having converging, parallel and diverging sections.

The jet stream spreads on leaving the nozzle and the high velocity stream fills and seals the inlet end of the combining tube, thus creating the same pressure in the tee as that produced in the jet stream by acceleration of the motive fluid. Fluids drawn into the tee, gases or liquids, receive momentum from the jet stream to produce a lower velocity mixed stream. This is still fast enough to undergo an energy transformation from velocity to pressure as it slows down in the diverging section of the combining tube.

The mixed fluid discharges from the ejector at a higher pressure than the suction condition, and seen from the point of view of the suction load, the ejector is thus a compressor without moving parts.

The mass ratio of suction fluid to motive fluid is known as the entrainment ratio and this value is determined by the pressure of the motive fluid as well as its enthalpy. The pressure ratio against which the unit is required to operate will also play an important role.

Steam as the Motive Fluid

The use of steam as a motive fluid provides the vacuum specialist with the possibility of designing for a very wide range of operating duties.

By combining the ejectors in stages it is feasible to achieve extremely high compression ratios. An example of this is the case of an evaporation conducted at say 2 kPa (abs). The evaporator contents will boil at about 18°C and the vapours produced can only be condensed with cooling water of say 12°C. This would only be possible in mid winter in South Africa and the problem is solved by compressing these vapours to a pressure of say 6 kPa (abs) corresponding to a dew point of 46°C. A thermo-compressor can readily perform this operation with an entrainment ratio of about unity. The combined vapours can now be readily condensed with 32°C cooling water. Any non-condensibles would be cooled to about 35°C to become the suction load for the next very much smaller ejector stage.

This unit would typically compress these vapours by a compression ratio of 4:1 to 24 kPa (abs) having a condensing temperature of 64°C. Once again, the combined vapours are condensed, this time in a very much smaller condensor and using much less water. The now still smaller volume of non-condensibles are again cooled to about 35°C to become the suction load of a final ejector stage.

This will compress the gases to 103 kPa (abs) ie 2 kPa or so above atmospheric pressure, to enable the vapours to be released below the surface of a hot well or to be discharged to atmosphere.

The overall compression ratio is thus:

$3 \times 4 \times 4{,}3 = 51{,}6$ to 1

Multistage sets can be built up in this way and the number of ejector stages can be clearly seen to be a function of the following factors:

(1) overall compression ratio

(2) motive stream pressure

(3) cooling water temperature

Water Driven Ejectors

This ejector is very useful in those applications where steam is not available and is generally used in single stage mode.

They have a much lower capacity for air than the same size of steam ejector and the maximum vacuum they can draw is limited by the cooling water temperature. With 20°C water, a well designed unit will produce an ultimate vacuum of 2,5 kPa (abs) rising to 4,5 kPa (abs) with 30°C water.

The units are particularly useful for simultaneous production of vacuum and condensation of water vapours and are still used in this manner on some vacuum pans.

A variation of this property enables these ejectors to be used for water heating. Water under pressure drives the ejector and steam is introduced at the side branch, enabling the water to be heated to temperatures as high as 140°C.

Further typical applications are:

(1) pump priming

(2) sump emptying

(3) conveying solids in a slurry form

Air Driven Ejectors

Compressed air has less energy/kg than steam. These ejectors thus find limited use for withdrawing air and gases, and are usually employed in single stage mode. This limits their vacuum raising capability to pressures of about 20 kPa (abs). They are seldom used in industry for withdrawing liquids, as the liquid and gas do not mix well in the combining tube when gas is the continuous phase.

A very good example of the application of an air driven ejector is the liquid ring/ejector combination unit. The liquid ring vacuum pump creates a vacuum to the underside of the ejector and this results in atmospheric air being drawn in through an expansion nozzle. The air is expanded in the tee of the ejector and reaches a velocity of approximately twice the speed of sound. This high velocity jet stream entrains air through the suction flange to the ejector, enabling a very much deeper vacuum to be established in a vessel than the liquid ring vacuum pump would be able to draw. Operating pressures as low as 0,5 kPa (abs) are entirely practical and this is achieved without the need of additional moving parts. The ejector capacity at suction conditions will be approximately 70% of the liquid ring pump displacement at 10 kPa (abs). The combination set is therefore particularly useful when a lower pressure is to be established than the liquid ring pump is capable of achieving on its own.

TABLE 1

Comparison between mechanical and ejector systems for raising vacuum

	Advantages	Disadvantages
Liquid Ring Pumps	Low energy requirements	Vacuum production and pumping capacity limited by water temperature
		Damage to rotor and stator if pump operates in the cavitation range
	Can operate at high vacuum in combination with ejectors	High cost of plant in special materials to resist corrosion
Ejectors	Can handle enormous volumes of gases at pressures down to 10 kPa	High energy cost for steam compared with electricity
	Can be fabricated from wide variety of corrosion resisting materials	
	Virtually maintenance free	