EJECTORS & EJECTOR THEORY

Steam ejectors are designed to convert the pressure energy of a motivating fluid to velocity energy to entrain suction fluid … and then to recompress the mixed fluids by converting velocity energy back into pressure energy. This is based on the theory that a properly designed nozzle followed by a properly designed throat or venturi will economically make use of 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 (shown below) are the simplest and most commonly used design. They are generally recommended for pressure from atmospheric to 3” Hg. Abs. Single-stage units typically discharge at or near atmospheric pressure.

Multi-stage non-condensing ejectors (shown below) are used where lower suction pressures are specified. 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 steam from the preceding stage and reduce load. This design is generally recommended for suction pressures from 4.0” Hg. Abs. to 0.5” Hg. Abs. in two-stage designs and from 25mm Hg. Abs. to 2 mm Hg. Abs. in three stage designs.

For handling large amounts of condensable vapors, a 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 intercondenser following the second stage is typically used. Three-stage
non-condensing units use relatively large quantities of motivating steam and are not generally recommended.

Ejector systems often 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 the recycle of ejector steam to the boiler.

For extremely low suction pressures, 4, 5 and 6-stage ejectors are utilized (see diagram below). Since the pressure between the first two stages of four-stage ejector or, the first three stages of a five-stage ejector is too low to permit condensing, these stages are designed as non-condensing with the subsequent stages condensing.

**Basic Construction**

Ejectors are composed of three basic parts: a nozzle, a mixing chamber and a diffuser. The diagram below left illustrates a typical ejector. A high pressure motivating fluid (Ma) and Mb) enters at 1, expands through the converging-diverging nozzle to 2. The suction fluid (Mb) enters at 3, mixes with the motivating fluid in the mixing chamber 4. Both Ma and Mb 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. The diagram below right 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.
Ejector Efficiency

There are many accepted formulae to express ejector efficiency. Typically, efficiency involves a comparison of energy output to energy input. This ratio is of little value in the selection and design of ejectors. Since ejectors approach a theoretically isentropic process, overall efficiency is expressed as a function of entrainment efficiency. The direct entrainment of a low velocity suction fluid by a motive fluid results in an unavoidable loss of kinetic energy owing to impact and turbulence 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 fluid.

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

Where:
- \(E_C\) = 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, an 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.

Ejectors operate optimally under 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 diffuse 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 for which the unit was designed. The table below illustrates how changes in operation can affect ejector performance:
EFFECT OF OPERATIONAL CHANGES ON CRITICAL FLOW EJECTOR PERFORMANCE

<table>
<thead>
<tr>
<th>MOTIVE PRESSURE</th>
<th>DISCHARGE PRESSURE</th>
<th>SUCTION PRESSURE</th>
<th>SUCTION CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease</td>
<td>Constant</td>
<td>Increase rapidly</td>
<td>Decrease rapidly</td>
</tr>
<tr>
<td>Constant</td>
<td>Increase</td>
<td>Increase rapidly</td>
<td>Decrease rapidly</td>
</tr>
<tr>
<td>Constant</td>
<td>Constant</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Increase</td>
<td>Constant</td>
<td>Constant</td>
<td>Decrease gradually</td>
</tr>
<tr>
<td>Constant</td>
<td>Decrease</td>
<td>Constant</td>
<td>Unchanged</td>
</tr>
</tbody>
</table>

In critical 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", 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.

Where the motivating fluid is steam, the quality of 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 decreased below 98%, a gradual decrease in suction pressure and suction capacity occurs. This phenomenon will be particularly noticed in units designed for high compression ratios and even more so in multi-stage units. Effective ejector compression ratios can be as high as 10:1 at close off (point of zero suction capacity) depending on motivating fluid pressure. Excessive steam superheat (higher than 50°F.) can also adversely affect the suction capacity of an 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 can be overcome.

EJECTOR MATERIALS OF CONSTRUCTION

Steam-jet ejectors are typically 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. We have designed steam jet Ejectors utilizing carbon, stainless steel, Monel, Hastelloy, Ni-resist, Haveg, Teflon, titanium, ceramics, and other materials.