Design of Vacuum Systems for Crude Oil Vacuum Tower Distillation

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Paper will discuss in detail design considerations involved in selecting steam ejector/liquid ring pump vacuum system for crude tower service. Materials of construction, energy utilization, packaging, system performance and flexibility will be addressed.

Crude Oil Vacuum Towers require reliable, trouble free vacuum systems that operate for months on end, between scheduled shutdowns. The key to a well designed system is the utilization of dependable vacuum equipment combined to achieve optimum energy consumption.

Steam jet ejectors have historically been accepted as being the logical and economical means of pulling vacuum on towers in refinery service. To produce the high vacuum required, they are staged together in two, three, or four stages depending on the level of vacuum. Ejectors can be single element or multi element systems (i.e., twin 50% element, twin 1/3 - 2/3 elements, triple element with each 1/3 capacity), or triple element with each 50% capacity. Multi element systems allow for flexibility in varying load situations. Along with the ejectors, special designed shell and tube heat exchangers are utilized to condense the steam and hydrocarbons, and in addition cool the gases at the various optimum interstage pressures. (Refer to Fig. 1 and 2 for typical schematics of equipment.) The primary stage(s) vary in size and are generally in the range of 15 to 70 feet long. They are either mounted on top of the tower pointing vertically down or located at the same platform elevation as the intercondensers, which is approximately 45 feet minimum above the condensate seal pot liquid level. Steam jet ejectors have no moving parts and are probably one of the most trustworthy pieces of equipment that function in a vacuum system. This does not mean they can be ignored indefinitely. Routine inspection, maintenance, and repair is usually taken care of during the normal turnaround.

Ejectors use medium to high pressure motive steam which passes through the motive nozzle where its pressure is dissipated in accelerating the steam to high velocity as it exits the motive nozzle mouth. The high velocity jet of steam issued from the nozzle mouth entrains the condensible and non-condensible gases entering the ejector suction from the process (tower). Friction between the motive steam and low pressure gases cause the latter to move with the motive steam. The steam and gases mix as they pass from the nozzle mouth into the diffuser. The divergent section of the downstream end of the diffuser converts the kinetic energy into pressure energy by decreasing the velocity of the mixture and increasing the pressure. A single stage ejector can compress the gases over a range of up to 12 to 1 (depending upon the actual suction and discharge pressure). (Refer to Fig. 3.)

A shell and tube heat exchanger, specifically designed for vacuum service, is strategically placed between ejector stages to condense a large portion of condensible gas. Additionally, the non-condensible gases are cooled thus decreasing the load to the next ejector stage. The condensers utilize cooling tower water and/or river water for the condensing medium.
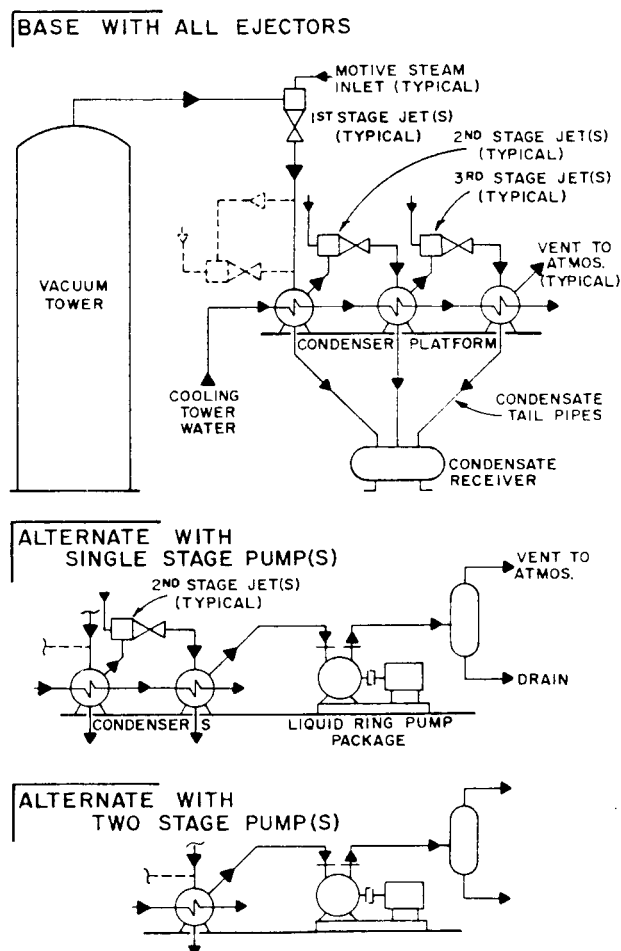

Fig. 1   Typical Schematics

baseplate. The liquid ring vacuum pump uses seal liquid (usually water) which is thrown to the periphery of the casing and forms a liquid ring. (Refer to Fig. 4.)

The liquid ring seals the space between the impeller blades and the casing. The chambers at the top most part of the impeller hub are filled with liquid. As the impeller rotates, the liquid ring moves away from the hub, increasing the space in the pumping chamber. This draws the gas into the chambers. As the impeller continues to rotate, 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 of compression, friction and condensation. The pump is driven by an electric motor at speeds varying from 400 RPM to 1750 RPM. Energy costs for the electricity to operate the motor and for the seal liquid fluid vary quite widely from one part of the country to the other, the same as with ejectors. The actual electrical costs are generally easy to identify in a certain locality. The cost of the seal liquid (usually water) can almost be ignored for an energy analysis, since the consumption is very small. Also, a complete recirculation type system or partial recirculation system could be utilized in which the costs are negligible. Electrical costs vary from $.02/KW-HR to as high as $.10/KW-HR.

The spiraling increase of fuel costs for generating steam compared to electrical costs for operating the motors on liquid ring vacuum pumps is the criteria for a positive alternative in energy savings, not to mention the consideration given to the ultimate savings by the end user for other utility costs (such as cooling tower water), erection costs, and savings resulting in smaller platforms. The concept of combining liquid ring pumps with steam jet ejectors results in utility cost savings that will have a payoff period from as short a time as 3 months up to 1-1/2 years. This is entirely

Energy costs for the utilities to operate an ejector-condenser unit varies widely from one part of the country to the other. Particularly with steam, it depends upon the method used to generate (such as coal, oil, gas and electricity). Generally speaking, steam varies from a cost of $1.00/1000 lbs. up to as high as $15.00/1000 lbs. The cost of cooling water varies from as low as $0.30/1000 gallons to as high as $1.80/1000 gallons. For the analogy that will be used, the cost of cooling water will not be considered. A complete, accurate analysis must take into consideration the figures that are relevant for the specifIc situation and locality.

Liquid Ring Vacuum Pumps have only been sparingly used in the United States in conjunction with steam ejectors for vacuum tower applications in the past. They are a rotating piece of equipment that can operate singly, or they can be paralleled to be consistent with any combination of ejectors. Routine inspection, maintenance and repair is required and is also accomplished during the normal scheduled turnaround. As with rotating equipment, some special consideration has to be given to items such as proper lubrication, vibration due to a faulty motor, poorly designed baseplate or pumps not mounted firm and level on the
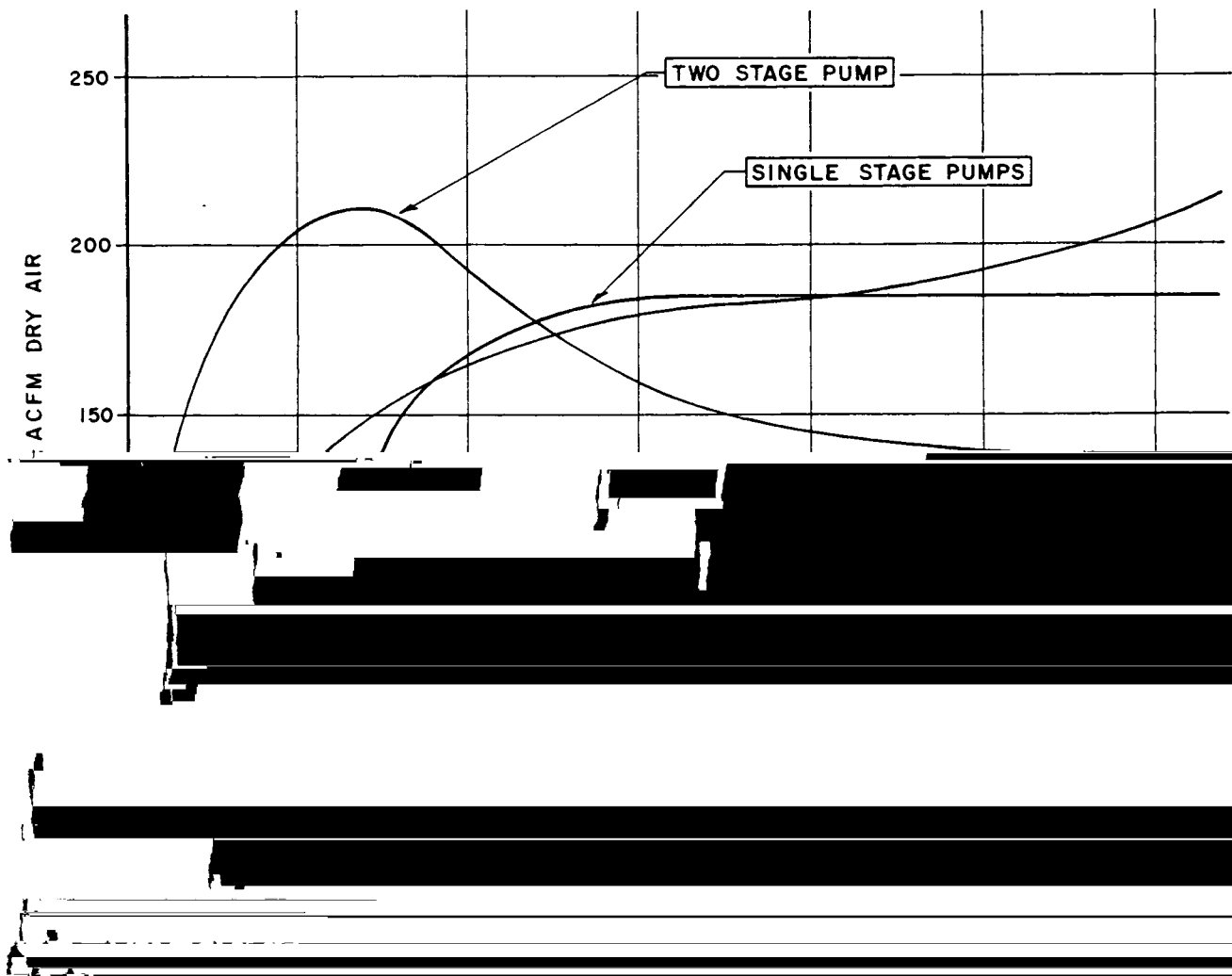
stainless steel motive nozzle. There are presently some systems that employ all stainless or high nickel alloys. The liquid ring pumps can be supplied in the same or superior materials.

The performance comparison of a single stage ejector discharging to atmospheric pressure, versus a single stage liquid ring pump, versus a two stage liquid ring pump is depicted in Figure 5.

There are several important items to point out in analyzing the curves. Based upon pumping capacity, a single stage pump should be utilized at pressures of approximately 200 mm HgA and higher, and a two stage pump at pressures less than 200 mm HgA. The single stage ejector curve represents the typical performance operating in this range. This ejector consumes 432 PPH of 100 PSIG steam while the single stage and two stage pumps absorb approximately the same BHP of 13. From a hogging or evacuation aspect, the time to evacuate 100 cubic feet from atmosphere to 200 mm HgA takes .88 minutes with the ejector and .85 minutes with the single stage pump, thus, almost the same time; and further concluding that the jet and pump are equal in performance for comparison purposes.

The curves shown in Fig. 6 compare the cost of steam and electricity. Observe that rates are listed, since as previously stated the costs for generating these utilities vary widely from one locality to another. With these various rates an individual can analyze the cost savings based upon the rates that are applicable. The abcissa is labeled in pounds per hour of steam (consumed or saved) . The ordinate is the steam or electrical cost per year. Example: Designing a three stage ejector system in which the third stage
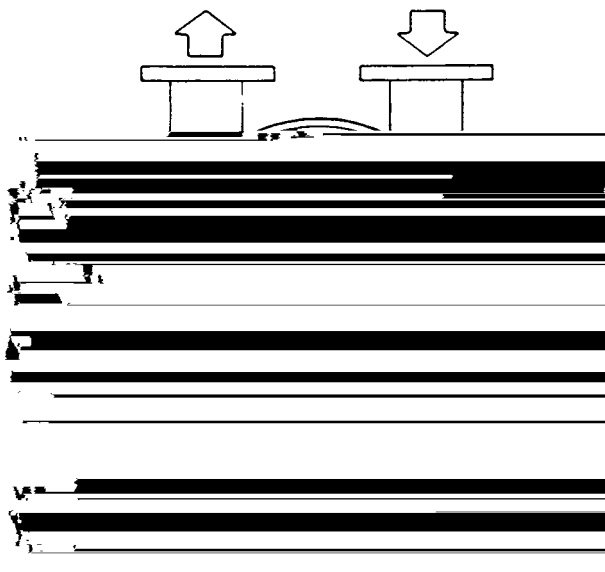
ejector consumes 1830 pounds per hour of 100 PSIG steam and
it is desired to compare the cost savings by using a combination
system, thus ending up with a two stage ejector and a liquid ring
vacuum pump of comparable capacity. The single stage liquid
ring pump absorbs 50 BHP and is of equal performance to the
third stage ejector. Arbitrarily selecting a steam cost of $5.00 per1000 pounds and an electrical cost of $.07 per KW-HR, the
steam cost per year to operate the third stage ejector is found bytaking the 1830 pounds per hour of steam consumed and move
vertically upward until the curve labeled $5.00 per 1000 poundscost of $80,000.00. For the liquid ring pump electrical cost, usethe same 1830 pou

A chart with y-axis labeled from 80,000 up to 1,000,000 (marks at 100,000, 200,000, 300,000, 400,000, 500,000, 600,000, 700,000, 800,000, 900,000, 1,000,000) and three curves labeled (A), (B), and (C).