Can Air-Operated Ejectors Solve Your Problem?

Improved vacuum engineering techniques have advanced performance of air-operated ejectors; modem units can be made to function over wide ranges of loads and pressures. Here are some details

BY C.G. LINCK

For many years manufacturers have been marketing air-operated ejector. These ejectors have by and large been of the "garden variety" type involving the more simple applications and without too much stress placed on the efficiency of the apparatus. We are speaking particularly of purge ejectors, liquid-moving ejectors, low-vacuum evacuation ejectors, and similar applications.

Today, however, the air-operated ejector is being considered for many applications and the efficiency of the unit has assumed prime importance. The aircraft industries, as well as several process industries, have begun to recognize the value of air operated ejectors, and in some instances, future installations will be made using air or a combination of air and steam as the motive fluid.

This article will concern itself with one such installation as well as some general data on air-operated ejectors.

To permit the reader to understand the function of an ejector, the principle of operation is given. See Fig. 2; the motive fluid, P_1, at a relatively high pressure is expanded through a nozzle to a lower pressure, P_2, thereby converting its energy to velocity, and, in turn, entrains the load fluid from the lower pressure, P_3 and compresses both fluids to an intermediate or discharge pressure, P_5.

An air-steam operated injector has recently been designed, built and successfully performance-tested for installation in the altitude study facilities at a large eastern university.

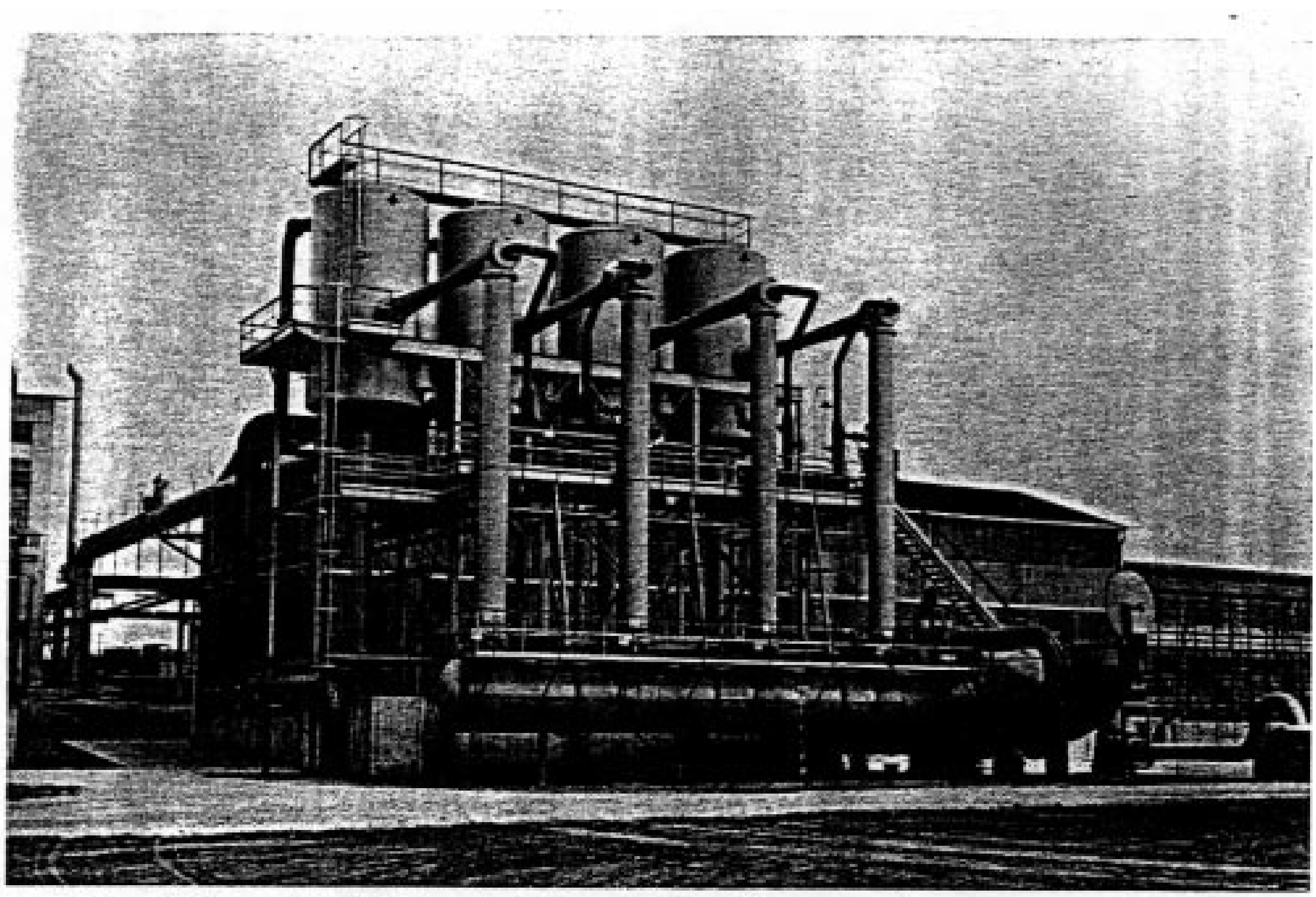

Fig. 1. One of the largest, this first-stage ejector in combination with two-stage barometric condenser handles test job

This ejector is being used to evacuate air and/or combustion products in aerodynamic and combustion experiments. The installation is believed to be the first of its size and type in the United States.

The motive fluid consists of 13,500 lb per hr of water vapor plus 24,950 lb per hr of air and combustion products. The mixture is at a temperature of 1000 F, and at a pressure of 90 psia.

TEMPERATURE RAISED

To attain the high temperature mixture, the university takes air from mechanical compressors at 200 F, injects and burns hydrocarbon fuel in a specially designed burner, and raises the temperature of the gas mixture to approximately 3500 F. Water is then injected into the stream to cool the mixture to 1000 F, thereby producing the motive fluid specified in the previous paragraph.

Usually an ejector, regardless of its type of motive, is designed for one condition or for compressing over one range, such as from 24 in. Hg vacuum to atmospheric pressure. In the apparatus under discussion, however, the ejector is required to function over many compression ranges. Note curve in Fig. 3 which pictures the ranges covered. The manufacturer in this case guaranteed the entire curve yet maintained high ejector efficiency.

PRESSURE CONVERTED TO VELOCITY

The design of the ejector is such that pressure energy is converted to velocity as previously stated. The first portion of the ejector is supersonic flow, the middle is sonic, and the latter part of the unit is subsonic. For the design under discussion, Fig. 4 shows Mach number encountered at three points of the unit. The Mach numbers are indicative only, since these will change for each particular range of compression.

Figure 5 shows the principal dimensions of the air-steam ejector as it left the manufacturer's plant ready for installation at the University's altitude test facilities. All dimensions are critical in nature and the shop or manufacturing technique must be of the highest standard in order not to sacrifice efficiency.

The materials of construction are listed below:

- Motive Air Inlet - Forged Steel, ASTM — A181
- Suction Chamber — Flanged Quality Steel, ASTM — A-285, Gr. C
- Air Nozzle — Stainless Steel
- Diffuser — Flanged Quality Steel, ASTM — A-285, Gr. C.

A liberal allowance for corrosion is added to the thickness required for pressure and vacuum service.

Referring to Fig. 2, a few general remarks will be of assistance to the engineer who is considering the use of air-operated ejectors for his facility.

POINTS TO CONSIDER

1. As P_1 increases in pressure, the amount required to perform a specified duty is decreased.
2. As P_5/P_3 increases, the amount of P_1 fluid increases. There is, however, no direct relationship between increasing P_5/P_3 and the extra motive required. For example, if we consider compressing from 8 in. Hg abs to 30 in. Hg abs, $P_5/P_3 = 30/8 = 3.75$. From Fig. 3 we note that the amount of motive required for each pound of load = 38400/11000 = 3.49/1. Then if we compress from 4 in. Hg abs to 30 in. Hg abs, $P_5/P_3 = 30/4 = 7.5$, so one might conclude the ratio would be 7.5/3.75 = 2 x 3.49 = 6.98. However, from Fig. 3 we can readily see the ratio is 38400/4300 = 9.0/1. In other words, increasing the compression ratio merely indicates that the amount of propellant required will also increase, the extent of which can only be determined by detailed calculations or by actual test.
3. P_2 and P_4, the nozzle mouth or outlet and the diffuser throat are of. first importance to performance. While the theory necessary for calculating the ejector is reasonably well-known by some manufacturers, the actual ejector deviates considerably from the theoretical. There is no mathematical answer for the deviation and therefore engineers interested in air- or gas-operated ejectors should refer their problems to experienced manufacturers of this type of equipment.

Referring to Fig. 6, it will be noted that air ratios for various vacua at various temperatures are plotted to picture the decrease in motive required as the temperature of the motive increases. The pressure of the motive air remains the same for all temperatures listed.

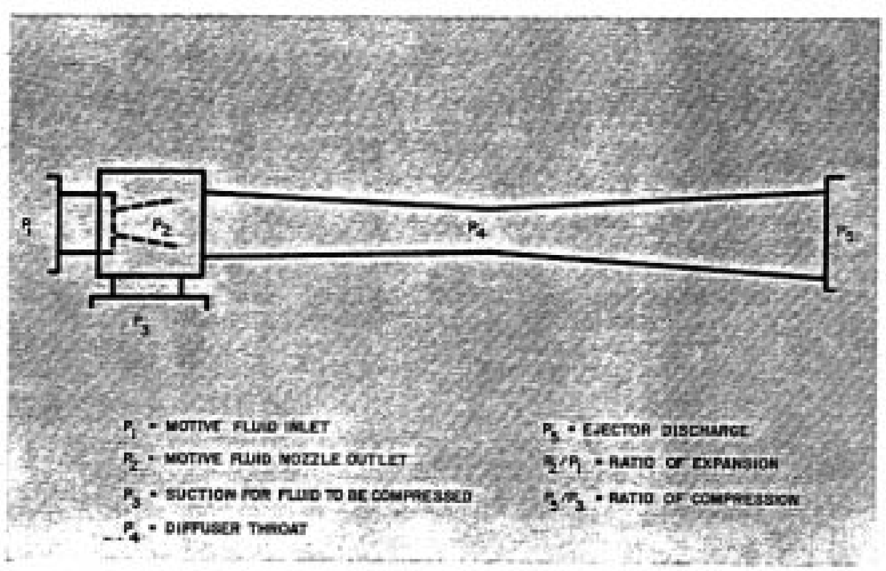

Fig. 2. Diagram of ejector; motive fluid at high pressure expands from P_1 to P_2, converting energy to velocity and entraining load fluid from low-pressure P_3

The reader will note that Fig. 6 does not show air temperatures beyond 800 F. This is because any further increase in air temperature (using 100 psig) will not decrease the amount of motive or propellant required.

This is caused by the fact that as the temperature of motive fluid is increased, two things occur. First, the velocity of expansion increases, but at the same time the duty required for compression increases. When the increase in compression duty offsets the advantages of the higher temperature motive, the "point of no return" has been reached.

FOR EACH PRESSURE, A TEMPERATURE

This means that for each air pressure there is one temperature which will yield maximum results. Some variation in best temperature for a particular motive pressure will exist since the compression ratio also plays a part in determining the most efficient temperature for any selected motive pressure.

It is further true that the load temperature will influence the selection of the most efficient motive temperature for any given motive pressure.

Figure 7 shows the ratios obtained for various air pressures when the propellant temperature is held constant. The effect of this curve is to point up the importance of the motive pressure as well as the motive temperature and other points that have been discussed.

Naturally, high-pressure air is extremely desirable, but it is many times possible to increase the air temperature and achieve the desired results even though the air pressure is moderately low.

INFORMATION NEEDED

In considering air, air-steam, or gas-operated ejectors, the engineer needs to know the following properties and conditions:

- Motive pressure
- Motive temperature
- Motive molecular weight
- Motive specific heat
- Motive specific gravity
- Load suction pressure
- Load suction temperature
- Load molecular
- Weight
- Load specific heat
- Load specific gravity

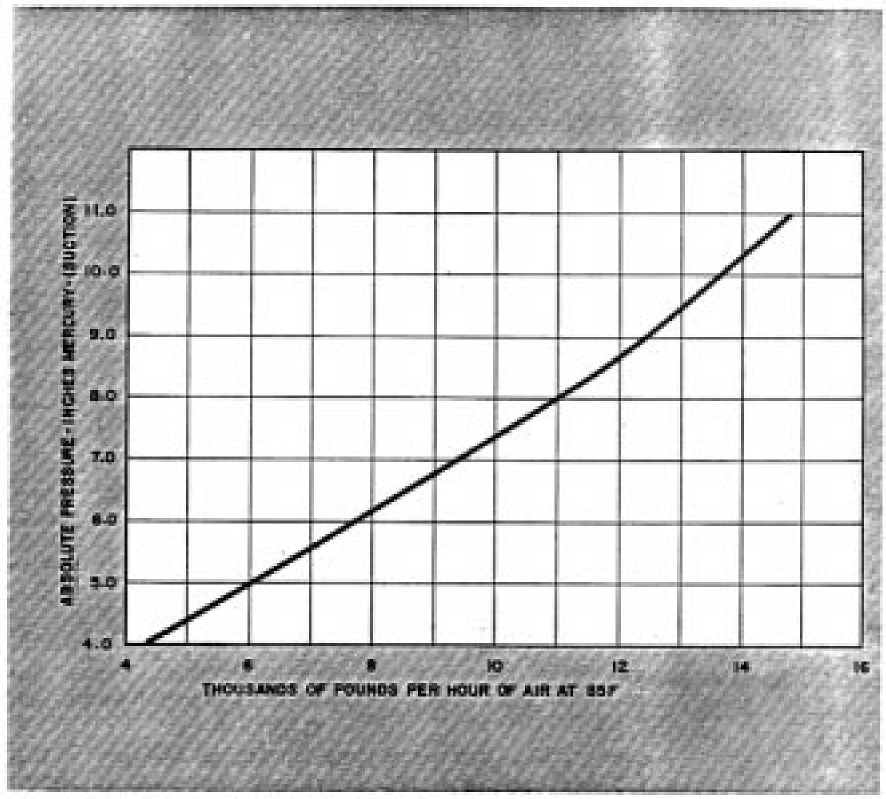

Fig. 3. Curve shows range of compression produced by an air ejector at a large eastern university. Most ejectors are designed to operate at one condition, and over relatively narrow range of compression; this unit functions over range above

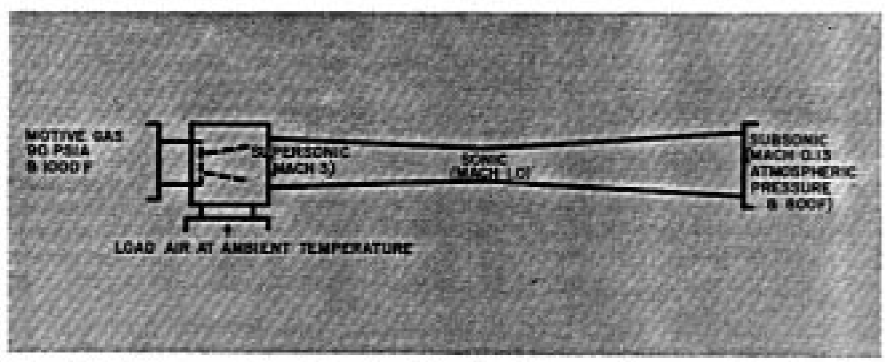

Fig. 4. Conditions existing in air ejector that has performance characteristics shown in Fig. 3. Motive fluid at inlet is supersonic, drops to sonic in throat, and to subsonic at outlet. Mach numbers typical of only one set of conditions

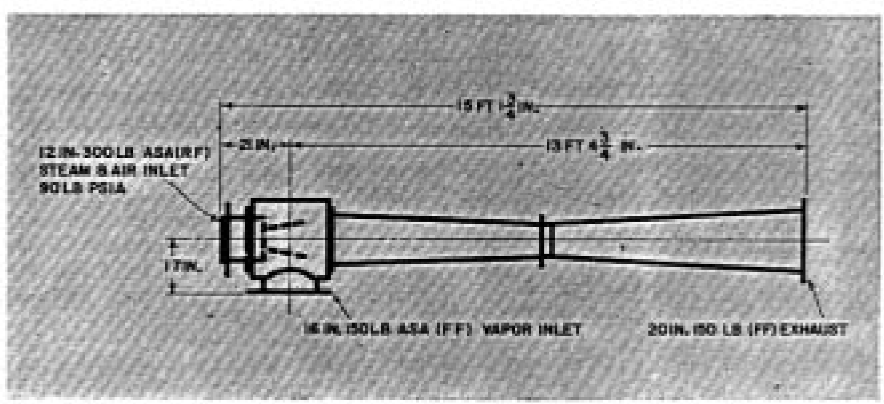

Fig. 5. Physical dimensions of ejector from Figs. 3 and 4. Dimensions are very critical, but performance is not matter of simple geometry; while theory is well known, actual design of this equipment requires experience with its intricacies

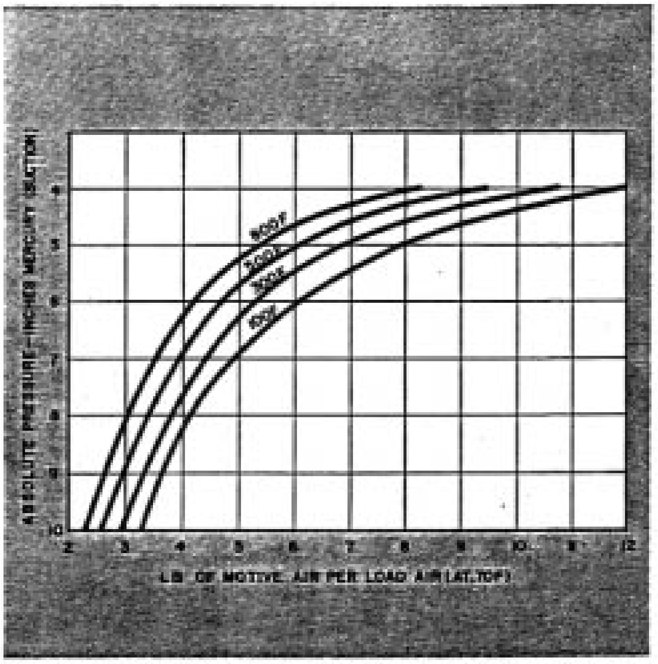

Fig. 6. Air ratios: various vacua at various temperatures; note decrease in motive required as temperature increases

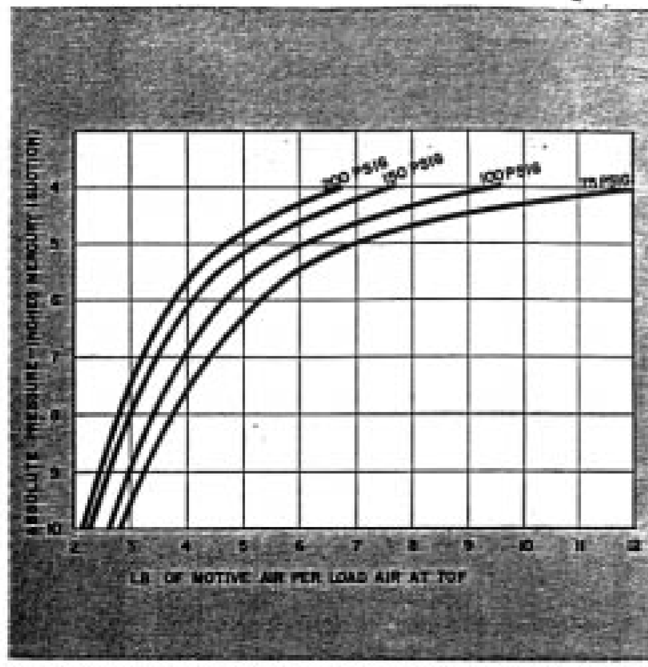

Fig. 7. Ratios obtained for various air pressures when the propellent temperature is constant; note motive pressure

Ejector discharge pressure. (Particular care should be taken to add to the discharge pressure any pressure losses anticipated from the ejector proper outlet to the final point of discharge.

In the months and years ahead, the engineer will see more and more use of the highly efficient and economical air- or gas-operated ejector. The initial cost is frequently lower than other types of vacuum producing apparatus, and the cost of obtaining high temperature motive is usually incidental to the project. Also, the operation of an air operated ejector is much quieter than ejectors motivated by steam. Like steam-operated ejectors, there are no moving parts, hence maintenance costs are negligible and operation is trouble free.