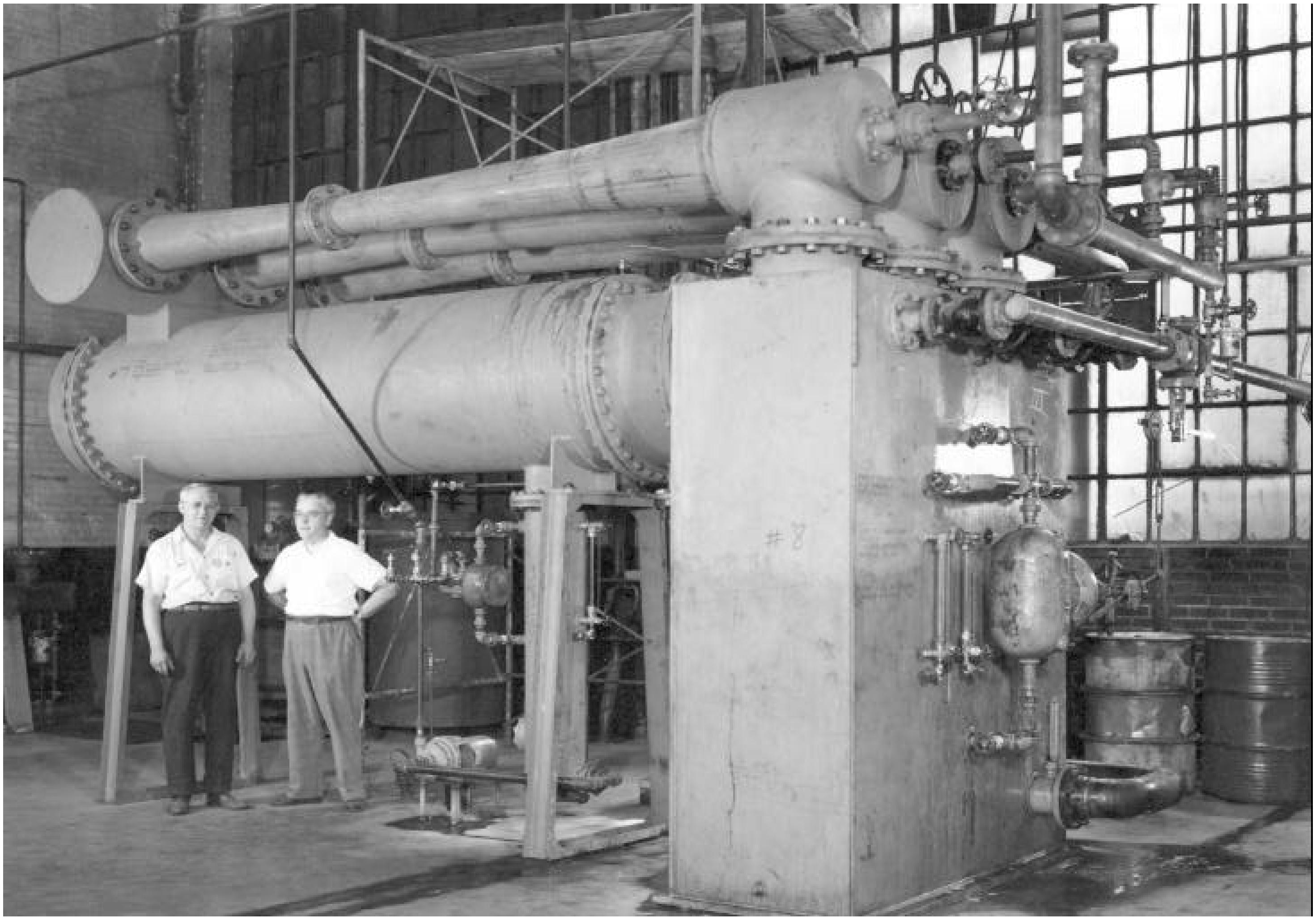


Air Ejectors Cheaper Than Steam

When all the cost factors are considered, the air-operated ejector often proves to be the superior method for producing vacuum. Here are figures you can use.

F. Duncan Berkeley

For many years the air-operated ejector has been a neglected child in the field of vacuum producing apparatus. It has been greatly overshadowed by its highly successful, fully reliable and popular kin, the steam ejector. The popularity of the steam ejector has been somewhat justified because air-operated ejectors have been limited in their use by a relatively expensive and somewhat scarce supply of high-pressure motive air. Major reasons for selecting steam rather than air to operate ejectors have been the unavailability of air compressors and the relatively high cost of compressed air in most localities.

Improvements in air compressors have greatly reduced the cost of compressed air as compared to 20 years ago; and the greater availability of compressed air in process plants today makes the air ejector a reasonable and in some instances a preferred means of producing a vacuum.

The fact that air is a non-condensible gas under common conditions of temperature and pressure, limits its use as a propelling material for ejectors to two or three stages. In a steam ejector the steam from each stage of multistage units can usually be condensed in an intercondenser and the successive stage need handle only the non-condensible gases plus a relatively small saturation component from all previous stages. By condensing the motive steam from previous stages, it is both economical and practical to use as many as five or more stages.

CONSIDER ALL THE FACTORS

Recent tests and studies on air-operated ejectors have brought to light some rather interesting and useful facts concerning these units. The results, although neither highly revolutionary nor startling, prove that the air jet has the same desirable feature as the steam jet; and in some instances can prove to be very economical and more desirable than the steam jet.

All factors of cost should be carefully considered for a specific application. They are:

- •Initial cost of the equipment used to produce the compressed air or steam.
- •Versatility of employing steam or air generating equipment for other uses in a plant or process.
- •Relative costs of compressed air and steam for a particular locality.
- •Operating requirements for the ejector, both vacuum and load. With all of these factors in mind, using the air-operated ejector often proves to be quite superior to other methods of producing vacuum.

HOW THEY WORK

All ejectors operate on a common principle. They entrain air or other fluids in a high velocity jet of propelling air, steam, water or other fluid. And they use the kinetic energy in the high velocity stream of that fluid to push back the atmosphere from the discharge of the ejector.

This would suggest that the higher the velocity of the jet from the nozzle of the ejector, the greater the pressure against which the ejector can exhaust. Or if the exhaust pressure remains constant, the higher the vacuum produced by the ejector. This is true and for any particular velocity of the jet there is, of course, a limit to the vacuum that can be produced.

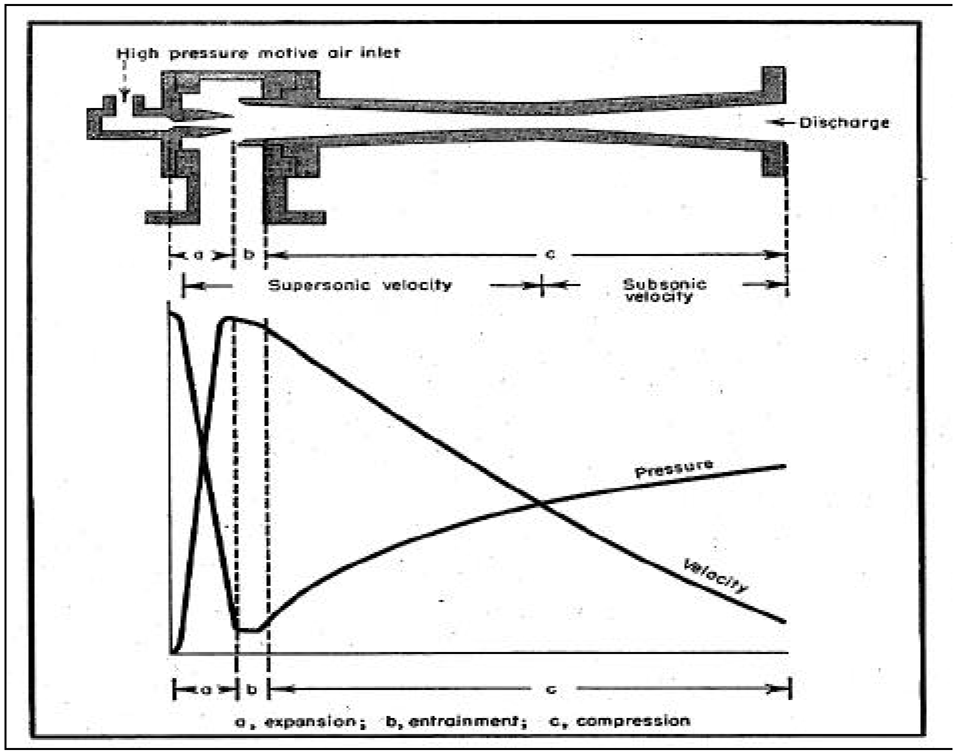


Fig. 1 - Ejector nozzle converts air pressure into velocity and the diffuser converts velocity back into pressure.

Fig. I illustrates approximately the conversion of air pressure into velocity in the nozzle of the ejector and the conversion of velocity into pressure in the diffuser.

Air, under the same conditions of temperature and pressure, has less internal energy in its molecules than steam. And theoretically air cannot produce as high a vacuum as can steam. However, the inefficiencies of the expansion and compression processes in an ejector when the ejector is operating over its maximum range of compression obscure the differences in ultimate vacuum produced.

For most practical purposes a one or two stage air ejector will produce as high an ultimate vacuum as will a one or two stage steam ejector. The steam jet, however, requires fewer lbs. of motive fluid to evacuate a closed vessel than the air jet and fewer lb./hr. of motive fluid to exhaust a constant load at a particular vacuum as compared to an air jet. Therefore we need to know some additional comparative characteristics to base our cost estimates on.

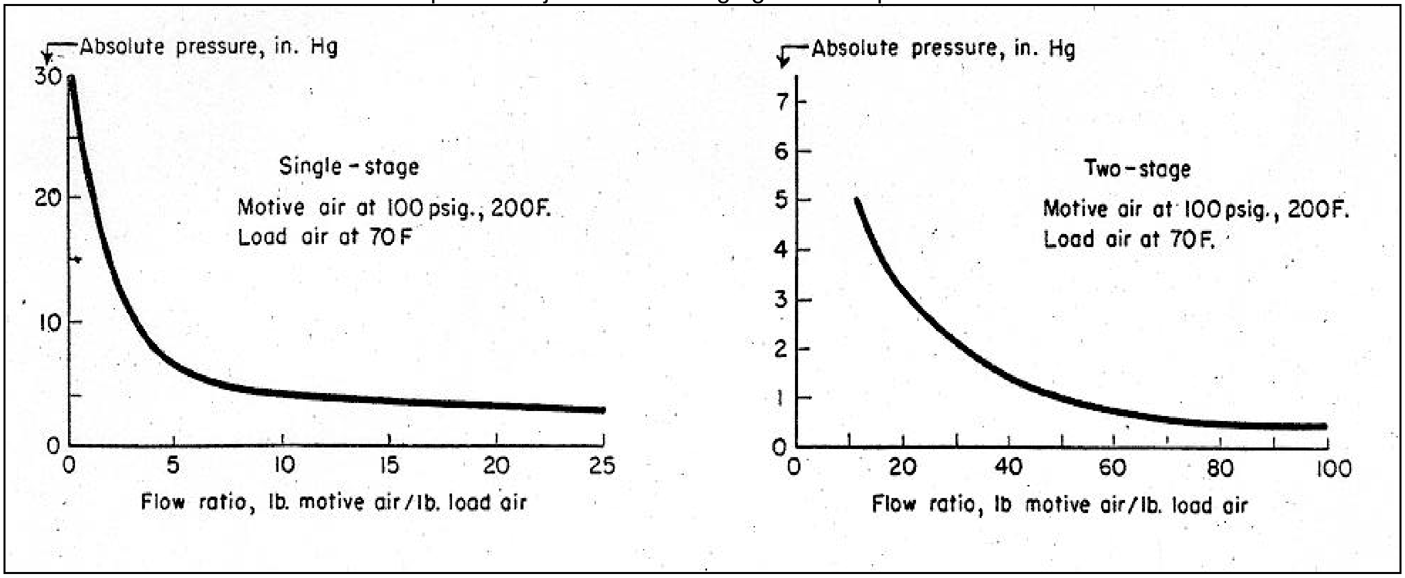
BASIS OF COMPARISON

Because 100 psig. is a very common pressure for both compressed air and steam in industrial plants, it is a good pressure on which to base a comparison between air-operated and steam operated ejectors.

200 F. is approximately the maximum air temperature at which 100 psig. single stage air compressors will deliver air without requiring the compressor to run excessively hot. The hotter the air to the ejector, the less air is required by the ejector for any particular condition of vacuum and load.

If the air aftercooler of a compressor is bypassed or if the cooling water to the aftercooler is shut off, relatively hot air can be obtained for use in an ejector. But by doing so the air storage tank capacity is reduced and condensate will collect in the storage tank and air lines.

This might be undesirable for some compressed air installations. It is more desirable to heat the air by means of an electric heater or with a steam to air heat exchanger. Only a very small amount of electricity or low pressure steam is required to reach 200 ºF.



Figs. 2 and 3 - Air consumption for single-stage and two-stage air-operated ejectors.

(or hotter), and in most cases the reduced air requirements of the ejector are well worth the additional expense.

By heating motive air to 200 F., the air required to operate an ejector can be reduced to as little as 70% of the air requirements for 70 F. air. Sometimes air ejectors are selected to keep the temperature of the load fluid low. This rules out steam ejectors. And to remove the load fluid in condensers most efficiently it would then be necessary to operate the ejector with cold air.

TEST RESULTS

Data from our test runs on one and two stage air ejectors (of optimum design) correlate very well with data on steam ejectors. We used air at 100 psig. and 200 F. in our tests and compared the results with steam ejectors operating on 100 psig. dry saturated steam .

Single stage air ejectors require 1.4. -1.5 lb. of air to handle the same condition of vacuum and load that 1.0 lb. of steam will when it is supplied to a single stage steam ejector.

In a two stage air ejector, 2.5-2.7 lb. of air will be needed to do the same job that 1.0 lb. of steam will do in a two stage non-condensing steam ejector.

These ratios change somewhat when the pressure of the motive air is changed. A typical figure for single stage might be 1.7 lb. of 200 psig air per lb. of dry saturated steam at 200 psig. Or 1.4 lb. of 60 psig. air per lb. of dry saturated steam at 60 psig .

Fig. 2 shows the ratio of motive air to load air required for one stage ejectors. The absolute pressure scale covers the operating vacuum range of one stage units. Fig. 3 shows the ratio of motive air to load air required for typical two stage ejectors designed for any particular vacuum in the operating range for two stage ejectors. The ratios are based on supplying motive air at 100 psig. and 200 F. to remove load air at 70 F.

These ratios will be higher for load air above 70 F. and lower for load air below 70 F. But the corrections are small between 50-90 F. If the ejector is to handle a fluid other than air, the flow ratio must be corrected for the difference in the thermodynamic properties of the load fluid and those of air. This correction factor is usually considered a function of the relative molecular weights of the load fluid and air.

Fig. 2 shows that for pressure above 3.2 in. Hg abs., a single stage air-operated ejector is more economical to operate than a two stage ejector (when the motive air pressure is 100 psig.). The exact pressure at which two stages of compression become more economical depends on the pressure of the motive air supply. Absolute pressures as low as 0.394 in. Hg abs. (10 mm.) are practical with a two stage air-operated ejector.

WHAT IT COSTS

Figs. 4, 5 and 6 show the operating costs of one and two stage air ejectors when the cost of the compressed air is known.

Compressor manufacturers have organized and published much useful data which permit an analysis of compressed air costs. These costs are made up of: .

- •Operating costs including power, labor, repairs, maintenance, lubricants, etc.
- •Depreciation of equipment.
- •Interest on the investment made for the equipment.

Power is the largest portion of total cost. And in many cases the cost of power need be the one consideration necessary for a study of compressed air costs.

We have used the tables in 'Compressed Air Data," Ingersoll-Rand Co., Phillipsburg, N.J. (1939) to compute the cost of power required for compressed air. The other costs, being unique to each application, should be studied to determine their relative importance and effect on the overall cost.

To use the "Compressed Air Data" tables it is necessary to know the brake horsepower required to compress and deliver 100-cfm. of air and the local cost of the various fuels under consideration.

Since the brake horsepower will vary considerably with the size and type of compressor, you should obtain exact data on brake horsepower requirements from the manufacturer after the air requirements are known. However, typical figures are shown in a table of the reference we mentioned above. And the use of these figures will permit an approximate cost analysis.

SAMPLE PROBLEM

Let's assume that an air-operated ejector is required to maintain an absolute pressure of 5 in. Hg in a system that has an air leakage of 25 lb/hr. The costs of various fuels available are:

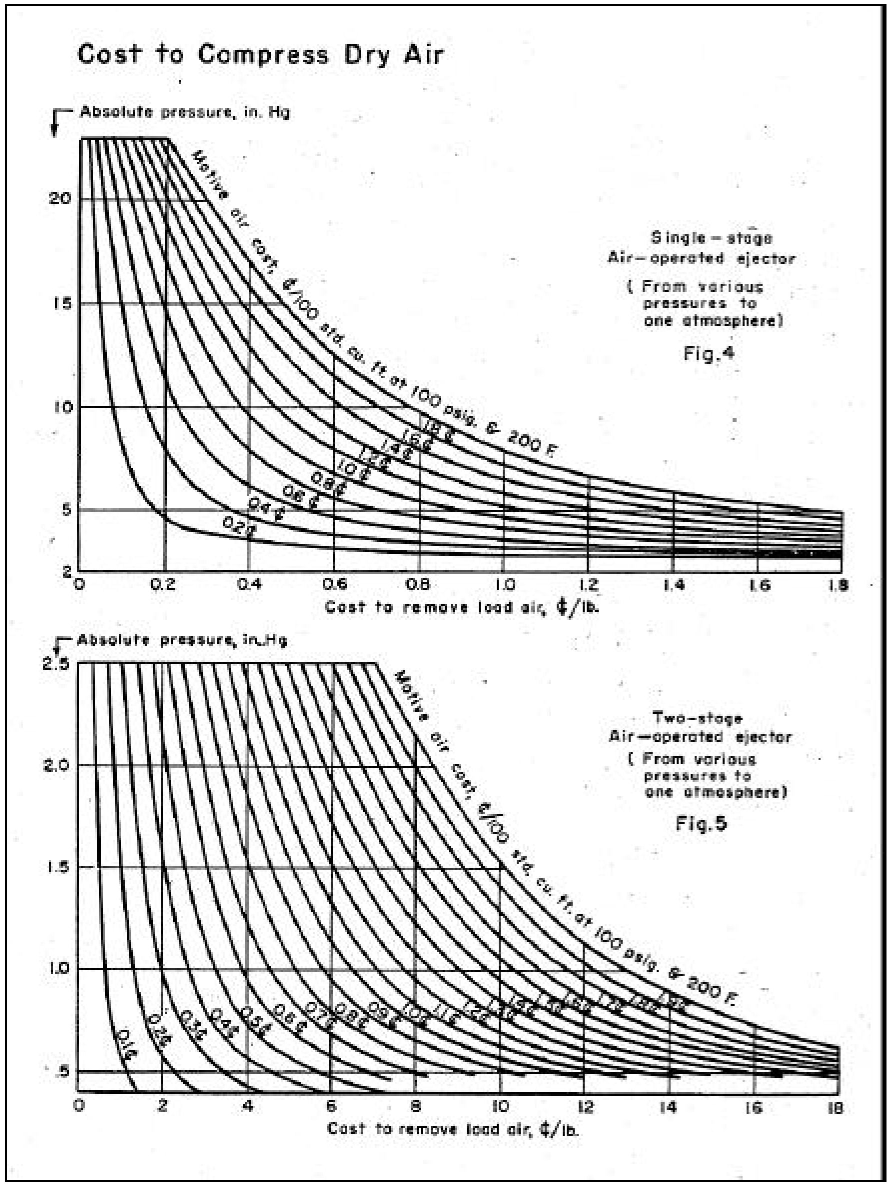
Electricity	1.5 c./kwh
Fuel oil	9.5 c./gal
Gas	63.7 c./M cu. ft.
Gasoline	22.0 c./gal.
Coal	$9.79/ton

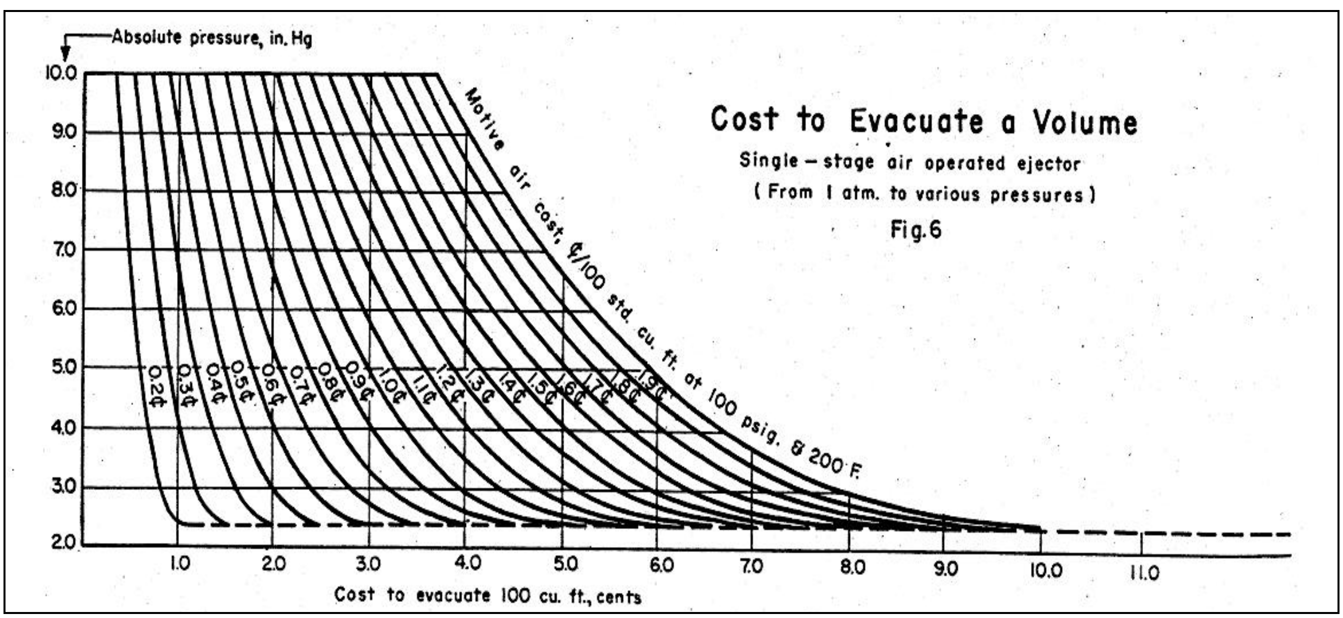
Fig. 2 shows that a one stage ejector will do the job and that 6.7 Ib of 100 psig., 200 F. motive air are required for every lb. of air to be evacuated. Therefore, the total motive air required to operate the ejector would be:

$$\frac{6.7\text{lb. motive air}}{\text{lb. load air}} \times \frac{25\text{ lb. load air}}{\text{hr.}} = 167.5\text{ lb. motive air/hr.}$$

We can now use Fig. 7 to find that 167.5 lb./hr. of air is equivalent to 37.5 standard cu. ft. of air per min.

From our reference, the brake horsepower requirements of a typical single





stage 100 psig. air compressor with a capacity of slightly more than 37.5 scfm. is found to be approximately 22 bhp./100 scfm. delivered. With this value and the fuel costs listed above we can enter the other tables of the “Compressed Air Data” book and find the power costs for running the compressor on the various fuels:

Electricity	0.412c. / 100 cu.ft.	(37.5) (60)=
	9.27 c./hr.	
Fuel Oil	0.218 c. / 100 cu. ft.	(37.5) (60)=
	4.91 c./hr.	
Gasoline	0.962 c. / 100 cu. ft.	(37.5) (60)=
	21.65 c./hr.	
Gas	0.242 c. / 100 cu. ft.	(37.5) (60)=
	5.45 c./hr.	

In order to determine the cost of air compressed by a steam turbine or steam engine driven compressor, we would have to know the steam rate of the turbine engine in lb. of steam per bhp.-hr. A typical figure might be 28 lb. of steam per bhp.-hr. Then the power cost for the ejector might be:

$9.79 / ton x 0.0733 c.-ton / 100 cu.ft.$ x (37.5) (60)
= 16.15c./hr.

The reference table we have used is based on evaporation rate of 7 lb. of water per lb. of coal burned. It will be necessary to correct this for the actual evaporation rate.

Our calculations show that for our assumed conditions a compressor driven by an engine burning fuel oil would be the cheapest way of producing the air necessary to operate the ejector (when only power costs are considered).

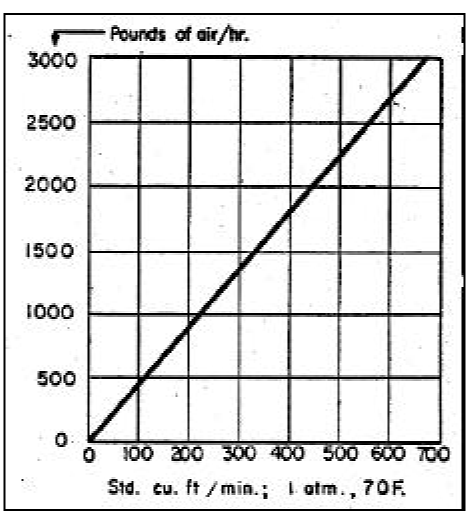


Fig. 7 - Volume-weight conversion chart

AIR COSTS ARE REASONABLE

When making cost analyses of air requirements from the reference tables, the various assumptions upon which each table is based should be checked against the actual conditions of operation. It is likely that some particular fuel will be outstandingly cheap due to local conditions. In such cases these approximate calculations will show conclusively which fuel is most economical.

Although the data above are limited to ejectors operating on 100 psig., 200 F. air, we can see that power costs of air-operated ejectors can be quite reasonable.

AIR vs STEAM

Under most circumstances where steam is already available, a steam ejector would be used in preference to an air-operated ejector. Economics would dictate the choice. If steam is not available, air might well be the cheaper motive fluid.

There are also cases where air-operated ejectors are selected for other than economic reasons. In general, air-operated ejectors are most desirable where the heating or diluting features of the steam ejector are objectionable; where compressed air is more readily available than steam; where the properties of air are desirable as the motivating fluid.

SOME APPLICATIONS

There are many services for which an air-operated ejector is ideally suited. Pump priming is readily done by means of an air or steam operated ejector which operates only long enough to exhaust the air from the pump casing and piping. This permits the system to become fined with the liquid to be pumped. The ejector is then isolated from the system by means of a valve. The pump is turned on. And the ejector air supply is turned off. This leaves the pump primed and ready for operation.

A siphon pipe system which uses gravity to draw water or some other liquid over a high elevation without the use of expensive pumps requires some initial priming to start-up. It can be primed by using an air-operated ejector operating on air from **a** portable or stationary compressor.

The pumping of corrosive, tarry or sludge liquids can be done without the use of special pumps by means of an air-operated ejector.

Frequently we want to recover vapor in an intercondenser in its pure state, undiluted and unheated. To accomplish this we can use an air-operated ejector for the initial stage of compression to compress the vapor to a pressure where it can be easily condensed. Either a steam ejector or an air-operated ejector can be used to maintain the required intercondenser vacuum.

THE THERMOCOMPRESSOR

Many applications require compressed air at a pressure below the available air pressure. This makes it necessary to throttle the air through an orifice or valve to reduce its pressure. The cost of compressing air to a high pressure and then throttling to a lower pressure for a particular application can be reduced by installing an air operated thermo-compressor.

Working on the same principle as a vacuum producing ejector, the thermocompressor picks up air at atmospheric pressure (or higher) and by means of a high velocity air jet compresses the atmospheric air to the required pressure. The savings accomplished by the thermocompressor are derived from reducing the consumption of high pressure air by the amount of atmospheric air that the thermocompressor will entrain.

Thermocompressors operating on air, steam and many other fluids have found a wide and useful field of application in industry.

The rugged and simple construction of ejectors along with the fact that they can handle large volumes of fluids (without the relatively. enormous proportions of other types of vacuum pumps) often determines when and where an ejector should be used. Other considerations may, of course, outweigh the size and simplicity factors. An overall picture of requirements is necessary to select the best suited vacuum pump for your needs.