

CENTRIFUGAL COMPRESSOR LABYRINTH SEAL SYSTEMS

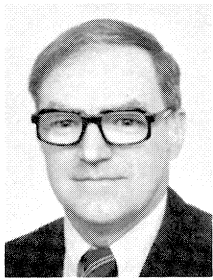
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ABSTRACT

For years, labyrinth shaft-end seals have been used for centrifugal compressors handling air and nonhazardous gases, and for low suction pressure compressors in hydrocarbon service. To prevent gas leakage from the hydrocarbon machines, either injection of inert gas or jet ejector systems have been applied with the seals. The ejectors were normally arranged to exhaust back to the compressor suction.

Early applications of labyrinth/ejector seal systems were generally on compressors with suction pressures in the 0-8 psig range, and the seal system operation was generally satisfactory. Many of the older machines have been uprated to higher suction pressures. The labyrinth/ejector seal systems have been applied to newer compressors with suction pressures as high as 15 psig. Many of the systems do not perform satisfactorily, and operators complain of leakage of hydrocarbons and contamination of the lube oil. This may be the result of noncritical-flow ejectors operating with critical pressure ratios.

Labyrinth/ejector seal systems can be designed to perform satisfactorily with the higher compressor suction pressures, but these systems often require critical-flow ejectors. Despite their relatively low initial cost, the economics of labyrinth/ejector seal systems for high compressor suction pressures may not compare favorably with oil-type seal systems because of the energy required to recycle motive gas.

INTRODUCTION

Labyrinth shaft-end seals have been used for centrifugal compressors handling air and nonhazardous gases, and for low suction pressure compressors in hydrocarbon service for many years. Early applications in industry involved compressor suction pressures in the range of 16 to 18 psia. To prevent hydrocarbon leakage at the machine, either injection of inert gas, or discharge gas powered ejectors exhausting to the compressor suction, were utilized. Generally, these systems performed satisfactorily.

Economics now favor higher pressures for the processes on which the labyrinth seal equipped compressors were applied. Most newer plants now have compressor suction pressures in the 26 to 28 psia range. Furthermore, most of the older units have been uprated, resulting in compressor suction pressures approaching or reaching the 26 to 28 psia range. Recent feedback on some of these machines with labyrinth seals now reveals a poor service record with this type of seal. This has prompted an investigation of possible causes of the reported problems, and a determination of why the successful systems work.

NITROGEN INJECTION FOR SHAFT SEALING

Low pressure hydrocarbon gas compressors on some of our plants built in the 40's and 50's were supplied with nitrogen injection systems to prevent hydrocarbon leakage from their labyrinth seals. This nitrogen flow is manually controlled and is fed into the labyrinth seal at sufficient pressure to cause part of the nitrogen to leak into the compressor and the remainder to leak along the shaft to the atmosphere. Any increase in labyrinth clearance or increase in compressor suction pressure would require increased nitrogen flow. Therefore, the nitrogen supply systems must be sized for maximum labyrinth clearances and maximum anticipated suction pressure.

EJECTOR SYSTEMS FOR LOW PRESSURE COMPRESSORS

Low pressure gas compressors for most catalytic cracking plants were supplied with labyrinth seals with ejector systems. Usually two ejectors were provided with each compressor. For these systems, the primary ejector is powered by the compressor discharge gas and exhausts into the compressor suction. The seal leakoff header is maintained at subatmospheric pressure, with changes in seal leakage rate accommodated by automatically varying the motive gas flow rate. An auxiliary, manually controlled, steam-powered ejector, exhausting to the atmosphere, is usually provided for sealing the casing when the compressor is down. For more recent installations, the auxiliary ejector has been designed to automatically cut in if the seal leakoff header pressure rises above a set point approaching atmospheric pressure. This automatic feature is now considered essential.

EJECTOR DESIGN DETAILS

Before proceeding, a review of the features of an ejector design will be given. Ejectors are also sometimes called educators (API 617) or jet compressors. They consist of a nozzle, a body or mixing area, and a diffuser, as shown in Figure 1. Motive gas is introduced into the ejector at high pressure through a nozzle. The nozzle accelerates the motive gas into a higher velocity stream with a reduced static pressure which causes a suction and entrains the low pressure gas entering the ejector suction connection. The motive gas and suction gas are

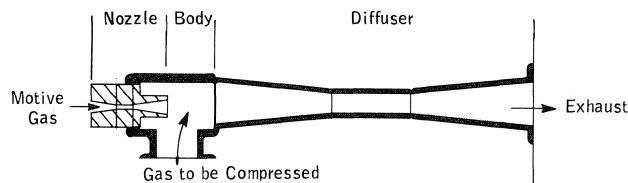


Figure 1. Typical Ejector.

mixed in the body of the ejector and then enter the diffuser where the high velocity is converted into static exhaust pressure.

Depending on the ratio of exhaust pressure to suction pressure, the ejector is either a critical-flow or subcritical-flow type. Critical pressure ratio is defined by the following equation:

$$P_{\text{crit}} = \left[\frac{(k+1)}{2} \right]^{\frac{k}{k-1}} \quad \text{where } k = C_p/C_v \quad (1)$$

When the ratio of exhaust pressure to suction pressure is less than or equal to critical, the diffuser section of the ejector can be simply diverging. On the other hand, if the ratio of exhaust pressure to suction pressure exceeds critical, the diffuser will have a converging supersonic diffuser section, a constant area transonic section, and a diverging subsonic diffuser section.

For low pressure gases normally found in catalytic cracking units, the ratio of specific heats (k) is usually in the region of 1.11 to 1.19. The resultant critical pressure ratio falls between 1.7 and 1.8. With an ejector suction pressure of 14 psia and a critical ratio of 1.7, the maximum exhaust pressure that can be met with a noncritical-flow ejector is 24 psia. Since the labyrinth seal ejector ports must be subatmospheric, the ejector suction is normally maintained at 14 psia. The ejectors normally exhaust to the compressor suction, so the above requirement demands that critical-flow type ejectors be used if compressor suction pressure exceeds 24 psia. This limit may be even lower depending on seal leakoff piping design and gas properties, and should be calculated for each system.

In our investigation of the recent poor service record with labyrinth seals, we found that none of the ejectors currently applied are the critical-flow type, although several of the installed compressors have suction pressures greater than 24 psia. Note that an ejector designed for a subcritical pressure ratio (subcritical-flow) will not operate with a critical pressure ratio (critical-flow) or super-critical ratio. On the other hand, an ejector designed for a critical or super-critical pressure ratio will operate satisfactorily with lower than design exhaust pressures as long as the motive gas pressure (and flow) and ejector suction pressure are maintained within 2% of the design values. We suspect that some of the reported labyrinth seal deficiencies are the result of misapplication of subcritical-flow ejectors in critical pressure ratio service.

EJECTOR CONTROLS

Because of the differences between the two types of ejectors, seal leakoff header pressure must be controlled in different ways. With a subcritical-flow ejector, the header pressure can be controlled by varying the motive gas flow rate. This may be accomplished with variable nozzle ejectors equipped with automatically controlled stems, or the motive gas flow can be varied with a control valve in the motive gas supply line to a fixed nozzle ejector. This control scheme is shown in Figure 2.

With a critical-flow ejector, the motive gas flow rate must be held nearly constant at its design rate, and the seal leakoff header pressure is controlled by recycling ejector exhaust gas back to the ejector suction. A simplified sketch of this type of control is shown in Figure 3.

For services where the compressor suction pressure can vary from below to above 24 psia, it may be advisable to supply a subcritical-flow ejector for the lower pressure operation, with an automatically activated critical-flow ejector for the higher pressure operation. The critical-flow ejector could be triggered by either increasing compressor suction pressure or increasing seal leakoff header pressure.

BUFFER GAS MAY BE REQUIRED

An important factor to be considered is whether ingestion of a small quantity of air can be tolerated both from a safety standpoint and from process considerations. The air is usually only a safety concern in systems where there is recontacting after the compressor discharge which results in absorption of most or all of the hydrocarbon vapor in the discharge drum, leaving a possibly explosive gas mixture.

Fouling of the seal leakoff piping resulting from the polymerization of hydrocarbon in the presence of air has also been reported. Fouling of the compressor internals and downstream equipment may also be aggravated by the presence of the small amount of oxygen.

If air ingestion cannot be tolerated for either of the two reasons discussed above, nitrogen buffer gas can be used. The cost of the nitrogen should be included in the economic analysis of new seal system alternatives.

SEALING AT SHUTDOWN

In order to prevent the leakage of hydrocarbon gas at the machine and possible contamination of the lube oil when a compressor is tripped, it is essential that an automatically activated auxiliary ejector be provided. This ejector can be powered by low pressure steam (50-150 psig), and can exhaust to the atmosphere for the short time required to block in and depressure the compressor casing. The auxiliary ejector should be activated by the shutdown circuit and/or increasing pressure in the seal leakoff header. The auxiliary ejector also serves as a backup in the event of malfunction of the primary ejector(s).

Figures 4 and 5 illustrate features to be included in noncritical-flow and critical-flow ejector systems. You will note that each sketch shows two gas powered ejectors. This stems from a requirement that labyrinth/ejector seal systems be capable of handling the range of leakage from normal labyrinth clearances to twice normal clearances. By utilizing split range gas powered ejectors as shown, the motive gas requirement for normal seal leakage is significantly reduced.

ADVANTAGES AND DISADVANTAGES OF LABYRINTH SEALS FOR NEW INSTALLATIONS

The first cost of labyrinth seals with an ejector system will always be significantly less than an alternative seal system. Operating costs, however, may be somewhat higher because of the need to recycle the motive gas used to power the ejector. If nitrogen buffering is required to prevent ingestion of air for whatever reason, the labyrinth seal system operation costs jump drastically.

Two major advantages of labyrinth seal systems are simplicity of operation and low maintenance.

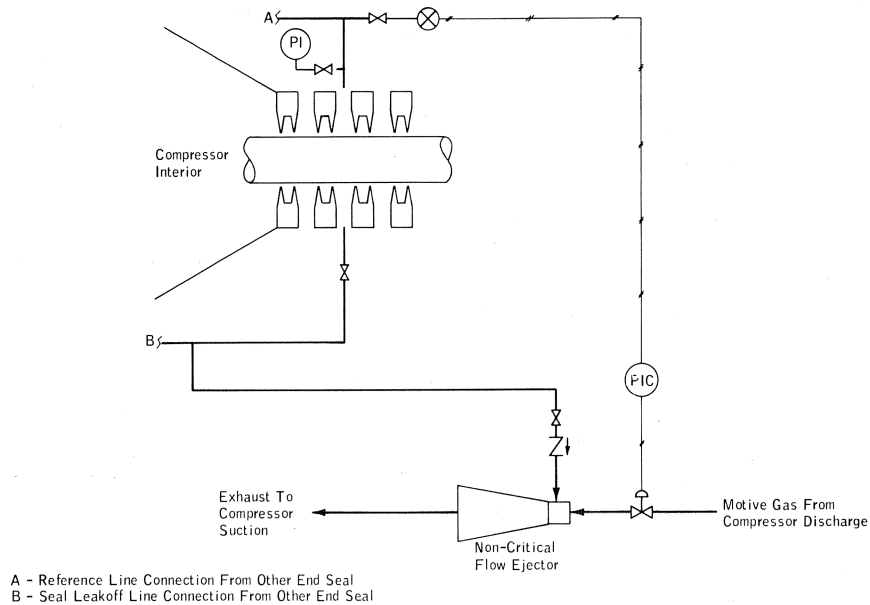


Figure 2. Noncritical-Flow Ejector Control Scheme.

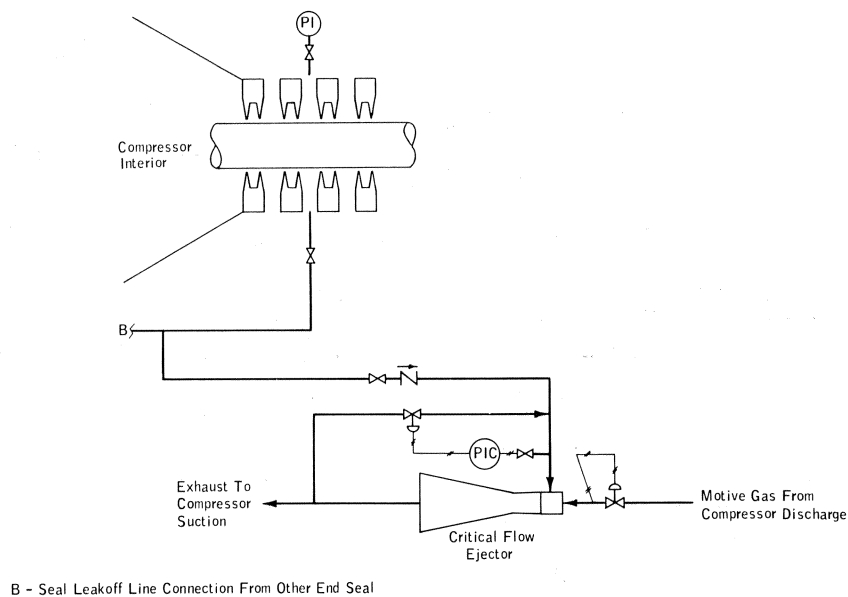


Figure 3. Critical-Flow Ejector.

CONSIDERATIONS FOR NEW SYSTEMS

In determining the requirements of new labyrinth/ejector seal systems, there are several factors which must be considered:

Arrangement

Usually the most economical and environmentally acceptable arrangement is to use compressor discharge gas as the ejector motive fluid, with the ejector(s) exhausting back to the compressor suction. Steam or other gases may be used as the motive fluid, and the ejector(s) may exhaust to the atmosphere or some other low pressure sink, but each alternative must be reviewed for economic, environmental, and process acceptability.

Buffer Gas

There are two possible needs for buffer gas in a labyrinth/ejector seal system. To prevent ingestion of massive amounts of air, it is essential to maintain the portion of the labyrinth between the ejector port and the compressor interior at a positive pressure even when operating with a subatmosphere compressor suction pressure. This can be accomplished by providing a pressure regulated buffer gas from the compressor discharge or interstage as shown in Figures 4 and 5. Secondly, if the system cannot tolerate the small amount of air that would normally be drawn in past the outer labyrinth teeth into the ejector, it is necessary to provide an inert gas buffer (usually nitrogen) between the ejector port and the atmospheric side of the seal.

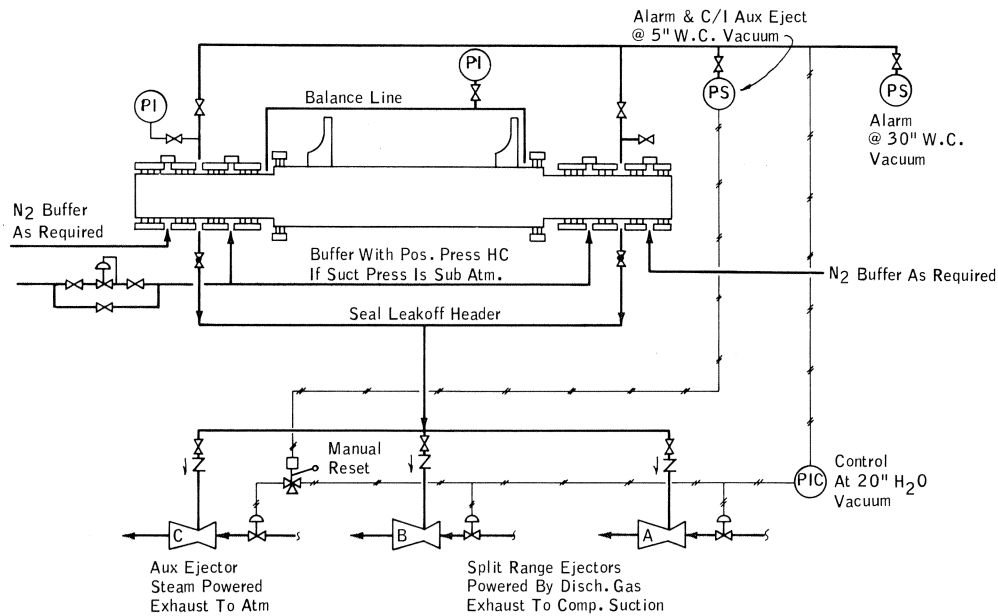


Figure 4. Noncritical-Flow Ejector System Features.

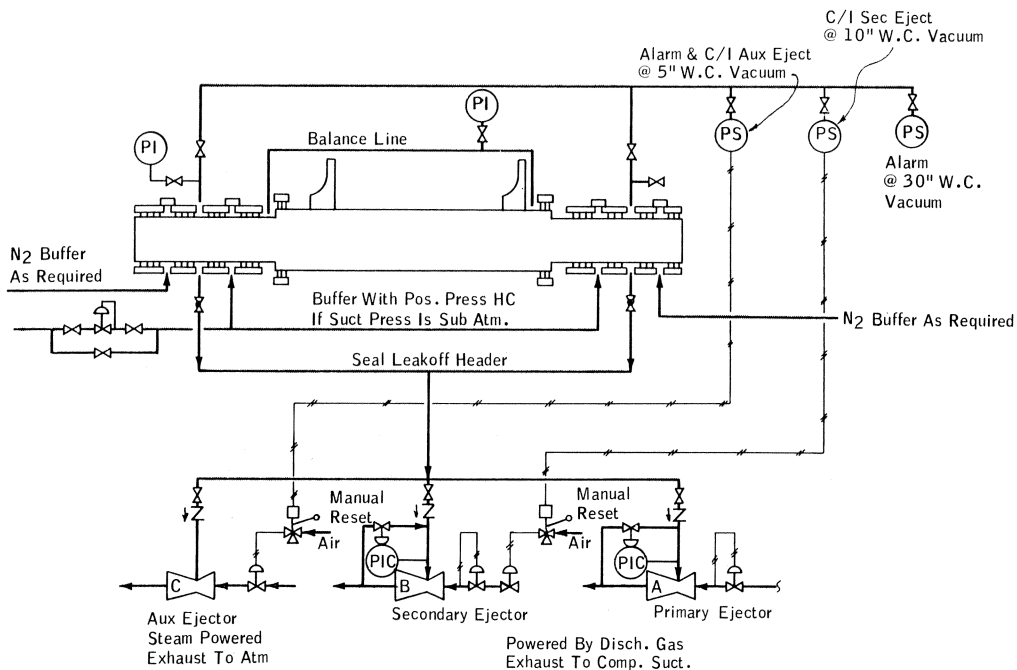


Figure 5. Critical-Flow Ejector System Features.

Flow rates

Normally, the compressor vendors are relied upon to provide labyrinth leakage rates and ejector sizing data, but procedures for calculating leakage are available in the literature. One source is Chapter 8 of "Gas and Air Compression Machinery" by Lyman F. Scheel published by McGraw-Hill in 1961.

A motive gas weight flow rate of four times the ejector suction weight flow is good for estimating purposes for subcritical-flow ejectors in catalytic cracking unit gas service.

Pressure ratio

As discussed earlier, the pressure ratio determines the type of ejector to be used, and determines the control system required. If the ejector is powered by the compressor discharge gas and exhausts to the compressor suction, approximately 24 psia suction pressure is the break point above which a critical-flow ejector is required.

CONCLUSION

Apparently the culprit in the deteriorating success of

labyrinth seals has been the historical increase of operating pressures. Suction pressures have been increased with the upgrading of existing plants and with new designs. Nitrogen injection systems and ejector systems which performed satisfactorily as originally installed are inadequate for the higher suction pressures in excess of 24-25 psia. Subcritical-flow ejectors have been unsuccessfully applied where critical-flow ejectors or oil seals should have been used.

We can conclude, however, that when careful attention is given to the sizing of piping and other system components, and the correct type of ejector is used for the pressure conditions, labyrinth/ejector seal systems will perform satisfactorily. Selection of labyrinth seals should be based on economic, environmental and process considerations.

