COMPRESSOR PERFORMANCE, FIELD DATA ACQUISITION AND EVALUATION

by

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COMPRESSOR PERFORMANCE

Centrifugal compressors are rugged designs that will perform satisfactorily for years at a time between scheduled maintenance shutdowns. However, there are times when the compressor's performance may be in question due to excessive power consumption or simply that it will not provide the compression job that is needed. Compressor performance is expressed in terms of brake horsepower required to compress a specified amount of gas flow from inlet pressure to discharge pressure and can be calculated from measurements of the following items: Gas composition; Inlet Pressure; Discharge Pressure; Inlet Temperature; Discharge Temperature; Gas Flow: and Speed. The type of instruments and method used to obtain this data has a direct effect upon the accuracy of the results. These requirements will be discussed in detail in the section on Field Data Acquisition.

The basic compressor characteristic curve is decribed in terms of inlet flow, head rise, and brake horsepower for each operating speed. A sample of a centrifugal performance curve is shown in Figure 1. From each set of data, which is comprised of the seven items listed above. one compressor operating point can be calculated and plotted in terms of head, flow, and power on the basic compressor characteristic curve. Normally five or six measurements are needed with a flow adjustment for each to completely describe the compressor curve for each speed. Usually field testing is not conducted on this large a scale, but rather the normal operating point is measured and the calculated results are compared to a manufacturer's supplied performance curve. These curves are either based upon the results of a shop test or if a test was not conducted prior to shipment, an estimated curve can be used.

The scope of the field tests depends upon the extent of the problem. For example, if the compressor performance is suspected to be drastically different than it should be, the manufacturer will need as much information as possible to try to determine from these tests what corrective action is recommended. Many times the reason for the operating difficulty can be determined from the test results and if new parts are needed, they can be manufactured ahead of time before the compressor is opened. There are applications where the compressor operating condition cannot be varied because of the process. The user and manufacturer must work together to establish the most meaningful test agenda before the test begins. This helps to eliminate misunderstandings and has proven to be the quickest way to get the job done.

Another reason for checking the compressor's performance is to determine if it has changed from the initial startup. If there is a change, such as reduced capacity, it may indicate that the compressor has become fouled by foreign material or the internal clearances have increased and a maintenance shutdown should be planned.

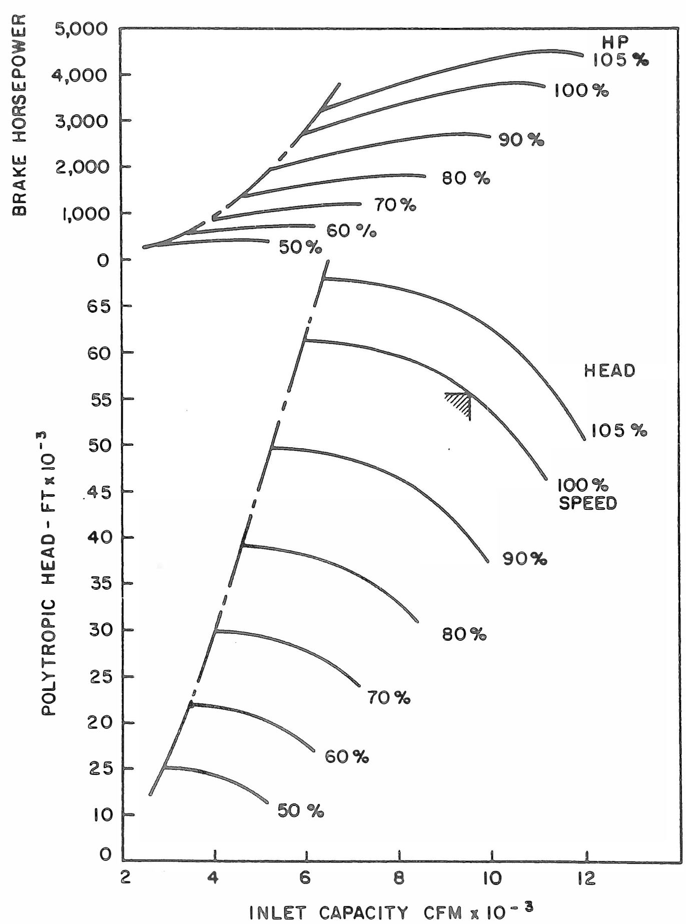

Figure 1. Compressor Performance Curve

This is particularly true if nothing significant has changed in the process, but the compressor has become the limiting factor in the plant's production.

FIELD DATA ACQUISITION

The ecquisition of field test data, if meaningful and accurate results are to be achieved, requires planning. These field tests are time consuming, inconvenient, and can be quite expensive. The testing agenda depends upon the purpose of the test. If the purpose of the test is to prove or disprove manufacturer's guarantees, then by all means the manufacturer should be consulted on the test procedure and will probably want a representative present during data acquisition. It is imperative that mutual agreement be reached between the user and the manufacturer concerning the testing accuracy, number of test points, method of recording the readings, etc., prior to the actual test in order to have the final results fulfill the intent.

When the purpose of the test is more of a routine nature and is only to provide information for the user's benefit, it is still recommended that the manufacturer be consulted. The manufacturer will usually be willing to provide a test procedure that outlines the minimum requirements, including the type of instrumentation, necessary to achieve a useful test result and a procedure for calculating the basic compressor characteristic curve.

The data that will be recorded during the test consists of readings of pressure, temperature, flow, speed, and gas properties. Measurements of power consumption are normally not available through direct readings, except when the compressor is driven by an electric motor, but rather are calculated from the other data.

The following is a table of instruments (per ASME PTC-10)[1] that may be used to test a compressor:

Pressure:	Bourdon tube gages Deadweight gages Liquidemanometers Barometers
Temperature:	Mercury in glass thermometers Thermocouples Resistant thermometers Thermowells
Flow:	Orifice plates Venturi tubes Flow nozzles
Speed:	Mechanical tachometers Electrical tachometers Digital electricity frequency counters Stroboscopes
Gas Properties:	Gas sample bottles Psychrometers

The accuracy of the test instruments must be verified before the test. Some suppliers specify the range of their instruments; these should be checked against an appropriate standard. Those instruments subject to changes in calibration during use should be checked before and after the test. The ASME PTC-10 also specifies that bourdon tube pressure gages be deadweight calibrated at approximately 5% intervals over the anticipated working range and that thermocouples and mercury-in-glass thermometers be certified at 20% intervals over the working range.

Flow measurements are obtained from either permanently or temporarily installed plant flow meters. When these meters are installed properly they provide flow readings that are sufficiently accurate for testing purposes. Commercially available flow meters state on the nameplate the accuracy of the instrument and these limits can be included when determining the overall accuracy of the compressor test.

When testing compressors that handle gases other than atmospheric air, a gas sample must be taken during the testing to determine the volumetric analyses of the gas mixture. When the gas composition varies during the test, it may be necessary to obtain several gas samples to evaluate the composition of the gas mixture. The analysis of the gas samples is obtained from an independent laboratory after the test has been completed.

The recommended location of the pressure and temperature instrumentation is shown by the diagram in Figure 2. The compressor performance is to be evaluated from inlet to discharge flange and therefore the pressures and temperatures should be measured as close to these connections as possible. This diagram locates four connections on both the suction and discharge of the compressor where readings are to be taken. Due to the limitation of some compressor installations and the accessibility of the piping, it may not be possible to obtain four readings of pressure and temperature at each measuring plane in the pipe. Under these circumstances, the instrumentation is placed in the pipe in the best arrangement possible and the potential errors in the readings are considered when evaluating the results.

During the testing the operating conditions of the compressor must be maintained as steady as possible. However, some small fluctuations can be tolerated without affecting the accuracy of the test. The table in Figure 3 is taken from the ASME Power Test Code—10 and gives allowable fluctuations of test readings during a test run. The ASME PTC-10 has also established allowable deviations for the compressor operating parameters that can exist during a test and still yield valid results. These limits apply to compressors that are operating with conditions that are different than the original compressor design conditions. These allowable deviations are shown in Figure 4. The stated departure allowances from specified operating conditions apply when the object of the test is to establish if the compressor performance meets the manufacturer's guarantees. This table of allowances can also be useful to the user. When the operating conditions of the compressor exceed these limits, it can be expected that the shape of the compressor characteristic curve, including stable range and efficiency may be different than what will be obtained when operating with the specified conditions.

The most important objective of field testing is to obtain accurate measurements in order to calculate the true performance of the compressor. The following is a list of rules of good practice for testing.

1. Plan the test ahead of time.

2. Prepare a test agenda that will accomplish the required objective.

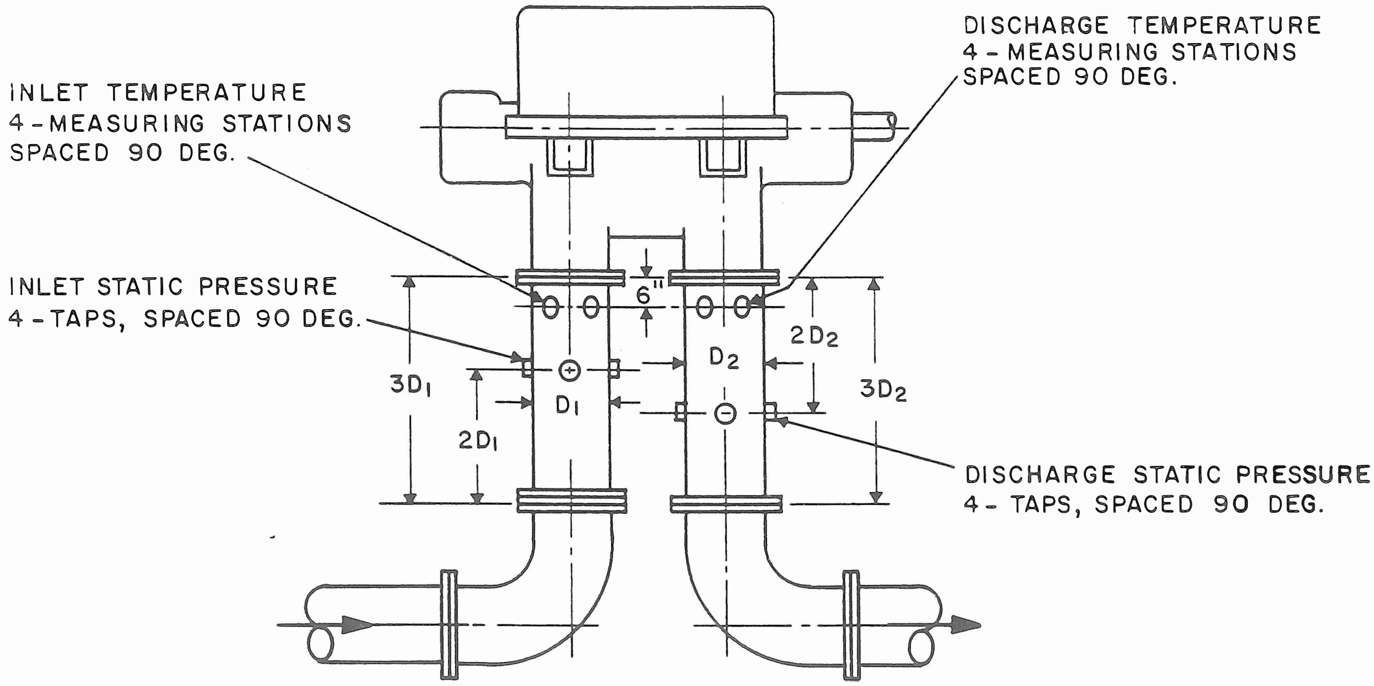

Figure 2. Instrumentation Diagram

3. Consult with the compressor manufacturer.
4. Use the best quality of calibrated instruments.
5. Take measurements simultaneously for each test run.
6. Record several sets of data for each test run.
7. Observe the data for consistency during the tes.
8. Allow the operating conditions to stabilize before recording data.
9. Do not rush the test.

COMPRESSOR PERFORMANCE TEST EVALUATION

The compressor's performance is calculated from the measured test data in accordance with well established thermodynamic methods. Section 5, of the ASME PTC-10 for compressors and exhausters, covers computation of the test results.

The method that is used to calculate the test results depends upon the properties of the gas being compressed. The calculation is simple when the perfect gas laws apply. When dealing with a real gas, the deviation from the perfect gas laws must be considered.

For perfect gases, the following relationships apply. From test measurements of:

inlet pressure, P_1 (PSIA)
discharge pressure, P_2 (PSIA)
inlet temperature, T_1 (°R)
discharge temperature. T_2 (°R)
flow rate, W (lbs./min.)
molecular weight, MW (ratio),

MEASUREMENT	UNIT	FLUCTUATION (1)
INLET PRESSURE	PSIA	2 %
INLET TEMPERATURE	R	0.5 %
DISCHARGE PRESSURE	PSIA	2 %
NOZZLE DIFFERENTIAL PRESSURE	PSI	2 %
NOZZLE TEMPERATURE	R	0.5 %
SPEED	RPM	0.5%
ELECTRIC MOTOR INPUT	KW	1.0%
SPECIFIC GRAVITY TEST GAS	RATIO	0.25%
LINE VOLTAGE	VOLTS	2 %

(1) PRESSURE AND TEMPERATURE FLUCTUATION FOR THE GAS EXPRESSED AS PERCENT OF AVERAGE ABSOLUTE VALUES.

Figure 3. Allowable Fluctuation of Test Readings During a Test Run

VARIABLE	UNIT	DEPARTURE % (1)	
(a) INLET PRESSURE	PSIA	5	(2)
(b) INLET TEMPERATURE	R	8	(2)
(c) SPECIFIC GRAVITY OF GAS	RATIO	2	(2)
(d) SPEED	RPM	2	–
(e) CAPACITY	CFM	4	

(1) DEPARTURES ARE BASED ON THE SPECIFIED VALUE WHERE PRESSURES AND TEMPERTURES ARE ABSOLUTE.

(2) THE COMBINED EFFECT OF ITEMS (a), (b) AND (c) SHALL NOT PRODUCE MORE THAN 8 PERCENT DEPARTURE IN INLET GAS DENSITY.

Figure 4. Allowable Departure from Specified Operating Conditions

the compressor polytropic head. Hdp. is calculated from the equation:

$$(1)\quad Hdp = RT\,\frac{n}{n-1}\left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right)$$

$$(2)\quad \text{where: } R = \frac{1545}{MW}$$

n = polytropic compression exponent (ratio).

Solve for n from the relationship

$$(3)\quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

Polytropic efficiency:

$$(4)\quad \eta P = \frac{Hdp}{\Delta h}$$

where Δh = enthalpy rise in the gas.

$$(5)\quad \Delta h = R\,\frac{K}{K-1}\,T_1\,(r^{\frac{n-1}{n}} - 1)$$

K = ratio of specific heats. $\frac{CP}{CV}$, of the gas.

$$(6)\quad \text{or } \eta P = \frac{Hdp}{\Delta h} = \frac{RT\,\frac{n}{n-1}\,(r^{\frac{n-1}{n}} - 1)}{RT\,\frac{K}{K-1}\,(r^{\frac{n-1}{n}} - 1)} = \frac{\frac{n}{n-1}}{\frac{K}{K-1}}$$

where: $\frac{P_2}{P_1} = r$ (ratio).

$$(7)\quad \text{Compressor gas power} = \frac{Hdp \times W}{33{,}000 \times \eta P} = \text{(Horsepower)}$$

The above equation is used to caluclate compressor gas horsepower. To convert this power to brake horsepower, corrections must be made for mechanical, seal, and radiation losses.

Therefore:

(8) Compressor BHP = gas HP + losses.

When a real gas is being compressed the compressor performance is determined from the following relationships:

$$(9)\quad Hdp = ZRT\,\frac{n}{n-1}\,(r^{\frac{n-1}{n}} - 1)$$

where Z = compressibility.

This equation is similar to equation (1) with the exception of an additional term 8. which adjusts the polytropic head for variations in the pressure-volume characteristic of the gas over the range of compression.

The polytropic efficiency is defined as:

$$(10)\quad \eta P = \frac{Hdp}{\Delta h}$$

The most difficult problem when dealing with real gases is to find the enthalpy rise in the gas due to compression, Δh, because the ratio of specific heats of the gas, K, is not constant over the range of compression. When reliable thermodynamic data is available for the gas, it is simply a matter of referring to charts or tables to obtain the enthalpy rise. However when the compressor handling a mixture of gases, the thermodynamic data is usually not available in the form of tables or charts and the performance calculation becomes more complicated.

API Data Book, Second Edition 1970[2], is an excellent reference for the physical and thermodynamic properties of gases and gas mixtures. Procedures are given for desk calculations with recommendations that some procedures be computerized. In addition to the above reference the ASME PTC-10, lists a bibliography of eighty-seven (87) different authorities who have published literature on the subject of thermodynamic properties of gases and gas mixtures. The Code also cautions the engineer that considerable variation in thermodynamic properties can be found among the various published papers on certain pure, commonly encountered gases. For this reason, it should be agreed upon prior to the test what thermodynamic data is to be used to evaluate the test data.

Once the polytropic efficiency and head are known, equations (7) and (8) are used to calculate compressor power consumption.

The procedures discussed in this paper, although correct, have been simplified and are meant to be an introduction to the subject of compressor field testing. For those who are actually faced with this problem, it is recommended that the references be studied.

REFERENCES

1. "ASME Power Test Code, PTC-10—1965 for Compressors and Exhausters," copyright 1965 by American Society of Mechanical Engineers.
2. "Technical Data Book—Petroleum Refining," American Petroleum Institute, copyright 1971.