Applications for Hydrocarbon Testing in Centrifugal Compressors

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ABSTRACT

The goal of any test must be to prove reliability. In centrifugal compressors there are basically two types of tests. The first proves the mechanical integrity, while the second verifies the aerodynamic performance. No one test can satisfy all goals so it is left to the purchaser to specify the type of test(s) which will satisfy his requirements. This paper discusses the limitations of various types of tests. Emphasis is given to Hydrocarbon Testing and, in particular, Class I Hydrocarbon Testing.

INTRODUCTION

Centrifugal compressor testing is in a state of continuous evolution. One basic mechanical test specification for centrifugal compressors (API-617, 1979) has remained basically unchanged over the past 20 years. Many performance tests are conducted in accordance with the ASME (PTC-10, 1965) which has remained unchanged since 1965. However, in this same time period, centrifugal compressors have been applied for ever increasing pressure, flows and horsepower. There is a continuing trend to single trains of compressors with no redundancy.

This trend, especially in remote locations or offshore where skilled personnel are not always available and downtime is extremely costly, has caused purchasers to seek tests that will resolve problems at the suppliers test stand rather than in the field. Optional tests most often specified are string testing, full load full pressure testing and more recently hydrocarbon testing. Testing is limited only by the centrifugal compressor manufacturer's test facilities and the purchaser's expected return on the monies invested in testing.

MECHANICAL TESTING

The only major recent evolution in mechanical test specifications was the effect of Industry acceptance of vibration proximity probes. These probes have led to tighter vibration acceptance criteria and to increased data recording (i.e., frequency spectra). However, most mechanical testing is done at low pressure because of test stand horsepower limits. Low pressure mechanical testing only verifies:

- Rotor Balance
- Proper Assembly
- Bearing Oil Flows and Temperatures
- Mechanical Integrity of the Compressor Rotor

For high pressure compressors, correct sealing pressures are not always used, therefore, critical speeds noted during mechanical testing may not be the critical speed observed during field operation since the damping effect of seals is neglected.

Complete unit testing, or as it is more commonly known, string testing, has become one commonly chosen optional test. As many components (i.e., oil systems, drivers, couplings, panels) as possible are utilized to simulate actual field operation. String testing does assure (Raubenheimer, 1984):

- a. All components are available.
- b. Assembly and maintenance of the components can be satisfactorily achieved.
- c. Mechanical performance may be acceptable.
- d. Sequencing control and mounting systems perform their function.

But, string testing is still a mechanical test and high pressure compressors are not normally operated at rated sealing pressure. In an attempt to provide full verification of operability in the field, more and more purchasers are specifying full load full pressure tests. By operating at rated pressures and rated horsepower, usually in a string, field operation is more closely simulated.

Very often full load full pressure tests can be conducted on inert gases (helium, nitrogen, carbon dioxide or a combination of these). Since properties of these gases are well known, it is possible to calculate performance of the compressor sufficiently accurate to confirm achievement of full load. Typically a gas is chosen to produce rated horsepower at the design speed and design discharge pressure. However, this is a single operating point only and many other operating parameters such as rated suction conditions and operating temperatures may not be established.

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Full load full pressure string tests do not always meet the following:
- Rated inlet pressures.
- Rated inlet temperatures.
- Rated interstage pressures or temperatures.
- Rated inlet density.
- Rated discharge temperature(s)

A FLFP test does provide the previously mentioned advantages of string tests plus verifying that components are satisfactorily designed for torque, pressures, and allows more accurate determination of critical speed(s), bearing and seal oil flows and temperatures.

Full load full pressure tests on inert gas cannot be performed for every train of equipment because of differences in properties between test and specified gases. In some cases, a full torque full pressure test has been substituted. This is actually two tests, possibly on different gases. The first proves the mechanical integrity at rated torque (not necessarily at rated speed) while the second tests the compressor at rated pressure and rated speed.

The FLFP test of a compressor designed for hydrocarbon service might also be accomplished utilizing a hydrocarbon test gas (usually natural gas and carbon dioxide mix). This will normally eliminate problems associated with gas property differences in test gases and should allow the compressor to be operated at rated inlet density. While still not matching rated density at every stage, vibration spectra can be observed at various operating densities as it has been observed that sub-synchronous vibrations are a function of densities; see Figure 1. However, it should be noted that if design densities can be obtained with inert gas, the results are just as satisfactory as with a hydrocarbon gas mix.

PERFORMANCE TESTING

Aerodynamic performance testing of centrifugal compressors is governed by codes such as "Power Test Code - Compressors and Exhausters" (ASME-PTC-10, 1965). The rules for this type testing remain constant. The purpose of this test is to verify performance of stages (individual impellers), sections (groups of impellers), or entire compressor cases. A gas of known gas properties is utilized.

Performance testing is used to verify the rated (design by ASME definition) point and the curve shape of the compressor characteristic. Typically five test points are used to establish the curve shape and one or two off-speed surge points establish the slope of the surge line. Optional test points are sometimes requested as needed to verify alternate operating points and other lower and higher speed curve shapes.

The Power Test Code provides for three classes of testing which, in simplified terms, are:
- Class I: Test gas same as specified gas; gas can be treated as perfect or real.
- Class II: Test gas differs from specified gas; gas is treated as perfect.
- Class III: Test gas differs from specified gas; gas of known thermodynamic properties must be utilized (i.e., air, nitrogen, carbon dioxide, helium and freon).

Classes II and III testing are usually performed at speed and operating conditions much different than specified in order to achieve correct volume reduction and also satisfy parameters defined in the codes.

Class I tests, for other than simple gases (i.e., air), usually introduce a second unknown, the gas properties of the specified gas. The code recognizes this fact in Appendix 78.02: "When the thermodynamic state is such that the gas mixture and its constituent gases must be treated as real gases, the method of defining the thermodynamic state of the constituent gases and thus arriving at their properties, shall be agreed upon in writing prior to the test." Even where there is agreement on property packages, it is not always possible to attribute the differences between predicted performance and as-tested performance to errors in prediction method or to errors in the gas property method. The goal of the test must be to achieve the best possible correlation and understanding of data. Reviews of various gas property packages have shown discrepancies as wide as 10% in predicted head.

Stricter observance of codes may not always achieve the reason for testing. Class I tests, although generally interpreted as the closest test to field operation, may not be the correct test if there are questions on correct gas properties. Other areas of
FIGURE 2: Compressibility deviations as observed during a hydrocarbon test of gas with high carbon dioxide content.

codes may be too permissive. A Class I test allows an eight percent departure from specified operating temperature (R); but as we can see in Figure 2, such an allowed deviation could introduce unacceptable errors in volume reduction.

Test facility limitations may introduce other reasons for deviation from codes. It may be unfeasible to have test facilities that could blend every possible gas composition. Even if such blending facilities were available, refrigeration and pressurization facilities would be needed to match any operating temperature and pressure (i.e., propane refrigeration).

Experience has shown that it is not always sufficient just to specify a code in an inquiry. The purchaser should be able to state a goal and then by working with the compressor vendor establish a test procedure that will achieve this goal, even if this requires exceeding or restricting the limits of codes.

HYDROCARBON TESTING

A recent trend in testing has been to test hydrocarbon gas compressors on synthesized hydrocarbon gases. If the unit is tested on the real gas at real pressures, the objectives of both performance and mechanical tests are met. However, there are some problem areas with this type test. Gas properties must be mutually agreed prior to test. It is also recommended that separate Class II or II performance tests be conducted prior to this test to:

• Accurately establish surge points
• Obtain characteristic curve shape for each section when there are multiple sections in one train

Since hydrocarbon testing is relatively new, it is not dealt with in the above referenced codes; and it is up to the purchaser and compressor vendor to establish testing criteria and to define expected results. Some of the key areas to be resolved are:

1. What is the purpose of the test; mechanical integrity or performance?
2. What gas property package will be used or will the results of the test be used to determine gas properties?

3. If performance is to be verified, how many test points per section? Note, it may be necessary to run each section separately to obtain curves from overload to surge.

4. Special restrictions such as suction temperature or gas composition limits.

5. Acceptance/rejection criteria for mechanical or performance reasons.

6. Contract equipment to be used.

Too often the term Class I hydrocarbon test has been substituted for full load full pressure tests on hydrocarbon gas. A FLFP test could be performed on hydrocarbon gas(es) and still not satisfy the requirements of a Class I test. In such cases, mechanical integrity is proven, but the unit still may not match the design volume reduction at every stage. For example, Class I performance testing requires a very strict matching of field and test gases, especially carbon dioxide content. Carbon dioxide is the most common cause of major changes in gas properties. As can be seen in Figure 3, maintenance of inlet pressures and temperatures is critical to prevent phase changes in the test gas.

A MODIFIED CLASS I TEST: THE DIFFERENCE

Recent field experience concerning differences between factory tests and observed field conditions resulted in Dresser Clark undertaking hydrocarbon performance tests on several compressors (Colby, 1987).

Prior to hydrocarbon testing, each compressor

![Figure 3: Phase map of a tested hydrocarbon gas utilizing SRK gas properties.](image-url)
underwent separate mechanical and Class III performance tests. The results of the Class III tests were used to correct the original predicted operating curves using mutually agreed gas properties. A hydrocarbon gas was blended to meet the following rules:

- ZRT specified vs. ZRT test must not exceed ± 2%.
- CO₂% specified vs. CO₂% test must not exceed ± 5%.

The purpose of the tests was to establish the performance map of each section from overload to near surge. Special instrumentation was added to measure shaft horsepower, gas density, gas composition (gas chromatograph) as well as the normal test parameters. One goal of the test was to determine which gas property packages came closest to predicting the observed performance. Any observed performance deviation from Class III test data should be a result of errors in the property predictions method or other leakage phenomena at full pressure.

As many as five different gas property packages were used in the analysis, and it was necessary for the purchaser to be involved with comparing deviations against predictions since, contrary to the code, a purpose of the test was to prove the accuracy of the performance subroutines. With the agreement of the customer, amended gas property subroutines were used to correct deviations which were observed on test (as they had been observed in the field).

Future goals are to measure compressor flow independent of gas properties. With this it will be possible to draw actual test curves (flow vs. power and pressure ratio) independent of gas property calculations. However, it is necessary that the Class III test be as accurate as possible which requires more restrictive codes or more innovative testing.

During these modified Class I performance tests, there was an opportunity to observe events that are not normally observed and could not have been anticipated by reasonable analysis. These events included various influences on vibration (Shemeld, 1986), solubility of gases in sealing oil, liquid formation in static gas lines and effects of gases on O-rings, especially on gases with high percentages of carbon dioxide.

Performance tests as described above and subsequent field operation did probe the accuracy of Class III test (refer to Figure 4). Future tests of the modified Class I type as herein described should only be necessary when gas conditions vary significantly from prior experience.

**RECOMMENDATIONS**

The Purchaser must establish test requirements based on factors such as remoteness of installation, experience of personnel and familiarity with process. The purchaser and supplier must mutually establish a testing plan to meet the purchaser's goals. In today's world, a simple reference to a standard code will not imply the success of a unit in the field.

It has been demonstrated that low pressure tests (Classes II or III) are sufficiently accurate to confirm compressor performance. Future hydrocarbon tests would be restricted to FLFP tests where gas properties restrict the use of inert gas or where gas properties are uncertain enough to require a Class I or modified Class I type test.

The added advantage of more testing will be to
provide more reliability and minimize time and costs for field erection.

A modified Class I test as described herein is one way to verify gas properties. More of this type testing will provide both customers and compressor manufacturers with more accurate gas property data which in turn will allow more realistic performance prediction.

REFERENCES

API-617, 1979, American Petroleum Institute Standard 617 "Centrifugal Compressors for General Refinery Services"

ASME PTC-10, 1965, Society of Mechanical Engineers Power Test Code PTC-10 "Compressors and Exhausters"


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