value during the test. For many gas mixtures these measurements may not be possible with available instruments.

Discussion

C. F. Koenig, 3rd.[4] This seems to be an excellent paper and we have little to offer except compliments. It is certainly true that PTC 10 is inadequate for testing of this nature, and prompt revision thereof will be of tremendous value to the industry. It also will tend to clear up some misconceptions which appear to exist in certain quarters, mostly because of incomplete evaluation of the gas dynamics involved.

The author makes the point that gas properties must be selected for the test which will result in the design volume ratio through the machine. We believe that a further consideration is important—that of Mach number or the ratio of gas velocity to the local sonic velocity at various points within the compressor. The performance of a compressor varies considerably with the Mach number, particularly when tip speeds and/or Mach numbers are high at the design point.

We try to select a gas such that both the design density ratio (= volume ratio) through the machine and the design Mach numbers are simulated as closely as possible. The test speed is usually not the design speed, unless the test gas is similar to the design gas.

It is usually found that, for gases lighter than air, tests can be run on air at reduced speed and the proper volume ratio and Mach number can be simulated closely. For gases heavier than air, it is almost always necessary to use a special test gas, e.g., Freon.

Where the test speed as calculated from the foregoing considerations is different from the design speed, we would run mechanical tests at full speed to check seals, thrust bearings, case deflections, and so on. In extreme cases, it may be necessary to use different gases in the loop for performance tests and mechanical tests. On "platforming" compressors, for example, where the molecular weight is about 6.0 and the k-value about 1.39, performance tests are run on air at about 50 per cent of rated speed. The pressure level is not vital for performance tests, except that efficiency usually improves 1 or 2 points at the high pressures. For mechanical tests at rated pressure, air would require far too much horsepower, so a mixture of helium and air—mostly helium—is used. Note that the helium-air mixture would not be suitable for performance tests because of the high k-value of helium.

This paper should do much toward encouraging the industry to look with favor on testing of this nature. For a relatively small cost per machine it furnishes valuable data on the machine being tested. It also provides valuable information for future development which otherwise would probably not be obtained for a long time and which will pay off in better compressors for the future.

T. O. Kuivinen.[5] The writer was very ably aided by Messrs. B. C. Thiel and John Fullemann in reviewing the author's paper on "closed systems," and the following is a consolidated discussion:

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[5] The Cooper-Bessemer Corporation, Mt. Vernon, Ohio.

We feel that this is an excellent paper revealing a wealth of experience obtained by the author. He is to be congratulated on this presentation. We fully agree with him on the wisdom of using closed loops, not only for research, but for production tests too.

One of the merits of closed systems (implied by the author but not spelled out in detail) is the evaluation of Reynolds-number effect (i.e., scale effect) on performance, which can be done easily by changing pressure levels. The author also mentions the need to consider supercompressibility and the fact that testing should not be attempted on gases where the compressibility effects are not well established. It is our belief that equipment is now available from instrument manufacturers whereby a simple method, originated by Dr. Burnnett of the Bureau of Mines, may be used to determine compressibility factors for the gas under consideration.

The present test code requires long straight runs after turns to insure accuracy. For large pipe sizes this becomes bulky and expensive. Does the author know if there is any activity considering relaxing the code toward shorter straight runs if turning-vane cascades are used instead of standard tube turns? Cascades provide better flow-energy distribution downstream than plain turns in the piping.

Author's Closure

The remarks by Mr. Koenig are well taken. They summarize the variables involved and emphasize the complexity of the problem.

Among these variables he mentions Mach number, which the author failed to include in the paper. When testing with substitute gases it is easy to get into serious trouble if velocities within the impellers approach the speed of sound. To avoid this pitfall it is necessary to examine the impeller design before a substitute gas is chosen.

A reference was made to the use of test speeds as low as 50 per cent of the rated speed. Although this is consistent with current theories of fluid dynamics, there is strong hesitancy on the part of some designers to accept tests where the speeds vary widely from the design value. For this reason the code limitations on the speed deviation must remain conservative.

Mr. Kuivinen, quite correctly, calls attention to the possibility of investigating the Reynolds-number effect by the simple expedient of changing the pressure level. It is to be expected that the experience with closed-system testing will produce some good papers on this subject in the near future.

Regarding the economic limitations of long pipe lengths specified in the present code, it will be observed that the code rules are of necessity conservative. The author has successfully used short pipe lengths by fitting elbows with turning vanes. It should be remembered, however, that short pipes cannot be safely used without investigating the prevailing velocity distributions with a pitot-tube traverse. These investigations are in themselves time-consuming and expensive and it may be cheaper to use longer pipe.

The comments by Mr. Koenig and Mr. Kuivinen are all constructive and contribute substantially to the development of the subject.