1972

Operation of Compressors Through Use of Load Stands

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INTRODUCTION

Compressors are an integral part of a cooling system where the compressor is frequently the object of research in itself since its performance is usually indicative of the overall efficiency and performance of the total system. Thus an expedient and efficient method for operating the compressor independent of the cooling system is highly desirable for research purposes. A method for accomplishing this is through the use of the hot gas load stand which can be used to operate the compressor by creating an interface between the compressor and the load stand which simulates the interface between the compressor and the normal cooling system.

THEORY OF OPERATION

The compressor is responsible for the compression portion of the thermodynamic cycle where the real compressor operates in the superheat region. The compression cycle is between points 1 and 2 of Figure 1. The load stand can be used to provide the necessary pressures and temperature at these points of interface of the compression cycle such that the compressor can be operated independently of the cooling system. The load stand satisfies three criteria at these interface points. (1) The prescribed pressures and temperatures can readily be achieved at these points within the range of operation of the stand. (2) The pressures and temperatures can readily be held constant to maintain steady state operation of the compressor. (3) The pressures and temperatures at the interfaces can be changed rapidly to achieve new steady state operating conditions.

LOAD STAND DESIGN

Figure 1 shows the thermodynamic cycle of the load stand with precooling. Figure 2 shows it without precooling. A schematic of the load stand is shown in Figure 3. The numbered points of Figure 1 and 2 correspond to the numbered points of Figure 3. In Figure 3, if precooling is not required, then the tubing and pre-cooler corresponding to points 2 and 3 would be deleted. The remaining system would be unchanged.

The load stand consists of three related systems: the cooling-throttling system, the gas supply system, and the cooling water system.

For the primary system with precooling, the cooling-throttling system, gas is accepted by the compressor at point 1 at the suction pressure, $P_s$, and it is compressed and discharged at point 2 at discharge pressure, $P_d$. The gas flows through the pre-cooler and it is cooled at constant pressure, and then it is returned to the compressor shell cavity at point 3. The cooled gas flow is used to cool the compressor motor unit and the gas is emitted at point 4, the second discharge. The gas is throttled by the expansion valve at a constant enthalpy between points 4 and 5. The gas is cooled at constant pressure by the main cooling system and the cycle is then repeated.

For the primary system without precooling, gas is accepted by the compressor at point 1 at the suction pressure, $P_s$, and it is compressed and discharged at point 2 at discharge pressure, $P_d$. The gas is then expanded at constant enthalpy, and then cooled by the main cooling to point 1 and the cycle is repeated.

The gas supply system is used to control the amount of gas present in the primary system. The gas supply tank is connected to the primary system at points 4 and 5. The "gas out" valve on the discharge side of the expansion valve, point 4, is used to remove gas from the primary system. The "gas in" valve which is located on the suction side of the expansion valve at
The above described load stand has been and thus by opening the bypass prior to reading the rotameter so that bypassing of the gas supply pressure, if necessary, to provide the necessary pressure differential which will cause the gas to flow into the primary system.

The cooling water system is used for the main cooling and the precooler (if required). The water source is hot and cold "tap" water. Because of water temperature fluctuations of the hot and cold water, water temperature control is necessary to provide the constant temperature mixture water which is used on the main cooler and the precooler. With a water temperature control, very stable steady state operation of the compressor can be maintained for extensive periods of operation. Usually the water mass flow rate and temperature are chosen to satisfy the requirements of the main cooler and then the cooling requirements for the precooler are satisfied by adjusting the precooler water mass flow rate. The water emitted from the main cooler and the precooler are discharged into a drain.

To measure mass flow rates of the gas in the primary system, a rotameter is used between the second discharge and the suction side. A valve is used in parallel with the rotameter so that bypassing of the rotameter can be accomplished. The line for the bypass should have its entrance physically "below" the rotameter. Oil will collect in the rotameter which does not permit an accurate reading of the rotameter. Thus by opening the bypass prior to reading the rotameter, the accumulated oil can be evacuated from the rotameter and passed into the primary system.

The above described load stand has been and is being used successfully at the Ray W. Herrick Laboratories. The authors do recommend possible changes in the above design for improvement and/or increased flexibility.

In the area of improvements, the following suggestions are made:

The "gas in" and "gas out" valves are normally single valves which permit the flow of "large" amounts of gas. It is recommended that two valves be incorporated in parallel for the "gas in" and also for the "gas out". One valve would be a "large" valve to permit the passage of large amounts of gas during gross changes in the system gas requirements. Because it is frequently necessary to "bleed" gas in or out of the primary system, a "small" valve should be used in parallel with the large valve. This improvement is highly recommended.

A second improvement would be in the water system in the form of water pressure regulation between the water control unit and the point on the pipes where the mixture water temperature sensor is located. The pressure regulation would provide a constant mass flow rate of mixture cooling water. This improvement is also highly recommended since it has been found by the authors that it can be difficult to provide a relatively constant mixture water mass flow rate through suitable valving of the hot and cold water when large changes in the mixture water temperature are made because of the water valving action of the water temperature control device.

A third improvement would be in the form of two independent cooling water systems where precooling is required, one for the main cooling, and the other for the precooler. This would provide greater flexibility in choosing the amount of cooling that would take place in the main cooling and the precooler. The authors have found that through experience, suitable water regulation can normally be achieved with the present system, but it can be somewhat inflexible at times. The decision to incorporate this improvement is basically one of economics since two water temperature control devices would be required. The authors recommend that for situations where regular use of the load stand will be with different compressors (of the same size or different sizes) and/or large variations of operating conditions, the above improvement is strongly suggested.

A final possible alteration of the present load stand design is in the main cooling and the precooler (if required). Normally the sizes of the main cooling and the precooler are designed for a particular size compressor, but if various sizes of compressors are to be used, increased flexibility of operation could be achieved by multiple counter-flow heat exchangers in parallel with suitable valves. The amount of cooling for a given compressor size could be achieved by incorporating the required number of exchangers, water temperature, and water flow rate. If this improvement is deemed desirable, it also recommended that independent water systems also be incorporated as described above if precooling is used.

The tubing sizes are flexible. Generally the tubing size should be chosen to be compatible with tubing size of the discharge and suction tubing size of the
compressor to be used with the stand or for the largest size compressor to be used with the load stand. Tubing lengths are not important for compressors used in the immediate vicinity of the load stand, but if the compressor is located some distance away, e.g. ten or twenty feet, problems can arise due to heat transfer from the tubing over the distances. This causes changes in the temperature and pressures of the gas which cannot be compensated for by the load stand, particularly on the suction side. Thus provisions should be made for insulation of the tubing if large distances are traversed. If fractional horsepower compressors are to be tested, it may be necessary to insulate all of the tubing of the load stand since sufficient heat conduction may occur between the pipes and the surroundings which alter the temperature and pressures which cannot be compensated for in the load stand.

For the sake of safety, it is also recommended that safety valves be installed on the discharge lines with suitable tubing on the valve to discharge the gas and oil away from the operator in case of a "blow". This feature is extremely important since it is very possible in the course of research to exceed the safe pressure limits of the system.

Provisions are made to measure both temperature and pressure. Temperatures are measured by thermocouples. The suction and discharge gas temperatures are measured on their respective lines near the compressor. The pressures of the suction and discharge are also measured on the lines near the compressor using Heise Pressure Gages.

The above design considerations should permit the flexible operation of a single compressor or different compressors using a single load stand under varied operating conditions.

COMPRESSOR OPERATION USING A LOAD STAND

If the hot gas cycle of Figure 1 or 2 is assumed, then the operating conditions of the compressor can be defined. By fixing the suction and discharge pressures, and the suction temperature, the isentropic compression from point 1 to point 2 is defined. By suitable cooling and expansion, the points 3, 4, and 5 are determined for precooling and the hot gas cycle is fixed. Without precooling, constant enthalpy expansion occurs between points 2 and 5 of Figure 2. Suitable main cooling will then yield the desired temperature and pressure of point 1 of Figure 2 and the hot gas cycle is fixed.

In actual operation, gas is bled into the system while suitable adjustments are made on the expansion valve to achieve the desired pressures while the temperatures and pressures are measured at the suction side at point 1. For precooling, the temperature and pressure is measured at the discharge side at point 4. The cooling water is also adjusted to fix points 3 and 4. The procedure is initially trial and error, but as one acquires experience, steady state operation is accomplished rather expeditiously.

With a load stand built with all or part of the above mentioned refinements, one should be able to establish operating conditions very quickly after a few initial runs. For a given compressor at steady state, one would note the required water flow rates, water mixture temperature, expansion valve setting, and thereafter, one would need only bleed in the required gas to achieve steady state as defined by the prescribed points.

SUMMARY

The use of the hot gas load stand provides an efficient means for operating a compressor while simultaneously maintaining excellent control of the compressor operating condition with a minimum amount of equipment.

The load stand lends itself very well to research purposes where quite varied operating conditions may be required. It also lends itself well to the testing of compressors since steady state operation can be controlled.

In general, the load stand provides an efficient and expedient means for operating compressors under various operating conditions.

Acknowledgement: The original concept of the load stand was obtained from Tecumseh Products Company.
Figure 1. Hot Gas Cycle With Precooling

Figure 2. Hot Gas Cycle Without Precooling
Figure 3. Compressor Load Stand

Figure 4. Front View of a Typical Load Stand

Figure 5. Rear View of a Typical Load Stand