1984

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BLOCKED SUCTION UNLOADING IMPROVES PART LOAD EFFICIENCY OF SEMI-HERMETIC RECIPROCATING COMPRESSOR

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ABSTRACT

This paper illustrates the improvement in part load efficiency of a semi-hermetic reciprocating compressor gained by using blocked suction unloading. The efficiency and operation of blocked suction unloading is compared with top head unloading and suction valve lifter unloading.

A description is given for each of the three types of unloading.

In addition to having the best part load efficiency, blocked suction unloading results in lower motor temperatures when compared to top head unloading.

In conclusion, blocked suction unloading is shown to be the most efficient of the three methods for unloading compressor cylinders.

INTRODUCTION

In order to more closely match compressor output or capacity to system requirements or load, it is necessary to design some type of compressor cylinder unloading into reciprocating compressors used in air conditioning and refrigeration systems. As system requirements or loads change, the compressor output, or capacity can then be changed to match the load. Therefore, compressor cylinder unloading provides for a gradual compressor capacity transition. Six cylinder compressors can be unloaded from 100%, or full load, in steps, down to 33% capacity, where only two cylinders are pumping. Four and eight cylinder compressors can be unloaded from 100% or full load, in steps, down to 25% capacity, where only one or two cylinders are pumping.

It is necessary that at least one or two cylinders remain permanently loaded so long as the compressor is running. This minimum flow of gas is necessary to cool the motor and the other unloaded cylinders. The percent of capacity for each step of unloading is determined by the number of working cylinders divided by the total number of cylinders in the compressor. For example, a six cylinder compressor with only 4 cylinders pumping is at 67% capacity, 2/3 of the cylinders pumping.

Of greater importance than having steps or percentage of unloading is the method used to unload the compressor cylinder. The method has a decided effect upon the overall efficiency of the system. This is because systems do not need to operate at full capacity all the time and therefore the compressor need not operate at full capacity all the time. Because compressors do operate at part load, part load efficiency becomes very important in the overall efficiency of the real world system.

Three of the most widely used methods for unloading compressor cylinders are top head unloading, (THU), suction valve lifter unloading, (SVL) and blocked suction unloading, (BSU).[1]

Top Head Unloading (THU)

Top head unloading (THU) is accomplished by connecting the discharge head over one or more compressor cylinders to the suction side of the compressor. This is done by a top head unloading valve which can connect the discharge head to either the suction or discharge side of the compressor. See Fig. 1. Normally, of course, the discharge head is connected to the discharge side of the compressor. When the discharge head is connected to the suction side of the compressor, gas is pumped through the cylinder but is not compressed to discharge pressure. In effect, the cylinder or cylinders become unloaded because no gas is delivered to the discharge side of the compressor. Since the gas does flow through the cylinder and back to the suction side of

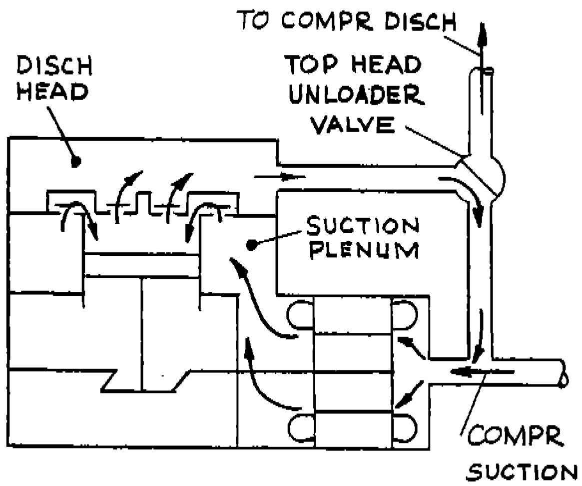

FIGURE 1. TOP HEAD UNLOADING, (THU) SHOWN UNLOADED TO COMPRESSOR SUCTION

the compressor, pressure losses develop as the gas flows through the valves. One pressure loss results as the gas is pulled into the cylinder through the suction valve. A second pressure loss occurs as the gas is pushed out of the cylinder through the discharge valve. A third pressure loss occurs as the gas is pushed back to the suction side from the discharge head through the unloading valve. These three pressure losses account for most of the inefficiency of top head unloading. See Figure 2 for typical efficiency, in KW/TON versus the number of cylinders loaded on a 30 ton six cylinder semi-hermetic compressor at 40° evaporator and 105° condensing.

Top head unloading, when piped as shown in Figure 1, causes an increase in the compressor suction temperature which in turn causes an increase in the compressor discharge temperature. It also causes an increase in motor temperature due to the higher suction temperature. See Figure 3. All these temperature increases are undesirable. They occur because with this type of unloading, gas from the unloaded cylinders is repeatedly recirculated across the warm motor. Particularly when there are more unloaded cylinders than working or pumping cylinders in a compressor, then most of the compressor suction gas will be made up of recirculated gas as opposed to fresh cooler gas from the evaporator. Consequently, suction temperature, discharge temperature and motor temperatures rise.

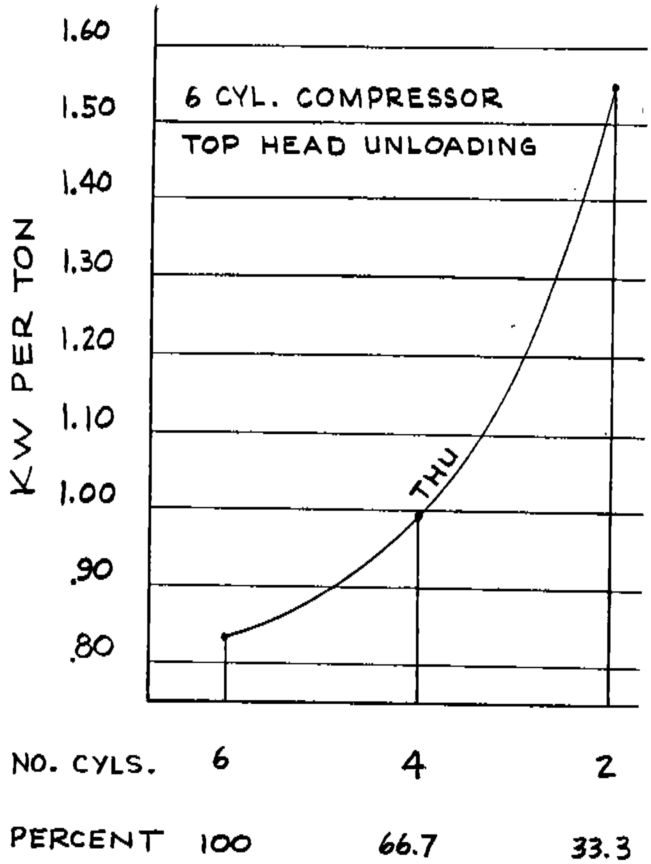

FIGURE 2. EFFICIENCY, KW/TON VS. NO. OF CYLINDERS WORKING AND % CAPACITY

Suction Valve Lifter Unloading (SVL)

Suction valve lifter unloading (SVL) is accomplished by lifting the suction valve and keeping it off its seat and open at all times when cylinder unloading is desired. See Figure 4. This causes gas to be pulled into the compressor cylinder through the open suction valve when the piston travels from top dead center to bottom dead center. When the piston travels from bottom dead center to top dead center, the same gas is pushed back out of the cylinder through the same suction valve which is being held open. There is no compression of gas in the cylinder to discharge pressure since the cylinder is continuously open to the suction side of the compressor. There are two valve pressure losses associated with suction valve lifter unloading. One pressure loss results from the flow of gas through the open suction valve, into the cylinder. The second pressure loss results from the flow of gas out of the cylinder through the open suction valve and back to the suction plenum. These two valve pressure losses account for most of the inefficiency of suction valve

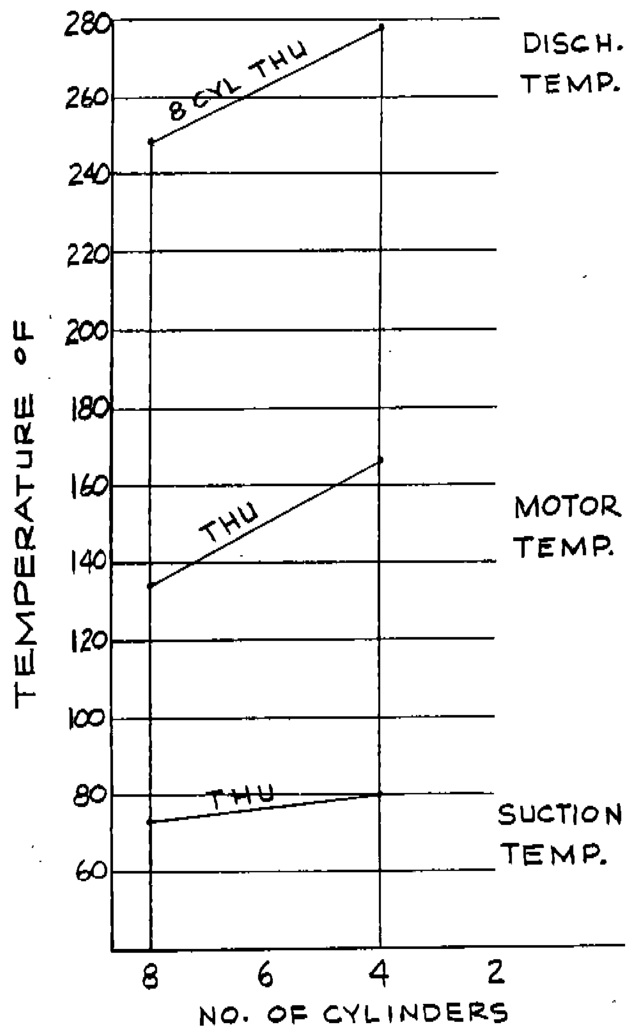

FIGURE 3. TEMP. DEG. F VS NO. OF CYLS WORKING IN AN 8 CYL COMPR, TOP HEAD UNLOADING

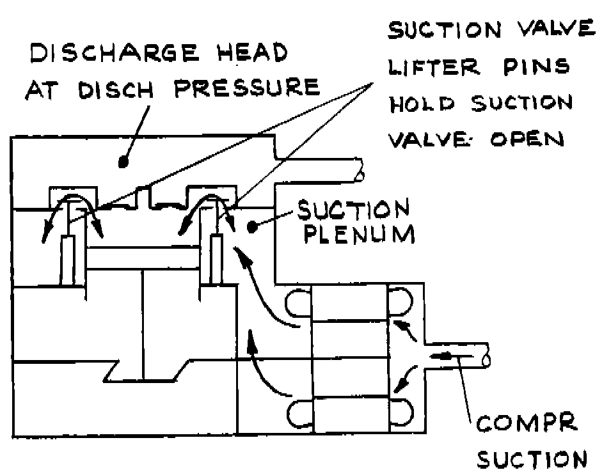

FIGURE 4. SUCTION VALVE LIFTER UNLOADING SHOWN UNLOADED

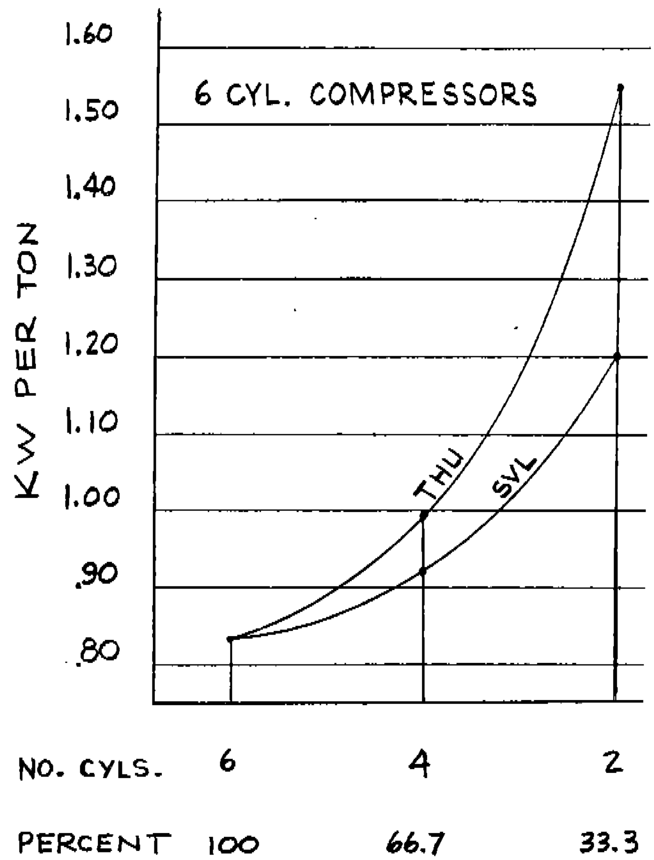

FIGURE 5. EFFICIENCY KW/TON VS NO. OF CYLS WORKING AND % CAPACITY, THU & SVL

lifter unloading. See Figure 5 for typical suction valve lifter efficiency in KW/TON versus the number of cylinders loaded on a 30 ton six cylinder semi-hermetic compressor at 40° evaporator and 105° condensing. It compares favorably with top head unloading efficiency, also shown on Figure 5.

In addition, there is no suction gas temperature increase because there is no gas recirculating across the motor as in top head unloading.

Blocked Suction Unloading (BSU)

Blocked suction unloading (BSU) is accomplished by literally blocking the flow of gas to the compressor cylinder. See Figure 6. It is done by a blocked suction unloader valve in the suction plenum just before the compressor cylinder suction valve. It stops the flow of suction gas to the cylinder. The compressor piston automatically pumps all the available gas to the discharge side of the compressor. This causes the suction plenum between the blocked suction

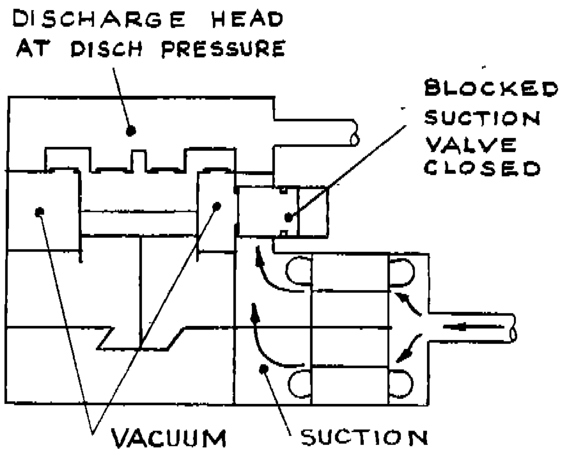

FIGURE 6. BLOCKED SUCTION UNLOADING (BSU) SHOWN UNLOADED WITH SUCTION BLOCKED

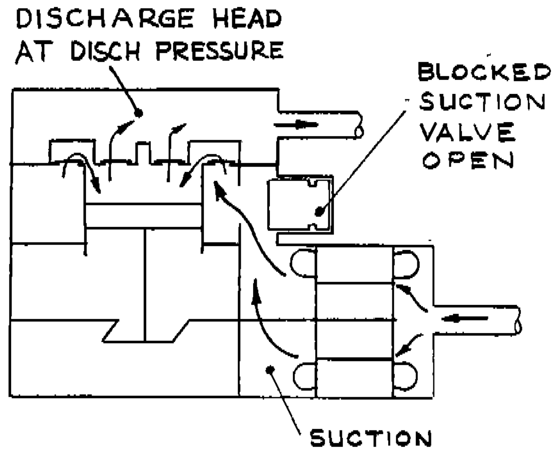

FIGURE 7. BLOCKED SUCTION UNLOADING (BSU) SHOWN IN LOADED POSITION

unloader valve and the compressor cylinder valve to be pulled down into a deep vacuum where it remains. The gas in the cylinder varies from a vacuum to discharge pressure and back to a vacuum as it is compressed and re-expands with each stroke of the piston. There is no flow of gas out of the cylinder to the discharge side, and there is no flow of gas into the cylinder from the suction plenum which is in a vacuum. Basically, there is no flow of gas through either the suction valve or the discharge valve. With the exception of irreversibility losses, the work done on the gas during the piston compression stroke is returned during the re-expansion stroke. Since there is no flow of gas, there is no gas recirculating across the motor as in top head unloading. When the blocked suction valve is opened, of course, there is the normal flow of gas to the cylinder, see Figure 7. When the blocked suction valve is closed and there is no flow of gas, there are no valve pressure losses, which accounts for the improved efficiency of blocked suction unloading as compared to top head unloading or suction valve lifter unloading. See Figure 8 where the KW per ton efficiencies of all three are compared. Because there is no gas recirculating across the motor, there is a decrease in motor temperature when unloading occurs. See Figure 9. Compared to top head unloading where motor temperature increases, with blocked suction unloading the motor temperature decreases.

With all of its advantages, the most critical problem with blocked suction unloading is leakage. It is absolutely necessary to establish and maintain a

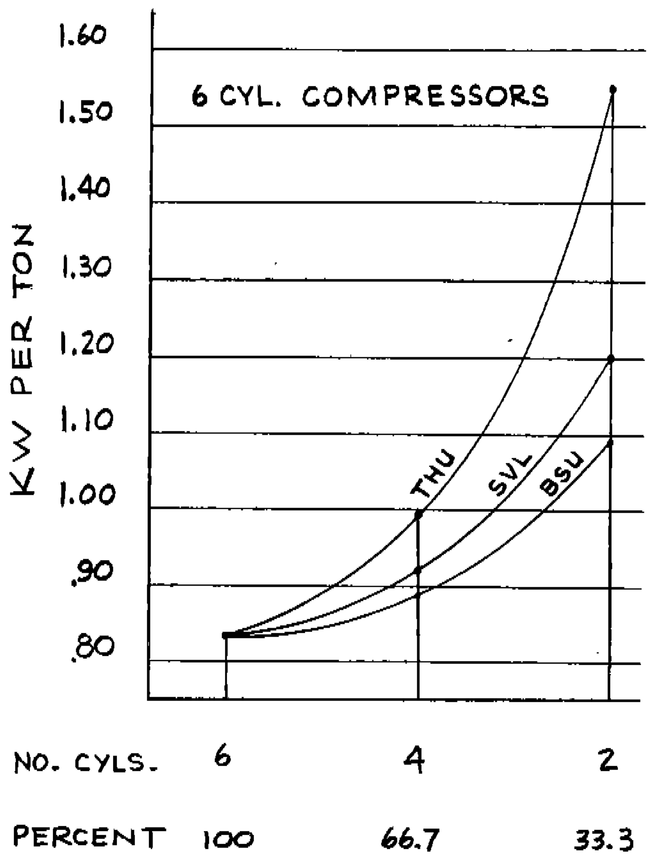

FIGURE 8. EFFICIENCY KW/TON VS NO. OF CYLS WORKING AND % CAPACITY, THU, SVL, BSU

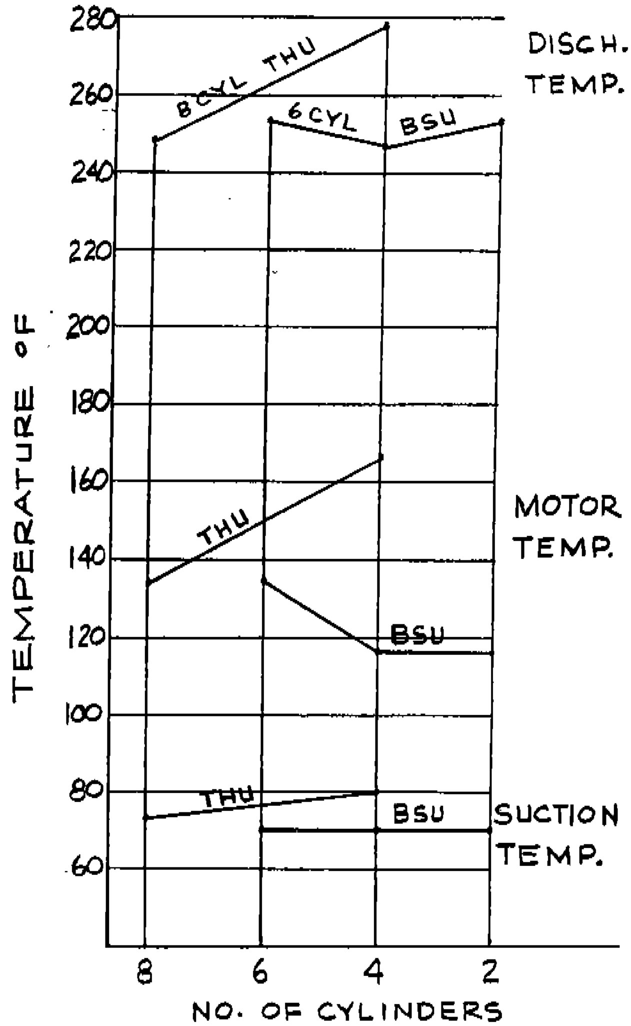

FIGURE 9. TEMP. DEG. F VS NO. OF CYLS WORKING IN AN 8 CYL COMPR WITH THU AND IN A 6 CYL COMPR WITH BSU

vacuum in the suction plenum leading to the unloaded cylinders. See Figure 10. If a small amount of gas leaks into the suction plenum, it will be drawn into the compressor cylinder where it will be compressed and pumped to the discharge side of the compressor. This pumped leakage gas is extremely hot since it is being compressed from a vacuum to full discharge pressure. The high compression ratio quickly results in elevated com-compressor discharge temperatures and elevated oil temperatures. A non-leaking seal at the blocked suction valve as well as leak-proof seals elsewhere in the suction plenum and at the discharge valve is essential to blocked suction unloading. The success of blocked suction unloading depends upon it.

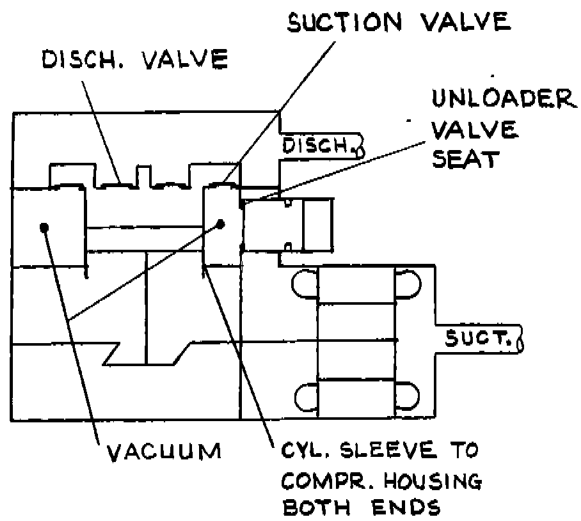

FIGURE 10. PLACES WHERE GOOD SEALS ARE REQUIRED TO MAINTAIN VACUUM IN BLOCKED SUCTION PLENUM

Conclusion

When compared to top head unloading, blocked suction unloading is significantly more efficient and also results in lowering rather than raising motor and operating temperatures.

Blocked suction unloading is slightly more efficient than suction valve lifter unloading, and both have relatively no ill effects upon the motor or operating temperatures.

For blocked suction unloading, it is of utmost importance to establish and maintain a vacuum in the unloaded or blocked suction plenum.

Notation

THU Top Head Unloading
SVL Suction Valve Lifter Unloading
BSU Blocked Suction Unloading

Reference

[1] Cheney, L.W., A New Approach to Compressor Capacity Modulation, 1974 Purdue Compressor Technology Conference pp 55-60.