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D. A. Collings
Tecumseh Products Company

Z. K. Yap
Tecumseh Products Company

D. K. Haller
Tecumseh Products Company

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COMPRESSOR MECHANISM COMPARISON FOR R744 APPLICATION

Douglas A. Collings, P.E., Project Engineer

Zer Kai Yap, Project Engineer

David K. Haller, P.E., Mgr. Adv. Eng.

Tecumseh Products Company, 100 E. Patterson Street
Tecumseh, MI, 49286, USA

ABSTRACT

The refrigeration and air conditioning industry shows much interest in environmentally-friendly natural refrigerants. One such refrigerant is R744, carbon dioxide. It is attractive because it is not toxic, not flammable, and is widely available as a byproduct of industrial processes. However, carbon dioxide (CO_2) systems operate at much higher pressures than systems using HCFC, HFC, or HFC-blend refrigerants. The roles of common compressor mechanisms appear established in the marketplace using current refrigerants, but applicability for CO_2 remains to be seen. The intrinsic properties of scroll, rolling piston, and reciprocating piston mechanisms are compared for their impact on efficiency.

INTRODUCTION

The refrigeration cycle using CO_2 is transcritical, and is characterized by common pressure ratios but extreme pressure differences acting upon the compressing elements. With this in mind, the three mechanisms are compared to each other using CO_2, then to HCFC 22 operation as a baseline.

For efficiency comparison the leakage potential, heat transfer potential, and torque are studied. Leakage potential is a quantified as a function of the sealing length and the pressure differential across it, at each point of the compression cycle. Heat transfer is similarly quantified, using surface area and temperature difference. Torque is calculated to make inferences towards motor design.

The time axis was normalized to one compression cycle for comparative purposes.

The pros and cons associated with design details for each mechanism are not considered.

LEAKAGE

Leakage to and from the compression chamber affects the efficiency of any compressor, and may be even more important in CO_2 application (8).

A rigid compressor model for each mechanism was designed to have equal displacement. Using CO_2, the scroll was designed for pressures indicative of operation at the ARI540-99 air conditioning condition. Using HCFC 22, the scroll was designed directly for the ARI540-99 air conditioning condition. The criterion selected for comparison to represent the leakage potential of the mechanism is a summation of each sealing line length in the compression chamber multiplied by the difference of the squares of the pressures across this line. This is calculated and plotted for increments through one compression cycle. The reciprocating piston and rolling piston designs are reasonably straightforward to calculate, but the scroll design is more complex, having up to six sealing line and pressure difference combinations to calculate and sum. Raising the pressures acting across a sealing line to a power greater than unity is common in the literature and reference materials (1,8).

Figure 1 presents the results for CO_2 compression. The rolling piston and scroll designs show the greatest potential for leakage during their compression cycles. The scroll plot is somewhat steady. Due to its small number of wraps, the compression chambers tend to be adjacent to suction and discharge. The rolling piston plot shows a sharp drop in leakage potential towards the end of its compression cycle. At this point the leakage into the compression chamber ceases to dominate, and leakage from the compression chamber into the following suction chamber becomes more significant.

Figure 2 presents the results for HCFC 22. Magnitudes of leakage potential are lower due to the lower pressure differences and the lower polytropic exponent. Plots for the rolling piston and reciprocating piston are similar in shape. The scroll mechanism has improved relative to the rolling piston later in its compression cycle. Here, the scroll has a greater number of wraps, and the compression chambers are adjacent to those having closer pressures.

The reciprocating piston has the lowest leakage potential in either case.

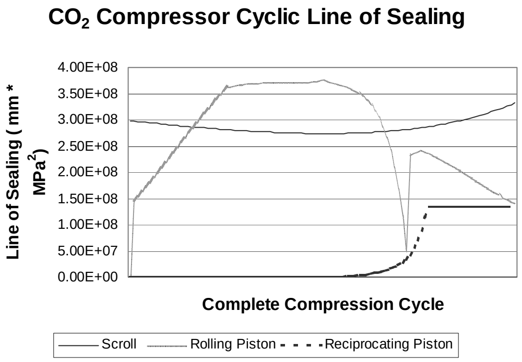

Fig 1. CO_2 Compressor Cyclic Line of Sealing

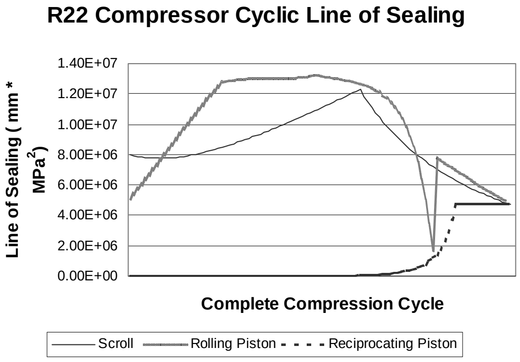

Fig 2. R22 Compressor Cyclic Line of Sealing

HEAT TRANSFER

Heat transfer phenomena can affect efficiency also, but the focus here is on keeping discharge temperatures at manageable levels. The ability to transfer heat of compression away from the chamber is viewed as helpful. The chosen criterion to represent heat transfer potential is the surface area of the compression chamber multiplied by the temperature difference across this area. The convective heat transfer coefficient is assumed to be equal for each mechanism with a given refrigerant. It is incrementally calculated similarly to leakage potential, summing all area and temperature difference combinations. To calculate temperature differences for the rolling piston and reciprocating piston designs, the compression chamber temperature is compared to the average temperature of the process. For the scroll, the temperature in the compression chamber is compared to the average temperatures in adjacent chambers.

Figure 3 presents results for CO_2, and Figure 4 presents results for HCFC 22. Positive values indicate heat transfer potential into the compressing gas. Heat transfer potentials for HCFC 22 are lower, again due to the lower temperature differences and the lower polytropic exponent. The plots for the reciprocating piston and rolling piston designs are similar in shape. These two mechanisms have relatively large chambers exposed to areas that are, on average, tending to be dominated by discharge temperature. In either case, the scroll shows noticeable potential for heat rejection, as the compressing chambers see closer temperatures in adjacent chambers, tending on average not to be dominated by discharge temperature.

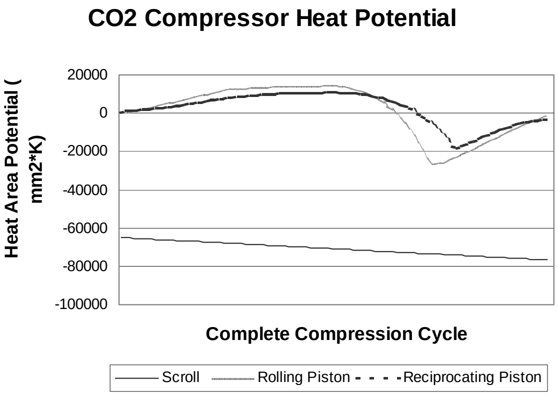

Fig 3. CO_2 Compressor Heat Potential

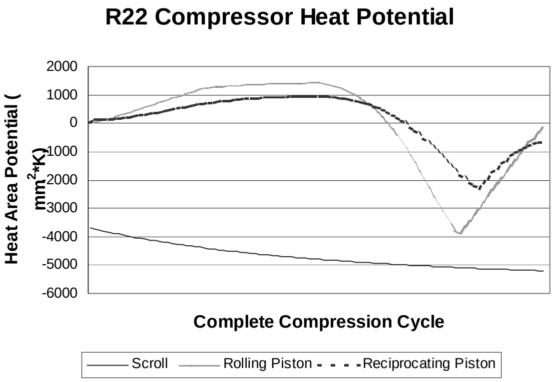

Fig 4. R22 Compressor Heat Potential

TORQUE

Frictionless torque calculations are presented in Figures 5 and 6. The scroll torque appears flat but has a small peak near its end. Comparing the CO_2 plots to those for HCFC 22, the plots rank the same and scale similarly. Comparing the mechanisms, the difference between rotating and reciprocating designs remains evident. The concern remains that the motor design required for the reciprocating piston's higher starting torque can compromise operating efficiency.

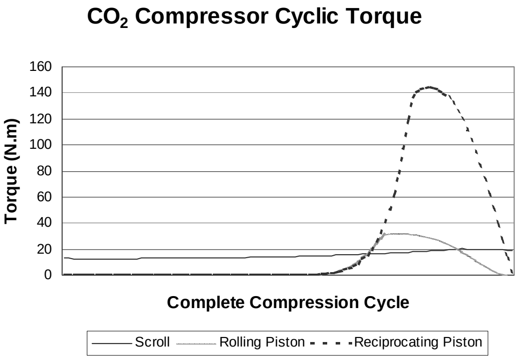

Fig. 5 CO_2 Compressor Cyclic Torque

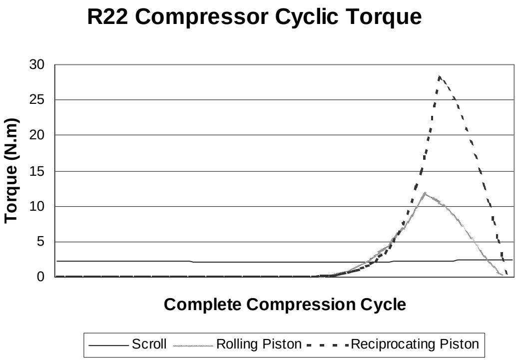

Fig 6. R22 Compressor Cyclic Torque

CONCLUSIONS

For the design change from conventional HCFC 22 to CO_2, the scroll shows potential sealing issues. The reciprocating piston had good sealing properties but very high peak torque. The rolling piston had average behavior in all three categories. None of the mechanisms ranked best in all three categories, therefore the success of a compressor in CO_2 application will likely depend on the designer's expertise.

SPECIAL THANKS

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