



A Hermetic Scroll Compressor For Application To High Heat-Of-Compression Gases

**John P. Elson, Ph.D., Director, Specialty Scroll Engineering
Brian R. Butler, Lead Project Engineer
Copeland Corporation, Division of Emerson Electric
Specialty Scroll Division**

ABSTRACT

A horizontal hermetic scroll compressor has been developed for applications with high heat-of-compression gases, including natural gas, air and helium (cryogenics). The compressor is a low profile horizontal design with oil-flooded cooling of the compression process. Combined with components required for oil separation and cooling, this design provides a smooth, continuous compression process featuring low noise and vibration, and performance comparable to other commercial oil flooded designs such as screw and rotary vane. The design approach allows the use of a production air conditioning compressor as the baseline model from which modifications are made for each specific use. Compressor operating characteristics and performance are discussed for each application.

1. INTRODUCTION

Hermetic and semi-hermetic compressor designs have been used traditionally with refrigerants due to both the cooling provided by the high density and high specific heat gas, and the low heat-of-compression associated with typical refrigerants. This results in gas compression temperatures of less than 150°C and oil sump temperatures less than 100°C, and moderate operating temperatures for the gas cooled compressor motor and mechanical components such as valves and bearings. Also, in view of both product performance and simplicity of design, hermetic and semi-hermetic compressors are a good choice for refrigerant applications.

For applications involving high heat-of-compression gases (high specific heat ratio) such as air, natural gas and helium, compression temperatures can reach 200°C to 300°C when pressure ratios are above 4-6. Also, due to the low density and low specific heat characteristic of these gases, a hermetic or semi-hermetic motor may not be adequately cooled. Due to both these factors, air-cooled electric motors and open drive compressors are commonly used for air compression. Typically, these compressors are of a multiple stage reciprocating type (with intercoolers) or an oil flooded screw or rotary vane compressor with both oil separation and oil cooling capability. To some extent these compressors also allow the separation of the inlet gas from the oil sump and thereby provide a degree of resistance to contamination.

A variation of this later concept is to allow oil to flood and cool both the motor compartment and the compression process. This approach fits the architecture of either a hermetic or semi-hermetic design when allowance is made for both oil extraction from the compressor and subsequent cooling and return of oil to the compressor. Scroll compressor technology is well suited for this application due to both its proven durability as a hermetic compressor product and its ability to accommodate oil flooding and motor cooling when applied in a horizontal mode of operation, and modified as defined in the next section of this paper. As a hermetic compressor designed for use with high-pressure refrigerants, the scroll compressor as applied to gas compression has a broad range of operation and is inherently free of leakage. Also, as with other oil-flooded commercial duty designs, continuous operation is normal with internal temperatures not exceeding 100°C. A wide range of operation is also possible with inlet pressure not required to be near atmospheric. Depending on the application, inlet pressure may vary from 0.3 to 8 bar(a), and discharge pressures from 3 – 25 bar(g). A pressure ratio capability from 3 – 15 has been demonstrated.

A multitude of compressor/system designs are possible with the application of a horizontal oil-flooded scroll compressor. Specific applications in natural gas, air and helium have been developed but other gas applications including hydrogen and refrigerants are being evaluated. Overall, the oil-flooded horizontal scroll concept presented here provides a variety of application possibilities requiring a durable industrial grade product for high heat-of-compression gases. In addition, the horizontal architecture provides a low profile, delivers low noise and vibration, and is well suited for variable speed control.

2. GAS COMPRESSION AND COOLING

The gas compression technology utilized with this horizontal design is a variation of a positive displacement scroll type hermetic compressor used successfully in air conditioning and refrigeration systems for over 15 years. In a scroll compressor, two identical involute scroll elements fit together to form a number of “pockets” which continually change in size and location as the gas is compressed. One scroll remains stationary while the other orbits about it. The orbiting scroll movement draws gas into two outer chambers and then moves it through successively smaller volume chambers until it reaches a maximum pressure at the involute center. At this point, the gas is released through a discharge port in the fixed scroll.

During each orbit of the orbiting scroll, multiple gas pockets are compressed simultaneously so that the compression is virtually continuous. Gas entering a typical air conditioning scroll requires approximately three orbits, or crankshaft rotations, to reach discharge pressure. The

scroll compression process is optimal at a specific design pressure ratio (based on the design volume ratio) but has reduced efficiency for increasingly higher pressure ratios. This efficiency reduction is common to most positive displacement compressors, and is due primarily to the greater inherent losses at higher-pressure ratios than to operation away from the design pressure ratio. For example, a scroll or piston refrigeration compressor may have isentropic efficiencies of 70% and 50% respectively at pressure ratios of 3 and 8. For pressure ratios much higher than the design pressure ratio e.g. higher than 8, a dynamic discharge valve at the scroll discharge can help reduce efficiency loss. Additional details on the operation of a scroll compressor can be found in Ref. (1,2)

High heat-of-compression gases such as natural gas and air require additional compressor and system design considerations not normally used with air conditioning or refrigeration compressors. With specific heat ratios of 1.3 to 1.4 versus 1.15 for typical refrigerants, gas temperatures can approach 200°C and higher at high-pressure ratios. To maintain discharge gas temperatures below a 100°C oil temperature objective, an oil injected, oil flooded compressor design concept was developed as shown in Figure 1 with further details available in Ref. (3). Coupled with the system components shown, compressor lubrication and cooling are accomplished while oil is separated from the gas and returned to the compressor. From

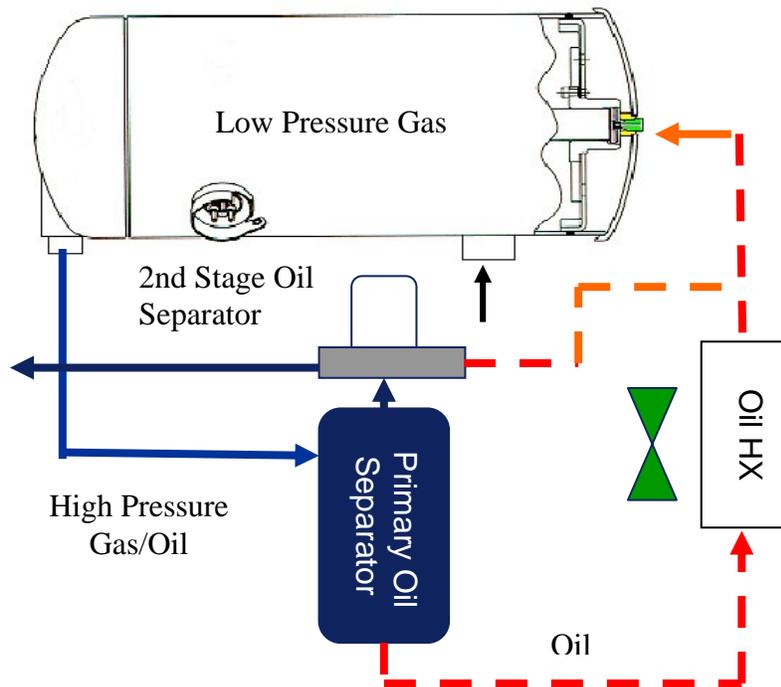


Figure 1. Compressor oil management system

the high-pressure oil separator, oil is injected directly into the compressor bearing system through the injector fitting installed in the former bottom cover of the typical vertical compressor. Once oil passes through the thrust plate, it is centrifuged as in the vertical design, and pressurized oil then flows to all the rotating components and bearings as it would in the vertical compressor case. As oil exits the bearing system and passes over motor components, motor heat is absorbed and motor temperatures below 80°C are achieved as is typical of vertical operation. Excess oil next collects at the bottom of the horizontal shell where it is extracted by the scroll suction process. Oil and gas pass through the scroll set with the high

specific heat of the oil serving to cool the compressed gas. The net effect of this oil-flooded process is that oil and gas exit the compressor at temperatures below 100°C while excellent lubrication of internal components is achieved. To increase or decrease the amount of cooling needed for specific applications, oil flow to the compressor is limited with the use of a restriction such as an orifice or capillary tube. Also, the integral oil cooler shown in Fig. 1 may be sized to provide varying degrees of cooling.

The majority of oil discharged with the compressor gas is collected in the primary oil separator and circulated back to the compressor. However, some of the oil passes through the primary separator and is collected in the secondary oil separator which reduces the oil exiting the system to approximately 2-5 parts per million. The secondary oil separator shown is a coalescent type filter that includes a return oil line to the compressor. Gas leaving the compression system is nearly oil free and at a low temperature but may be further cooled with a gas cooler if desired.

3. APPLICATIONS

Due to the use of a pressure dependent lubrication system, oil flow to the bearings is relatively independent of compressor speed, and continuous lubrication may be expected over a broad range of compressor speeds. However, in some system designs, it may be necessary to insure discharge pressure is achieved after a short period of compressor operation to insure oil is supplied to the compressor bearings soon after startup. Bearing oil film thickness and speed related loads become the primary limitation for an allowable operating speed range for this design. For the horizontal design evaluated here, an operating speed range of 3:1 has been achieved with compressor speeds from 1750 RPM to 5250 RPM.

For some compressor applications, multiple compressors are desired to provide additional mass flow, flow modulation or redundancy in case of compressor failure. With the horizontal compressor concept demonstrated here, multiple compressors may readily be joined together for parallel flow. In addition to providing manifolds for the inlet and discharge gas connections, an oil supply line is required for each additional compressor added to the system. Oil management is straightforward in that a single oil separation system can be used for all compressors, and complicated oil balancing is not required. As with other multiple compressor applications, a discharge check valve is often employed with each compressor to prevent backflow to a non-operating compressor.

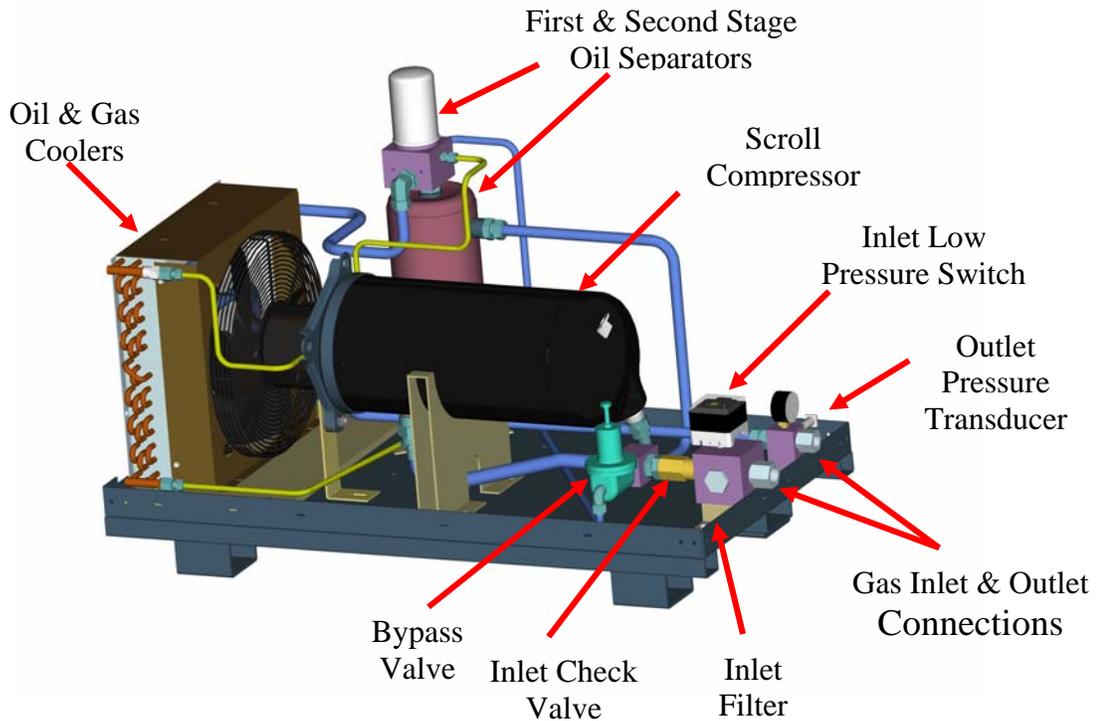
When compressing both natural gas and air, water vapor may be present in the inlet gas. As this gas is compressed, gas temperature must be controlled at a temperature high enough to prevent condensation of water in both the compressor high side and the oil separation system. This is achieved by controlling discharge gas temperature to approximately 90°C using an on/off or variable speed control for the oil cooler fan.

3.1 Fuel gas booster

The initial application of this horizontal scroll technology has been with fuel gas booster systems designed for use with power generation equipment such as micro-turbines, dual fuel diesel gensets and fuel cells. In these applications pipeline quality natural gas is boosted in

pressure from near atmospheric to the 6-8 bar(g) pressure typically required to operate these power generation devices. The major mechanical components of a fuel gas booster system are highlighted in Fig. 2 below.

Figure 2. Fuel gas booster mechanical components



Gas flow enters the unit through the inlet connection and flows through the inlet filter, low pressure switch and check valve to the compressor. For safety purposes, the low-pressure switch prevents pipeline vacuum conditions, and the check valve prevents the pressurization of the supply line due to reverse gas flow on compressor shutdown. Oil and gas management then occurs as previously described except gas delivery is controlled through both a variable frequency drive and a discharge gas bypass valve. The bypass valve is only required during micro-turbine startup when the fuel gas booster system is on standby and zero fuel is required. During normal operation the variable speed drive for the compressor controls compressor speed to deliver the correct amount of fuel at the desired delivery pressure. A pressure transducer at the outlet of the system provides the feedback signal for the variable speed drive. A system like that shown in Fig. 2 can be integrated into a micro-turbine or built as a separate stand-alone package with electronics and housing. High reliability and low noise (75 dBA @ 1 meter) have been demonstrated with this later option. Further details on this system are given in Ref. (4).

Performance data for a fuel gas booster can be expressed similarly to that used with air compressors with output being measured in gas volume flow (m^3/hr), and input being measured in electrical power (kW). Specific capacity, characterized by output divided by input, can then be used as a means for comparing the relative efficiency of gas booster products. For specific fuels such as natural gas, the output parameter may be converted to mass flow by multiplying volume flow by the density of the gas at inlet conditions. However,

for the purpose of product comparison, it is more straightforward to use specific capacity as the baseline comparison parameter. When using a variable speed or variable flow machine, it is also helpful to characterize operating performance in a single chart that gives product performance over the entire range of flow.

Fig. 3 below shows both output flow and input power parameters as a function of variable flow. Two sets of data are shown here to demonstrate performance as a function of inlet

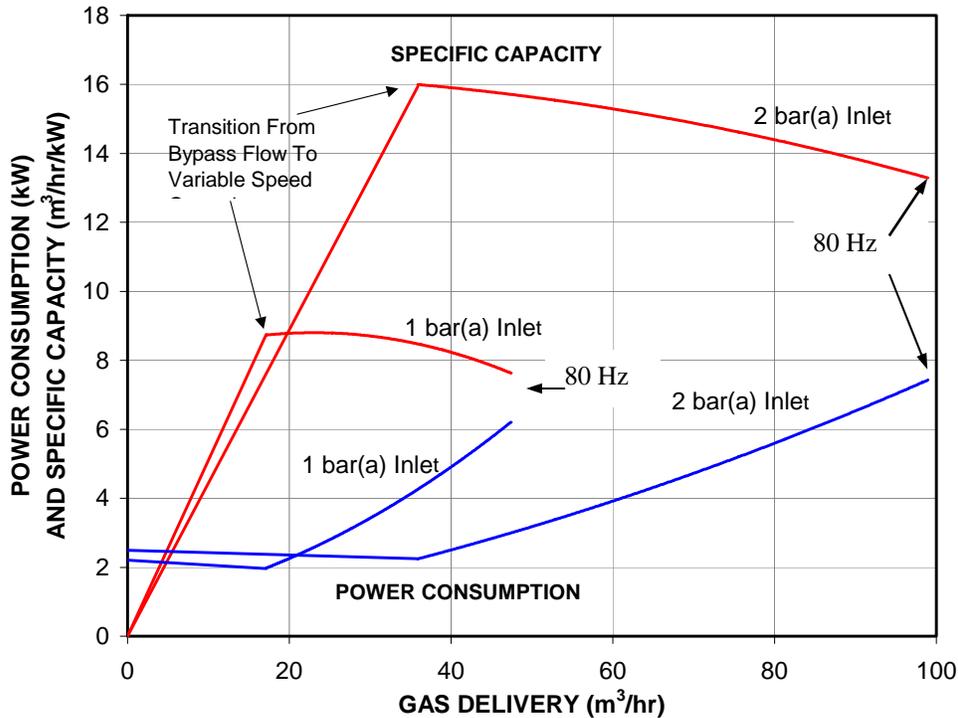


Figure 3. Fuel gas booster performance

pressure at a constant inlet temperature of 16°C. Delivery pressure in this chart is set at a typical level of 6 bar(g) although actual use pressures may vary from 4 bar(g) to 7 bar(g). Beginning with the specific capacity curve labeled 1.0 bar(a), note that specific capacity increases linearly as the system bypass valve closes from full bypass to zero bypass at the minimum compressor operating speed of 1750 RPM (30 Hz). In this range, the power generator is in a startup mode where the fuel demand starts at zero and increases gradually. As this is a transient situation, the low specific capacity in this region has minimal effect on overall operating performance of the fuel delivery system. When more flow is required than can be delivered at the minimum operating speed, the variable frequency drive takes control and peak performance follows. Specific capacity is highest at the 2.0 bar(a) inlet pressure due to the higher theoretical efficiency obtained at lower operating pressure ratios (3 versus 6) for the compressor.

Theoretical performance, as measured by isentropic efficiency, is nearly constant with inlet pressure: 49% at 1 bar(a) and 47% at 2 bar(a). This efficiency is comparable to refrigeration scroll compressors and other gas compressors, but well below the 70% attainable with high efficiency air conditioning scroll compressors. The difference in efficiency is due primarily to the significant heating of the gas entering the scrolls at the 16°C gas inlet temperature, and the pressure losses in the gas boost system that are not included in typical compressor

performance data. For example, without the inclusion of system pressure losses, the isentropic efficiency at the two respective inlet pressures becomes 53% and 58%. Overall, the efficiency of the scroll fuel gas booster is very good, particularly when the advantages of variable speed operation are taken into account versus other high loss modulation approaches.

3.2 Vapor recovery (oil and gas)

Another application for the system described above is oil field gas vapor recovery. With oil well production, a wet natural gas known as casing gas is also present. This gas must be removed for optimum oil well operation and has in the past been vented or flared at the site. In addition to being an environmental issue identified by the Kyoto Protocol, gas venting and flaring is wasteful of valuable energy resources. However, with proper collection and processing, wellhead gas can be reclaimed and delivered economically to a processing plant. Depending on the oil well location, the available gas may be “sweet” or “sour” (low or high in hydrogen sulfide content), and it will likely contain some hydrocarbon vapor. Most oil well gas is 100% saturated with water vapor requiring the compressor system design to address water management. Finally to prepare the well head gas for transfer to a processing plant, the fuel gas system must have the flexibility to collect gas at inlet pressures varying from 0.5 bar(a) to 3 or 4 bar(a) while delivering gas at pressures up to 7 bar(g).

The hermetic scroll system design discussed above has been successfully applied to oil wells with “sweet”, water saturated natural gas with near atmospheric inlet pressures. However, the hermetic design will also allow both sub-atmospheric and positive pressure operation without concern for air leakage in or gas leakage out of the compressor. Water vapor is also controlled in this design by maintaining discharge gas temperatures at about 90°C with the use of a fan control thermostat on the oil cooler. Future applications will evaluate increasingly “sour” gas sites that may require special internal compressor components beyond the special motor and materials already used for the natural gas application.

3.3 Air compression

Air compression is similar to “wet” natural gas compression with the exception that discharge gas pressures up to 12 bar(g) may be required. With increased pressure and a corresponding increase in heat-of-compression, the needed additional cooling is attained with the adjustment of the oil flow restriction used to control oil return to the compressor. The scroll horizontal compressor as designed for air compression is generally less complicated than the natural gas design due to the use of fewer components and the need for special materials resistant to natural gas contaminants. Also, variable speed fuel control is not a basic requirement as in the fuel control system.

An example of 2 Hp air compressor platform is shown in Fig. 4. Using the same basic package shown here, a variety of compressor flow requirements can be met from 3.4 to 34.0 m³/hr. Combining this package with a storage tank and a pressure control results in a system capable of a continuous operation duty cycle. Also, due to the oil film bearings employed in this type of scroll compressor, a product life cycle of 40,000 hours or more can be expected with normal maintenance including oil and air filter replacement.

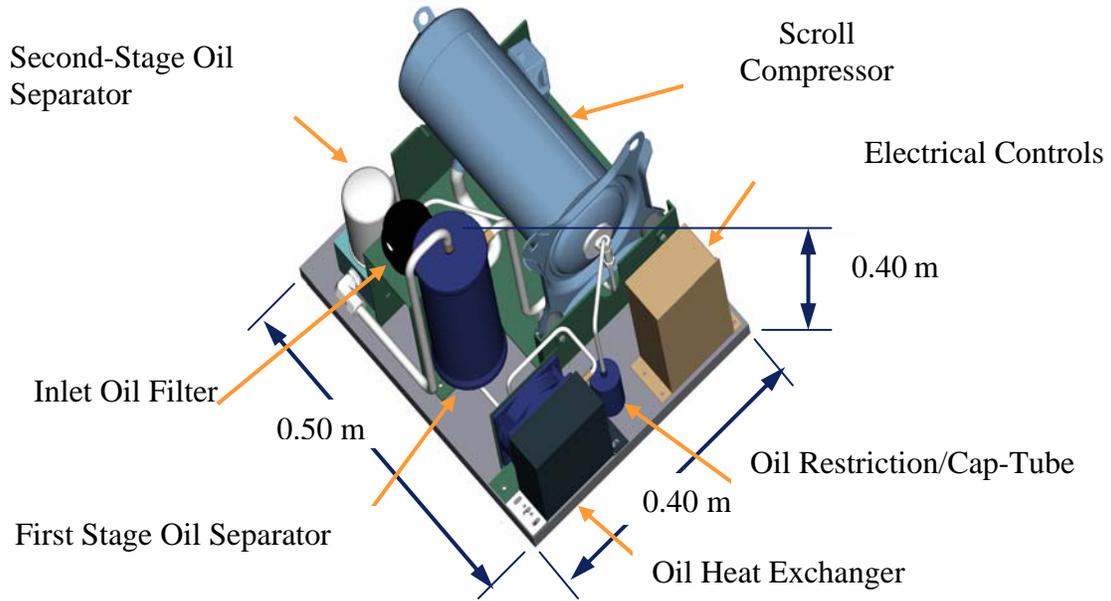


Figure 4. 2Hp Air compressor system

Air compressor performance for the horizontal scroll has been measured relative to other technologies as shown in Fig. 5 below. Performance in this chart is expressed in terms of specific capacity ($\text{m}^3/\text{hr}/\text{kW}$) with the input power being electrical power to the motor.

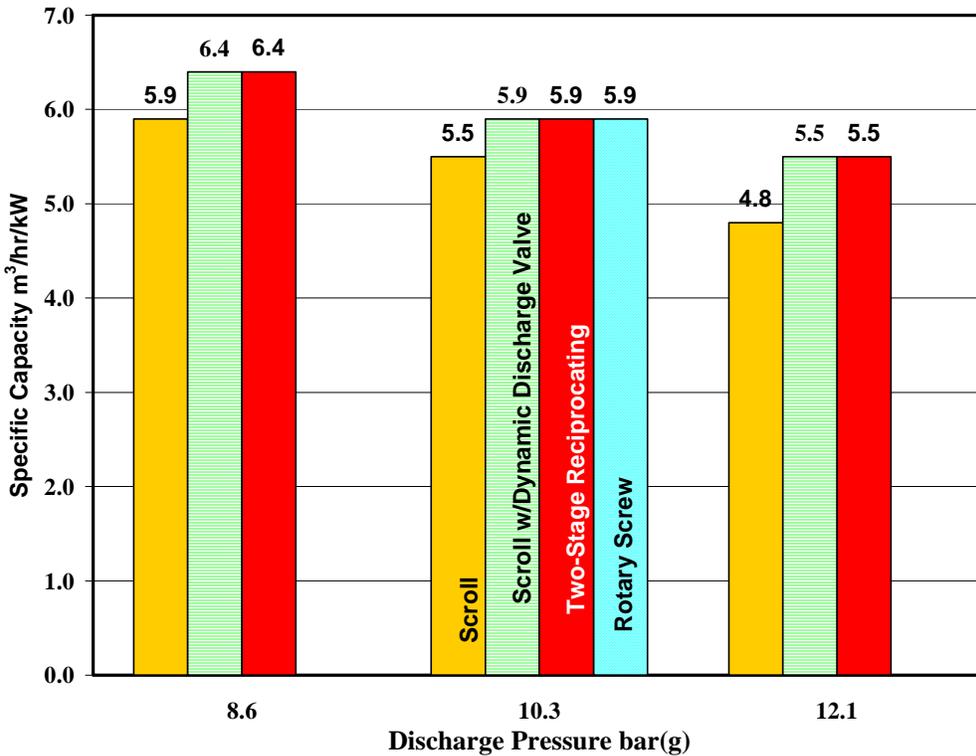


Figure 5. Air compressor performance

This chart shows hermetic scroll performance is comparable to other compressor technologies when a dynamic discharge valve is used in the design. For operating pressures below 6-8 bar(g), the discharge valve offers minor efficiency improvement and can be removed from the design. In comparison to single stage reciprocating compressors, scroll performance is better without using a valve. The use of a scroll discharge valve has been proven reliable in scroll refrigeration compressors designed for continuous duty and long life. Overall, hermetic scroll air compressor performance, long life, and low noise and vibration make it a good candidate for commercial quality air compressor systems.

3.4 Cryogenic - helium

Another potential application for a horizontal scroll is helium compression for such applications as MRI (Magnetic Resonance Imaging) machines. Scroll compressors are currently being applied to this application but the horizontal scroll presented here allows systems to be developed for a broad range of volume flow as with air compressors. System design for this application is similar to that used with air compression except that additional oil filtration is used to reduce oil passage to trace amounts. With the MRI helium application, inlet pressure and outlet pressures are typically 7 and 21 bar(g) respectively. The pressure ratio here is not particularly high but an oil-flooded design is still required for controlling compressor temperatures to acceptable levels for continuous operation. The 21bar(g) discharge pressure is also not a problem due the compressor's origin as an air conditioning compressor operating up to 25 bar(g) and higher. Initial testing for this application has shown performance comparable to current competitive products.

3.5 Air conditioning and refrigeration

For air conditioning and refrigeration applications, the closed loop system requires only a single stage of oil separation, and oil cooling is provided by the refrigerant and heat rejection from the system condenser. However, due to the use of refrigerant cooling for both the oil and the hermetic motor, the horizontal oil-flooded design typically is 5-10 % lower in efficiency than conventional non oil-flooded designs. One advantage of the horizontal concept is applications where minimal vertical clearance will limit the use of vertical design compressors. Also, if variable frequency inverter drives are required as with some transportation applications, the broad variable speed range of this horizontal design will allow energy efficiency improvement through flow modulation.

SUMMARY

A horizontal hermetic scroll compressor design has been presented for use with a variety of compressor applications involving high heat-of-compression gases. The horizontal design utilizes a high-pressure oil sump and oil-flooded scroll elements to limit compression temperatures for a variety of gases including natural gas, air and helium. Performance data indicates comparable performance for this design relative to other technologies. Long life can also be expected due to both low temperature operation and the high endurance scroll design derived from proven air conditioning scroll compressors. Several current applications have been identified for use of this technology with both pipeline and oil well natural gas. Also, air and helium compressor applications were discussed along with performance comparisons of this concept with existing product types.

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