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Twin-Screw Compressor Performance and Complex Ester Lubricants with HCFC-22

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TWIN-SCREW COMPRESSOR PERFORMANCE AND COMPLEX ESTER LUBRICANTS WITH HCFC-22

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ABSTRACT

Oil flooded twin-screw compressors with HCFC-22 have mainly been used for industrial refrigeration. Due to the planned CFC restrictions and the high overall efficiency, the screw compressor with HCFC-22 is taking market shares from:

- CFC-11 centrifugals, water cooled chillers,
- HCFC-22 reciprocating compressors, air cooled chillers,
- R502 reciprocating compressors, commercial refrigeration.

The new applications call for new demands of suitable screw compressor lubricants, mainly due to:

- requirements for small oil separators,
- short dwell time in oil sump,
- good oil return characteristics,
- no or limited external oil cooling,
- high discharge temperature.

The use of mineral lubricants is limited because of high viscosity requirements. The use of polyalphaolefins (PAOs), is limited because of potential phase separation (liquid refrigerant and lubricant) in the refrigeration system. The complex ester lubricant family is discussed. Screw compressor performance, based on gas rig tests, is compared for R22/PAO and R22/complex ester.

INTRODUCTION

The twin-screw compressor consists of two mating, helically grooved rotors "male and female" in a stationary housing with inlet and outlet ports. There are three different types of twin-screw compressors: oil flooded, oil reduced and oil free (reference 1). This paper deals with the oil flooded twin-screw compressor. When the screw compressor first was introduced as a refrigeration compressor, lubricants were limited to those available which were already in use for reciprocating refrigeration compressors. The main difference between the screw compressor and the reciprocating compressor with respect to the oil system are:

- The screw compressor has an oil separator and an oil sump situated on the high pressure side.

- The compression chamber is flooded with oil to seal the threads that are under compression.

This means that the lubricant has more effect on performance than it does with the reciprocating compressor. In order to reach high performance, the screw compressor needs a lubricant with a very limited solubility of the refrigerant at discharge conditions (at the oil separator). (See figure 1 for typical solubility of HCFC-22 in different lubricants). Limited solubility will reduce or eliminate by-passing of refrigerant from discharge to suction or to a lower situated thread or external by-pass (over the oil system). Low solubility of refrigerant gas in oil leads to both high volumetric efficiency and low torque. Most lubricants with low solubility also have low miscibility. The refrigeration system normally calls for high miscibility in order to obtain good oil return from the evaporator and undisturbed heat transfer in the evaporator (reference 2). Figure 2 shows typical miscibility characteristics for different oils with HCFC-22.

RELIABILITY CONSIDERATIONS

The lubricant supplied to the bearings in a screw compressor needs a viscosity of about 10 cSt, taking the degree of solubility of refrigerant gas and its effect on viscosity into consideration. The lubricant needs to have quite high viscosity when undiluted to compensate for viscosity losses. This is significant when the oil is uncooled or the discharge temperature is limited to approximately 110°C with oil cooling or liquid refrigerant injection. The high viscosity requirements are also important when the condensing temperature is higher, which is the case for air-cooled condensers. High discharge temperatures call for a very stable lubricant.

Another reliability problem is oil starvation. The oil sump has limited capacity in the systems studied. At the same time the oil carry over is in the range of 0.1 to 2% by weight. If phase separation (liquid refrigerant and oil) occurs in the refrigeration system, the lubricant supplied to the bearings is not suitable. Even if a system is designed to never reach an oil and liquid refrigerant two phase region, it can still experience phase separation due to aging of the involved components. The best way to avoid oil return problems (phase separation) is to always operate above the critical solution temperature. The small oil sump (short dwell time - less than one minute) and the large proportion of the total supplied lubricant circulating in the refrigeration system calls for a lubricant with few additives and one molecule type and size, if possible. This means that blends should be avoided.

OIL SELECTION

Refrigeration grade mineral oils are often not available with physical properties that provide optimum performance in screw compressors. Synthetic lubricants offer a wide range of properties and the opportunity to customize a lubricant for a particular refrigeration system. The use of synthetic oils for this purpose began in 1929 (reference 3 & 4). The synthetic lubricants were originally considered for their ability to solve problems encountered with the use of mineral oils such as; wax separation, poor miscibility with some refrigerants, and carbonization of valves in reciprocating compressors. Recently, additional advantages were reported by many synthetic lubricant manufacturers and in literature. Advantages include good stability in the presence of refrigerants at high temperatures, better viscosity temperature characteristics, improved hydrodynamic lubrication of compressor bearings and better lubricity in the presence of refrigerants through viscosity dilution relationships (reference 5, 6, 7, 8, & 9).

Higher viscosity, 100 to 320 ISO, modified complex esters present a new class of refrigeration lubricants (reference 8). These fluids are carefully designed for high miscibility at lower temperatures with lower solubility at higher temperatures. Swelling of elastomers is less than with conventional neopentyl esters and diesters.

All viscosity grades of the complex ester oils tested are completely miscible with HCFC-22 to -68°C (-90°F). A high viscosity index, absence of wax, and good low temperature fluidity adds to these properties for excellent low temperature behavior. Efficient compression sealing is provided by compensating for the effect of the dissolved refrigerant while maintaining good oil return. Figure 3 shows an estimate of the viscosity/temperature characteristics of this oil with HCFC-22. Systems which include oil/gas separators will have the additional benefit of an extremely low lubricant vapor pressure.

VISCOSITY SELECTION

When the type of oil is selected, the viscosity grade is critical. This section describes the rotor requirements. The screw compressor has now reached a high degree of maturity and it appears to be appropriate that norms for the classification of screw rotors are created (reference 10, 11, & 12).

The following types of classes have been suggested:

- Clearance Class, giving information about the sealing qualities of a set of rotors.

- Angular Meshing Class, having its strongest bearing on the running qualities of a rotor set.

- Contact Pattern Class, providing a verdict on reliability and longevity.

A standard gradation system is not yet available but for this general discussion the following system should be appropriate:

Class 1: What can be accomplished with most modern manufacturing.

Class 2: What is generally accepted practice today.

Class 3: Lowest acceptable quality, where first cost is more important than performance.

Rotors can handle quite low viscosity if the following assumptions are made:

- Male rotor drive with a transferred torque to the female rotor a maximum thirty percent of the input torque.

- An angular meshing class a maximum of two.

- A contact pattern class a maximum of two.

Incorrect angular meshing and contact pattern will require a lubricant of higher viscosity. The oil as a sealing agent normally requires higher viscosity than the oil as a lubricant for the rotors. The main parameters are the rotor tip speed and the rotor clearance class. Figure 4 gives the general viscosity recommendations for the complex ester lubricant in screw compressors with HCFC-22 as the refrigerant with the following additional assumptions:

- Uncooled or discharge temperature limited - cooled oil with a maximum discharge temperature = 110°C (230°F).

- A condensing temperature around 50°C(122°F).

COMPRESSOR PERFORMANCE COMPARISON

A screw compressor with a male rotor diameter of 113 mm has been tested with a complex ester lubricant ISO 320 and a PAO lubricant ISO 220 with HCFC-22. The displacement of the compressor is 175.3 m^3/h (103 CFM) at 3550 rpm. The test was run at a male rotor tip speed of 21 m/s and a condensing temperature of 54.4°C (130°F). The viscosity of the diluted lubricants is estimated to be the same for both of the lubricants.

Figure 5 shows the performance comparison (adiabatic efficiency) of the two lubricants vs. pressure ratio. The adiabatic efficiency is always higher at pressure ratios up to 4 for the complex ester lubricant compared with the PAO lubricant.

Figure 6 shows the capacity comparison (volumetric efficiency) vs. pressure ratio. The volumetric efficiency is almost always slightly lower for the complex ester compared with the PAO lubricant.

Figure 7 shows the performance comparison (adiabatic efficiency) vs. built in volume ratio at a pressure ratio of 2.5. The adiabatic efficiency is always higher for the complex ester lubricant compared with the PAO lubricant.

Figure 8 shows the capacity comparison (volumetric efficiency) vs. built in volume ratio at a pressure ratio of 2.5. The complex ester lubricant gives a slightly higher volumetric efficiency.

As a summary of the results it can be said that the compressor performance of the complex ester lubricant came out better than expected, since the expectation was slightly lower performance than compared with the PAO. The PAO lubricant has been chosen as the comparison lubricant since it normally gives the highest compressor performance (higher than mineral oil) for uncooled and discharge temperature limited compressors. However, the PAO requires an oil separator which is not cost effective for many applications (oil carry over less than 1000 PPM).

The comparison test was carried out on a gas test rig, taking only compressor performance into consideration. What counts is, of course, the performance of a complete refrigeration system. The complex ester lubricant has many favors for both the screw compressor and the refrigeration system.

CONCLUSIONS

A complex ester lubricant is very suitable lubricant for screw compressors operating on HCFC-22 with uncooled, limited cooled oil or liquid refrigerant injection.

The screw compressor HCFC-22 performance with the complex ester lubricant is superior compared with the PAO lubricant at low pressure ratios.

The complex ester lubricant can allow cost effective oil separators since it has outstanding miscibility characteristics.

ACKNOWLEDGEMENTS

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SOLUBILITY OF HCFC-22
DIFFERENT LUBRICANTS

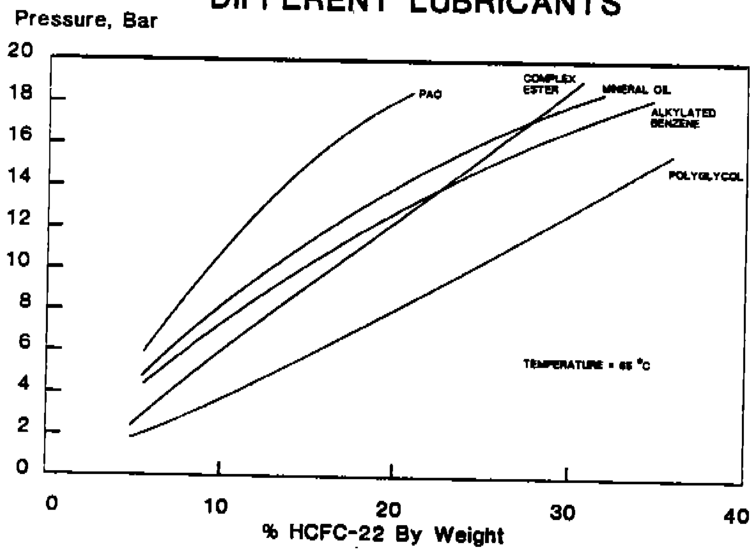

FIGURE 1

MISCIBILITY CHARACTERISTICS
DIFFERENT LUBRICANTS WITH HCFC-22

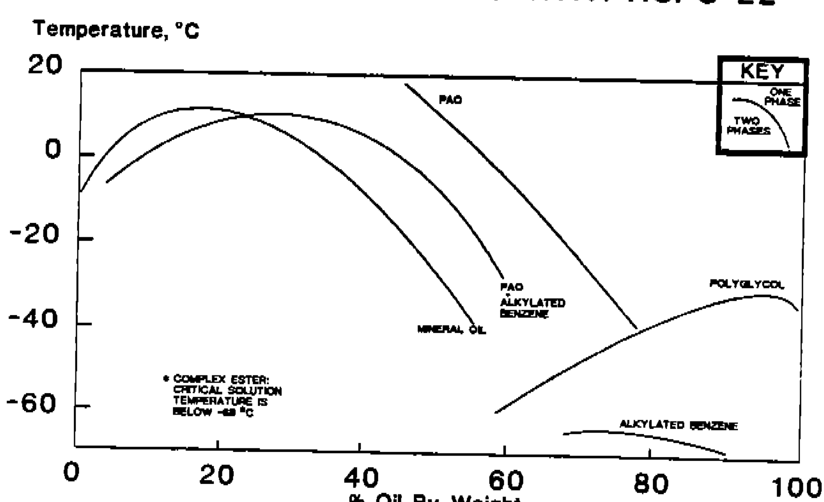

FIGURE 2

VISCOSITY/TEMPERATURE RELATIONSHIP
20% BY WEIGHT HCFC-22 DILUTION

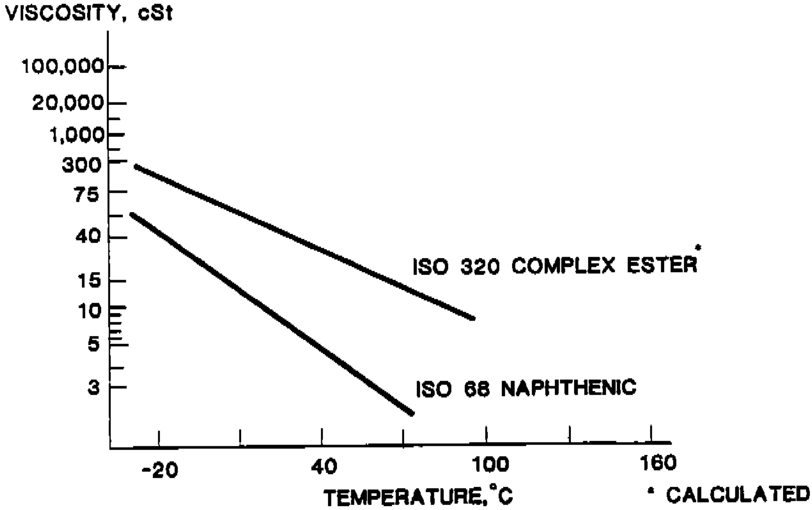

FIGURE 3

VISCOSITY RECOMMENDATION
COMPLEX ESTER LUBRICANT

MALE ROTOR TIP SPEED M/S	ROTOR CLEARANCE CLASS				
	1	1.5	2	2.5	3
20	200	320	320	-	-
30	150	200	200	320	320
40	100	150	150	200	200
50	-	100	100	150	150

FIGURE 4

COMPRESSOR PERFORMANCE
ADIABATIC EFFICIENCY
COMPLEX ESTER/PAO

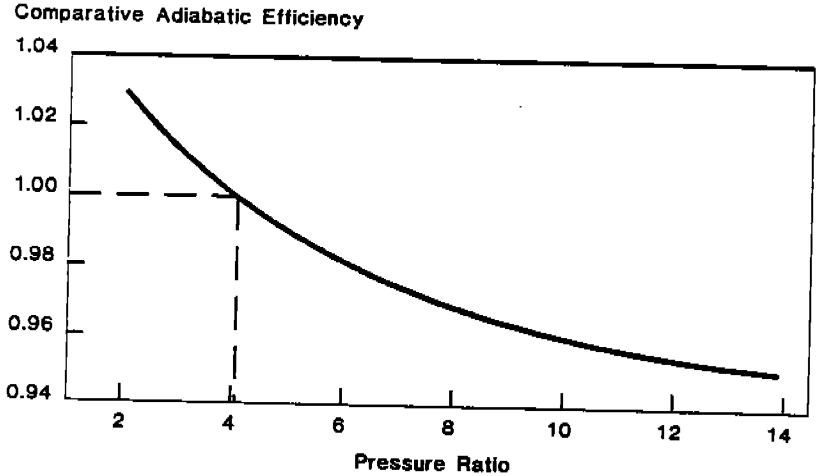

FIGURE 5

COMPRESSOR CAPACITY
VOLUMETRIC EFFICIENCY
COMPLEX ESTER/PAO

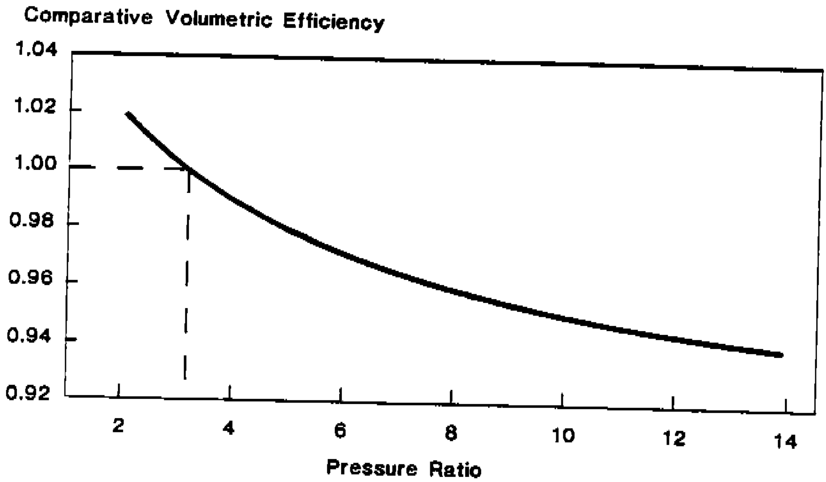

FIGURE 6

COMPRESSOR PERFORMANCE
ADIABATIC EFFICIENCY
COMPLEX ESTER/PAO

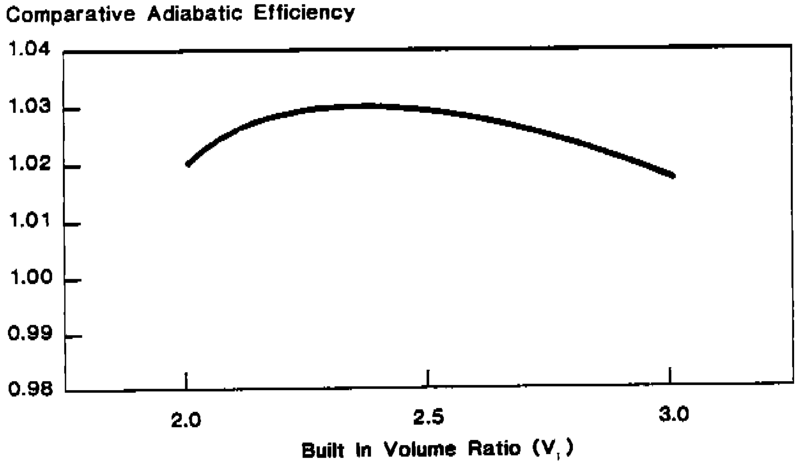

FIGURE 7

COMPRESSOR CAPACITY
VOLUMETRIC EFFICIENCY
COMPLEX ESTER/PAO

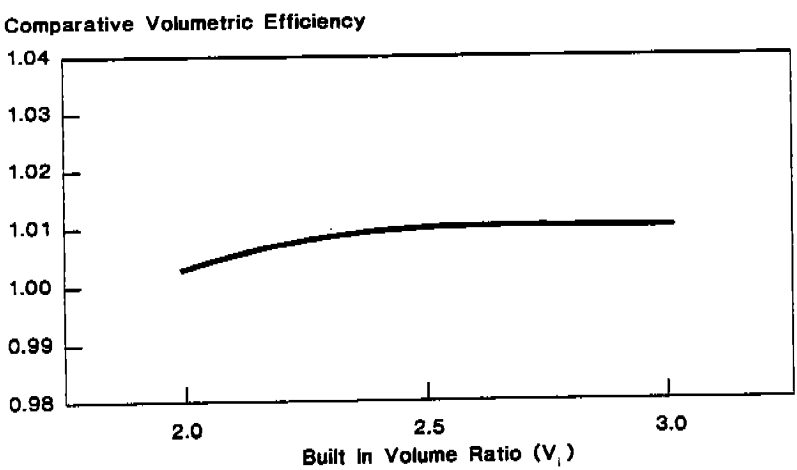

FIGURE 8