Life Cycle Testing of Hermetic Compressors With Alternatives to CFC-12

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ABSTRACT

Life cycle tests of hermetic compressors were conducted using a specially designed test rig that employs a gas cycle. They were conducted at an ambient temperature of 50°C and suction and discharge pressures of 2.2 bar and 18.5 bar respectively. The oil temperature was maintained between 80-100°C. The duration of test was 2000h.

After completion of the test, the oil samples were tested for total acid number and metal contents (Cu, Fe and Al). Any chemical degradation of refrigerant sample was assessed using NMR and FT-IR spectroscopes. The wear effects of compressor parts were measured using perthography.

An assessment of conventional mineral oil with CFC-12 and various grades of hydrocarbon (HC-290 and HC-600a) blends including DIN grade, CARE-30, a blend of HC-290/HC-600a from Indian sources, destenched LPG, and commercial grade LPG has been done. HFC-134a and Polyol ester oil (POE) combination has also been studied. The comprehensive test results from the above assessment and comparative ratings are presented.

INTRODUCTION

Life cycle tests are conducted on hermetic compressors to study the chemical and material compatibility of parts exposed to refrigerant and oil. The test gives the representation of a compressor's reliability after a long period. It takes into consideration the behaviour of materials in the compressor in the presence of refrigerant and oil at relatively high temperature and pressure.

A special kind of test rig has been prepared by the Research center for Refrigeration and Heat Pumps Ltd. (FKW) in collaboration with the University of Hannover, Germany. The test method developed by FKW is intended to compare the well known combination of CFC-12 and mineral oil (MO) with other refrigerant-lubricant combinations, e.g. hydrocarbon mixture and MO or HFC refrigerant with ester based lubricants.

To make a comparison between different oil types and refrigerants, it is necessary to run the tests under identical pressure and temperature conditions. Investigations to determine the quality of different oils can be made once the principal selection of the refrigerant is determined.

EXPERIMENTS

LIFE CYCLE TEST RIG - It employs a simplified gas cycle without evaporation and condensation of the refrigerant. The cycle involves the compression of superheated vapour from a specified suction pressure of 2.2 bar to a fixed discharge pressure of 18.5 bar. The test circuit was maintained at a constant ambient temperature of 50°C. The details of the test rig and the procedure have been presented elsewhere (Devotta, 1997; FKW, 1995; Patil, 1997; Patil, and Patil, 1998).

The compressors were of 100 W capacity used by a popular Indian refrigerator company. The life cycle tests were done with combinations of MO and HC-290 and HC-600a blends including DIN grade, CARE-30, a blend from Indian sources, destenched LPG, and commercial grade LPG. HFC-134a and Polyol ester oil (POE) combination was also studied. The results of compressors tested with above combinations are compared with the base line test of CFC-12/MO. All tests were for 2000h. In the case of commercial-LPG/MO and Care 30/MO, tests were not completed. These units were stopped at 1457h and 1579h respectively due to some breakdown of the compressors during a power failure.

After a test, the compressor and various components were individually inspected for any notable damage to materials, e.g. abnormal metal wear, degradation of polymeric materials and for thermal and chemical effects. The parts were also observed for reaction products such as sludge, tar and coke. The compressor parts were visually rated for the degree of damage.

The wear effects of these parts were measured by using perthography. The oil samples were examined for the following: (i) Acidity (Total Acidity Number) by KOH titration, (ii) Metal content by Atomic Absorption spectroscopy, (iii) Chemical decomposition by NMR spectroscopy, whenever possible.

More details on the tests and results are documented elsewhere (Devotta et al., 1997; Devotta et al., 1998; Patil, 1997; Patil, 1998; and Patil, 1999).

RESULTS AND DISCUSSION

CFC-12/MO - Inner part of the compressor had turned faint brown. The drained lubricating oil was reddish brown and it appeared to have become more viscous. The lubricating oil had some floating particles on the sides of the housing. These floating particles may be due to sludge or metal wear. The insulating plastics strips on the motor winding had become hard.

On the cylinder head i.e. on suction and discharge sides, there was some sludge formation. In these chambers, there was no indication of the corrosion or copper plating. The surface of the cylinder or bore showed some traces of sludge, lacquer like brownish coating (probably due to coking or burning of the oil) and thermal effect. Like the sludge on the cylinder suction chamber, the suction side valve plate also had a similar coating. The valve plate, had only brownish coating and sludge and there was no corrosion or copper plating. The suction valve and the discharge valve had also a deposit of sludge layer along with lacquer. The sludge formation was uniform.

Another important part of the compressor i.e. top portion of the piston had become black. It showed a uniform layer of black colour. The lateral surface of the piston had some wear impressions. Crank shaft showed some copper plating. The piston pin had more wear. All these effects were on the surface of the piston pin facing towards the piston.

HFC-134a/ POE Oil - The inner housing of the compressor had some faint layer of brownish lacquer like coating due to the thermal degradation or coking of the oil. This was slightly more than the compressor tested with CFC-12. The slot insulation strips were hard. On the cylinder head i.e. on suction and discharge plenum, like CFC-12, there was some sludge formation on the base surface. On the top surface of the cylinder head, there was a non-uniform layer of lacquer. The surface of the cylinder or bore had some black spots near bottom dead centre.

On the valve plate (suction side), there was a significant brownish coating with black spots. The valve plate (discharge side) had a comparatively dark layer and sludge. The surface of the valve plate (cylinder side) near the discharge valve had a similar deposit but the deposition on valve plate was comparatively more.

The surface of suction valve leaf exposed to suction vapour had turned reddish brown. There was a dark shade of lacquer around the circumference of the valve leaf circle. The discharge valve, like CFC-12, had also been deposited with a dark uniform layer and sludge.

The top surface of the piston had turned black with some black spots over the surface. The skirt portion of the piston showed some wear impression around the circumference near the top with some formation of brownish coating. The connecting rod showed some copper plating on the bigger ring side. Some brownish coating was also deposited on the smaller end.

HC-290/HC-600a (50/50 Wt.%) Blend/ MO - The housing of the compressor did not show any sludge or corrosion over the surface. The drained lubricating oil appeared slightly dark brown colour with no floating particles. The oil in this test was not as much viscous as it was in the case of CFC-12 and HFC-134a. The upper compressor shell was very clean and there was no change in colour. The insulating plastics strips were not as hard and exhibited the flexibility.

The suction side cylinder head and the discharge chamber had sludge in traces but in comparison, both were clean. These chambers had no coating or corrosion on the inside surfaces. The surface of the cylinder was very clean with no traces of sludge. However, some wear impressions were seen on the surface. On the suction side valve plate, there was no sludge. There were traces on the discharge side as suggested by the blackish shade. Also, the cylinder side of the valve plate had turned faint black which was an indication of the sludge in traces. The coating and sludge on the above parts and the sides were negligible, compared to CFC-12/MO. The suction and discharge valves were very clean, compared to the case with CFC-12/MO.

The piston head was comparatively clean. There was a very light shade of black colour. The piston and the piston skirt was also very clean with comparatively low wear impressions. Also, there was no copper plating or lacquer and sludge formed on its surface. For the crank shaft, the copper plating and the wear of the surface facing the piston were in the lower range of the visual rating. Comparatively, the copper plating on the crank shaft was less than that of CFC-12/MO. Some copper plating had appeared on the piston pins (top side) with slight impressions of wear. Like the CFC-12/MO, in this compressor too, there was no corrosion of any parts. From the global summaries of both compressors, evidently the compatibility of the compressor parts with HC-290/HC-600a blend/MO is better than with CFC-12/MO.

Care-30/MO - The compressor with Care-30 had a breakdown during the test due to power failure. The slot insulation strips have become, hard and brittle and bale straps were broken. The lubricating oil had become dark because of the burn out. Therefore, no analysis of the oil sample was carried out.

Most of the effects were again similar to earlier cases, however, some of the effects were relatively low. The housing of the compressor was relatively clean. The top surface of the cylinder showed some non-uniform layer of brownish coating with relatively low wear. On the connecting rod, there was copper plating inside the small ring. The piston pin had two small strips of brownish colour with very little wear effect. The effects of Care 30/MO on the compressor parts were less than CFC-12/MO combination.

Destenched-LPG/MO - The housing of the compressor had a layer dark brown coating similar to earlier cases. There were no traces of the sludge over the winding of the stator. The slot insulation strips were hard. The cylinder head suction plenum had some deposition of sludge. On the discharge side plenum, there was a layer of sludge and brownish deposits on the wall surface. The base surface of the discharge side plenum was less affected. Like CFC-12, the surface of cylinder bore was deposited with a layer of brownish coating with some wear impressions.

The valve plate (suction side), compared to CFC-12, was relatively less affected. There was no sludge formation or corrosion of the surface. On the valve plate (discharge side), the whole surface was covered with a black coat and sludge. On the valve plate (cylinder side), 60% of the area was covered by a brownish coating. The coating was more near the discharge valve with some sludge.

The suction valve leaf, unlike CFC-12, was quite clean except with very thin brownish coating around the circumference. On the discharge valve leaf, like CFC-12, there was a uniform deposition of sludge and lacquer. On the piston skirt surface, like CFC-12, there was a considerable wear impression and faint black layer of lacquer over the surface near the top. On the top surface of the piston, there were spots of brownish coating with a slight effect of sludge. The piston pin, similar to CFC-12, had copper plating on the middle surface with noticeable wear. On the connecting rod, there was copper plating inside the smaller ring and a brownish coating near the bigger ring.

Commercial LPG/MO - During the test, there was a power failure leading to the burn-out of starting winding while restarting at the high temperature ambient. The oil was very dark in colour because of the burn-out. Therefore, no analysis of the oil sample was carried out.

Most of the effects were similar to the earlier cases with CFC-12, HFC-134a and destenched LPG case. However, contrary to the expectations, the results of this test showed better compatibility like other HC fluids tested. The cylinder surface had some layer of brownish coating and deposits of lacquer with some wear impressions. On the connecting rod, there was some copper plating on the inside and outside surface of the smaller ring. The piston skirt surface had more copper plating. The piston pin had very less wear compared to CFC-12.

Surface finish measurement - The surface finish measurement of the moving parts of the compressor gives the measure of the wear on its surface and the positions of maximum wear. The cylinder, piston, and piston pin were tested by using perthography for surface roughness. For cylinder and piston, both sides were tested whereas the piston pin was tested on its outside surface facing the piston.

The perthography measurements for CFC-12/MO revealed that there was no considerable wear over the surfaces of cylinder and piston. The measurements for the piston pin showed considerable changes and these are the indications of maximum wear of the surface. The piston pin had undergone a change in its diameter after the test by 0.02 mm; the change in its average roughness value is 0.967mm. There was no considerable wear on the cylinder and.piston of CFC-12/MO observed.

The surface finish measurements of the cylinder, piston and piston pin of the compressor tested with the HC blend, showed very little difference in the roughness values, before and after the test. It was observed that these values were less than the values obtained for Compressor with CFC-12/MO combination. These results suggest comparatively negligible wear. There were no observable changes in the diameters of the piston, excenter and piston pin. Thus it can be concluded that there was no adverse effect of the HC mixture and MO combination on the metallic moving parts of the compressor.

Generally, in all the cases, the wear was more on the piston pin and piston. In the case of HFC-134a, the cylinder, piston and piston pin were more affected than any other compressor tested. The compressor parts tested with DIN grade HC mixture (Patil, 1997) were least affected followed by CFC-12 and D-LPG. From the visual marks, it appeared that the compressor tested with Care-30 might be as good as or just worse than DIN grade HC mixture.

Total acid number - The acidity of the three oil samples were measured by KOH titration in the Organic Chemistry Division of NCL. The results are tabulated in Table 1.

The acidity of the lubricating oil with HFC-134a had increased from 1490 ppm to 3890 ppm after the test. The value of the original POE itself was substantially high indicating that the oil had been hydrolysed by the absorption of moisture, in spite of keeping in a tightly covered container. It was a very clear indication that with a higher acid formation, the copper plating and other sludge formation were much higher than that for CFC-12/ MO. In the case of D-LPG, the acidity of the oil had increased from 40.86 ppm to 118.5 ppm. This is more than that of CFC-12 but much less than HFC-134a.

Metal content - In the system, contaminants, such as organic acids, metal halides, motor insulation breakdown products etc. will preferentially concentrate in the lubricating oil rather than in the refrigerant. The metal content of the oil was measured by the Chemita Model 203, Atomic Absorption Emission Spectrophotometer.

The metal analysis, presented in Table 2, shows that the contents of iron present in the POE oil after test was more. This shows that there was more friction between cylinder and piston in case of HFC-134a/POE combination. The copper, may be from the winding of the motor and from the system itself. In the case of HFC-134a and D-LPG there were some considerable copper contents in the oil. Visual inspections also showed that the copper transfer in these combinations were more.

Chemical decomposition and reactions - The structural analysis of the oil samples before and after the test suggests the reactions between the oil and refrigerant. Therefore, the MO samples were analysed by using the Fourier Transform Infrared (FT-IR) Spectrophotometer and Proton Nuclear Magnetic Resonance (NMR).

FT-IR spectrophotometer - of the oil was done by using Perkin- Elmer 16 PC. The FT-IR spectrometry of all oil samples showed that there was no change in the chemical structure of the oils after the tests. However, there were some indications to suggest the formation of organic acids in very small concentrations. These organic acids are not as reactive as the inorganic acids like hydrochloric acid. A few other modifications of the original chemical structure could be observed but in a negligible order. Thus, the interpretation of the FT-IRs of the oil samples showed no considerable degradation of the oil.

Nuclear Magnetic Resonance - of the oil samples was carried out by using Perkin Elmer AC-200. Similar to the FT-IR results, the NMR analysis of all the samples also suggested that there was no chemical degradation of the oil.

CONCLUSION

From the visual rating, it can be concluded that the copper plating was much more in case of HFC-134a as compared to CFC-12 and other refrigerants. The copper plating, in the case of D-LPG, was more than CFC-12, but less than HFC-134a. The effect of sludge, lacquer and wear on parts were almost similar to CFC-12. In the case of C-LPG, there were only minor effects of copper plating, lacquer and sludge on the compressor parts. The compressor tested with DIN grade HC mixture showed excellent results, far better than the compressor tested with Care-30. The acidity of the POE oil, after the test was more than that of MO after the test. The iron and copper contents were also more than that of the MO from HC tests.

From the perthography results, it can be concluded that the compressor operating with Care-30 exhibited the least wear condition. Compressor with HFC-134a had a higher degree of wear than CFC-12. The average roughness values for all alternative refrigerants other than HC-134a and HC-Mix (DIN grade) were less than CFC-12. For piston pins, the Indian HC-Mix gave the minimum while the HFC-134a/ POE the maximum wear amongst all the refrigerant/oil combinations. The hydrocarbon mixtures, irrespective of the source, gave the lowest average roughness values, although average roughness value was the least for the Indian HC-mix.

From the above results, it can be concluded that the hydrocarbon mixture is better compatible with the hermetic compressor materials than with CFC-12 and HFC-134a even under retrofit conditions. This gives an opportunity to retrofit appliances with the HC mixture without any concern for stability.

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TABLE 1: ACIDITY OF OIL SAMPLES

Sr.No.	Refrigerant/Oil	Acidity (ppm)
1	MO (before test) (Patil, 1997)	40.86
2	CFC-12/ MO (Patil, 1997)	85.34
3	POE oil (before test)	149
4	HFC-134a/ POE oil (Patil, 1998)	1318.9
5	HC-290/HC-600a (50/50 Wt.%) Blend (DIN grade)/ MO (Patil, 1997)	40.54
6	Care-30/MO (Patil, 1998)	*
7	D- LPG/ MO (Patil, 1998)	188.5
8	Indian HC-Mix/MO (Patil, 1998)	252.5
9	C-LPG/MO (Patil, 1998)	*

* The tests with Care-30and C-LPG were abandoned after 1579 hours and 1457 hours respectively due to burnout of compressor windings. Therefore, their analysis was not carried out.

TABLE 2: METAL CONTENT IN OIL SAMPLES

Sr.No.	Compressor/Refrigerant/Oil	Content (ppm)		
		Fe	Cu	Al
1	MO (before test) (Pati, 1997)	< 1	< 1	< 1
2	CFC-12/ MO (after test) (Patil, 1997)	< 1	< 1	< 1
3	HFC-134a/ POE oil (after test)	60	3.25	8.7
4	HC-290/HC-600a (50/50Wt.%) Blend/MO (DIN grade) (Patil, 1998)	< 1	< 1	< 1
5	Care-30/MO (Patil, 1998)	*	*	*
6	D- LPG/MO (Patil, 1998)	5.9	3.5	< 1
7	INDIAN HC-Mix/MO (Patil, 1998)	1.3	5.1	1.8
8	C-LPG/MO (Patil, 1998)	*	*	*

* The tests with Care-30and C-LPG were abandoned after 1579 hours and 1457 hours respectively due to burnout of compressor windings. Therefore, their analysis was not carried out.