Field related tests for developing rotary screw air compressor lubricants

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SUMMARY

This paper discusses the lubrication of rotary screw air compressors. The various requirements for the lubricants and lab test methods are listed. The main attention is focussed on the evaluation of the thermal/oxidation stability of the lubricant. A form of coalescer blocking tendency test (CBT) is also described. It is shown that well formulated mineral oil based products can achieve similar life-times as synthetic based products. Detergent containing lubricants seem to offer no benefits compared to a non-detergent type.

1. INTRODUCTION

Rotary screw compressors are becoming increasingly popular in industry. Their benefits compared with conventional reciprocating piston compressors are:

- compact size
- lower initial and maintenance costs
- lower operational noise
- pulsation free air delivery

The oil in such a compressor has to lubricate the screws, bearings and gears and has to seal the clearance between the screws /1/ /2/. Further it has to remove the heat of compression. The lubricating oil in an oil flooded rotary screw compressor is intimately mixed with the air. The separation of the oil/air mixture takes place in an oil separator unit (coalescer). Most of the oil falls out as large droplets and is separated from the air simply due to gravity. Smaller oil droplets are separated in the coalescer filter which can have a pore size less than 2 micrometers. The oil is then cooled in an oil cooler, filtered and returned to the compressor.

Attempts to reduce the level of oil carry-over , in order to minimize the oil consumption and to improve the quality/purity of the compressed air, has lead to the development and use of finer coalescer filters. Together with the tendency to reduce the oil volume and to extend oil change intervals these developments put increasing pressure on the use of more oxidation stable and less sludge forming lubricants to avoid filter blockages.

Simple lab tests often have only limited correlation with field performance /3/. The purpose of this study was thus to identify suitable lab tests, and to examine the potential of the coalescer blocking tendency test as a useful tool to screen various lubricants under field related conditions.

2. SPECIFICATIONS

The current German DIN 51506 VD-L specification gives the minimum requirements for mineral oil based compressor lubricants with lubricated compression chambers, not provided with cooling by injection. It is dubious whether the VD-L ageing requirements are suitable to specify an oil for rotary screw applications. However, they give at least an indication of the carbon forming tendency of the compressor lubricant.

The new ISO 6743-3A or British Standard BS 6413 Sec. 3.1 (1988) differentiates between the various types of air compressors and their application severity, i.e. ISO-L DAA, DAB, DAC for light, medium and heavy duty reciprocating or vane compressors and DAG, DAH, DAJ for oil flooded rotary vane and screw compressors.

3. LUBRICANT REQUIREMENTS

The most important properties required for the lubricant in an oil flooded rotary screw compressor are:

- Oxidation and Thermal Stability
- Demulsibility with Water
- Rust and Copper Corrosion Prevention
- Foam Inhibition and Air Release Control
- Material Compatibility (i.e. seals, paint, metals)
- High Flash Point, Low Evaporation Loss

The last above mentioned properties are mainly dependent on the type and quality of the basestock and can hardly be influenced by additives.

In this paper the primary concern is focussed on the oxidation stability of the lubricant. This will be discussed in detail in the next section.

Condensed water from the compressed air can emulsify with the lubricant and decrease the performance of the oil. Good water separation is therefore necessary to avoid damage to the compressor. Detergent type oils such as Automotive Transmission Fluids, engine oils or specially developed detergent containing compressor oils seem to be questionable in this respect. Suitable bench tests include the ASTM D 1401 emulsification test (DIN 51599).

The rust prevention and the protection of copper parts can be checked with the ASTM D 665 (DIN 51585) and ASTM D 130 (DIN 51759) tests.

Suitable methods to evaluate foam and air entrainment properties are the ASTM D 892 (DIN 51566) and the ASTM D 3427 (DIN 51381) tests respectively.

Wear protection is required for satisfactory operation specially during the start-up period. The FZG (DIN 51354 part

2) is a suitable test to get an indication of the antiwear properties.

4. THERMAL AND OXIDATION STABILITY

One of the most important requirements of a rotary screw compressor oil is its thermal and oxidation stability. The environment for such a lubricant is one of the most severely oxidizing in which any oil is required to work /4/. The reaction between the oil, additives and oxygen leads to the formation of both soluble and insoluble acids and polymers (sludge) which, apart from their aggressivity towards metal parts, can block the coalescer filter. The thermal breakdown of the basestock itself can also lead to the formation of carbon deposits which can also block the filter. The oxidation/thermal stability given in the DIN 51506 VD-L specification investigates the carbon forming tendency of a lubricant after ageing with air in the presence of an iron oxide catalyst. The carbon residue after distillation of 80 % of the lubricant is also evaluated, and the viscosity increase of the remaining 20 % gives an indication of the boiling range of the oil.

The Conradson Carbon Residue (CCR) after the oxidation can be influenced by additives whereas the CCR after distillation is dependant on the basestock quality and cannot be reduced by the use of additives as shown in Table 1. Table 2 gives some typical CCR-figures for different base fluids and a fully formulated compressor lubricant.

It is thus questionable whether the oxidation/thermal stability demands specified by the DIN 51506 VD-L are relevant to rotary screw air compressor lubricants. A number of basestocks were therefore examined using the following oxidation/thermal stability tests:

- ASTM D 943 (TOST)
- Rotary Bomb Oxidation Test (ASTM D 2272)
- Differential Scanning Calorimetrie (DSC)

Table 1: Conradson Carbon Residue (CCR) of various lubricants after the DIN 51352 part 2 oxidation test and after DIN 51356 distillation.

FLUID	DIN 51532(2) CCR, m%	EVAPOR. LOSS, %	20% DISTILLATION RES. CCR, m%	KV40,mm2/s
A	4.6	9.3	0.26	152.4
A1	5.6	7.2	0.23	167.5
A2	1.0	8.5	0.23	167.3
VD-L	2.5	20.0	0.30	230.0

A: highly refined mineral oil, ISO VG 46
A1: A plus 0.3% phenolic type anti-oxidant
A2: A plus 0.5% aminic type anti-oxidant

Table 2: Typical DIN 51352 part 2 (PNEUROP) oxidation test results for various compressor base fluids

FLUID	DIN 51352 PART 2 (PNEUROP) CCR, m%	EVAPOR. LOSS, %
B	6.2	17.3
C	2.6	18.0
D	7.7	15.9
E	1.9	19.8

B: mineral oil w/o additives
C: synth. base (PAO) w/o additives
D: di-ester, w/o additives
E: fully formulated product with B

ASTM D 943 (TOST) Test

The ASTM D 943 thermal oxidation stability test is considered to be particular applicable to lubricants which may suffer water contamination. The evaluation involves adding 60 ml of water and an iron-copper catalyst to the oil which is maintained at 95 deg C whilst blown with 3 l of air per hour. The oxidation life is usually quoted as the time it take until a certain total acid number (i.e. 2mg KOH/g acc. DIN 51524 part 2) is achieved. Some typical figures are given in Table 3.

Table 3: ASTM D 943 results for some typical compressor lubricants (ISO VG 46)

	time, hours	TAN, mg KOH/g
Compressor Oil (mineral oil based)	>4000	2.0
Hydraulic Oil	2200	2.0
Turbine Oil		
(mineral oil based)	4000	2.0
(PAO based)	9000	2.0

The obvious disadvantage of this method is its long duration. No evaluation of the sludge formation is carried out. It is advisable to check also the viscosity on a regular basis and to monitor the change of the total acid number. Nevertheless, this technique ranked the tested oils in a similar order compared to their field performance.

Rotary Bomb Oxidation Test (ROBOT)

The Rotary Bomb Oxidation Test (ASTM D 2272) is also a suitable test to evaluate the oxidation resistance of a lubricant especially when the test is run in parallel with a used or artificially aged oil sample. The oils tested in this paper were aged in an open beaker for 7 days at 120 degC. The ROBOT Test itself involves placing 50 g of oil plus 5 ml of water and a copper catalyst coil inside a bomb equipped with a pressure gauge. The bomb is then charged with oxygen to a pressure of 620 kPa and maintained at 150 deg C whilst rotated at 100 rpm. The oxidation stability is related to the bomb life which is the number of minutes required to observe a pressure drop of more than 175 kPa. The results are shown in Table 4.

These results lead to the following ranking in terms of oxidation stability: poly-alpha olefin ≅ mineral oil based Compressor Oil > Turbine Oil > Hydraulic Oil.

Table 4: ROBOT Test Results

Sample	Condition	Life, min
Premium Compressor Oil, mineral oil based	fresh	> 540
	aged	400
Synth. Compressor Oil PAO based	fresh	> 540
	aged	480
Hydraulic Oil	fresh	310
	aged	290
Turbine Oil	fresh	350
	aged	305

Differential Scanning Calorimetry (DSC)

DSC is also a helpful method for obtaining some indication of the oxidation life of various lubricants /5/. It involves heating a thin film of the oil sample on an aluminium pan in an atmosphere of oxygen and measuring the exotherm corresponding to oxidation. The same oil samples as in the ROBOT test were run under these conditions and the results were fairly similar as shown in Table 5.

Table 5: DSC Results of various Compressor Lubricants
(Heat rate:10K/min, 1bar oxygen)

Sample	Degn*, deg C	EOT** deg C
Compressor Oil mineral oil based	233.2	254.6
Compressor Oil PAO based	233.8	256.8
Hydraulic Oil	229.4	249.6
Turbine Oil	230.6	241.2

* Degn = First signs of degradation
** EOT = Extrapolated Onset Temperature

5. COALESCER BLOCKING TENDENCY TEST

The coalescer filter cleans the compressed air by removing the fine oil droplets carried over by the air. In the fine pores of the filter small oil droplets are combined and form bigger droplets ("coalescere" (latin) = "to melt together"). These are then able to flow back into the oil sump due to gravity.

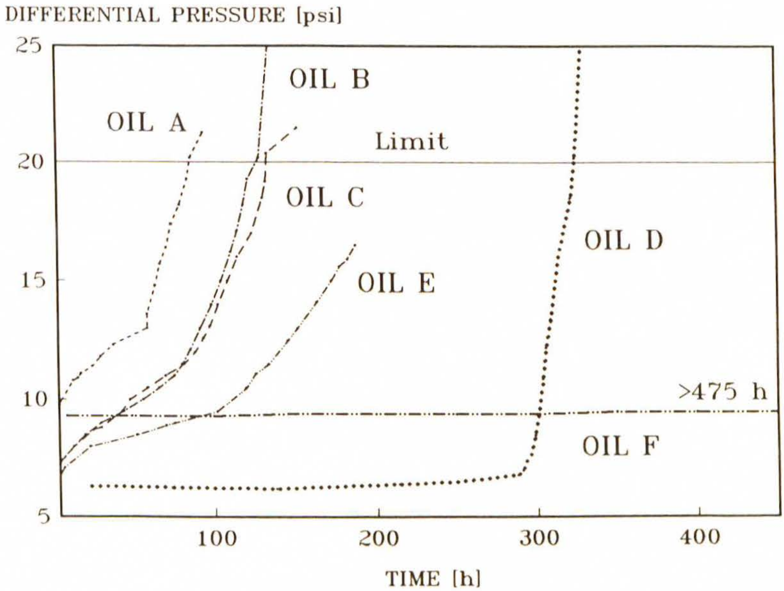
Finer coalescer filters place greater demands on the lubricant to reduce the amount of oil carried over in the compressed air /6/. However, once an oil has exceeded its useful life, degradation products are formed which adhere to and block the coalescer filter. This produces a differential pressure across the filter which may result in mechanical failure. The coalescer blocking tendency (CBT) thus provides a valuable indication of the useful life of the lubricant in a rotary screw compressor. Figure 4 in Appendix A shows schematically the arrangement of the compressor rig. The detailed test conditions are summarized in Table 6 (Appendix A).

The whole rig is fully computer controlled and runs in a temperature controlled test chamber. The blocking of the coalescer is accelerated by the use of a 1.2 micrometer separator filter which has 85 % of its surface masked off with oil resistant paint and a specially made stainless steel shroud. Furthermore, 50 ppm of both a soluble copper and iron naphtenate catalyst are added to the oil which is held at 120 deg C during the test. The pressure increase across the coalescer is monitored against time. The test is stopped once the filter has been blocked as indicated by a pressure differential of 138 kPa (20 psi). During each run oil samples were taken (usually at the beginning, after approx. 100 h and when the test was finished) and their viscosity and total acid number (TAN) evaluated.

The test results are shown in Figures 1, 2 and 3.

The Oils A, B, **C** and F are mineral oil based compressor oils (ISO VG 68) passsing the VD-L specification. Graph E shows the

FIGURES 1+2: CBT–Test Results of various Oils



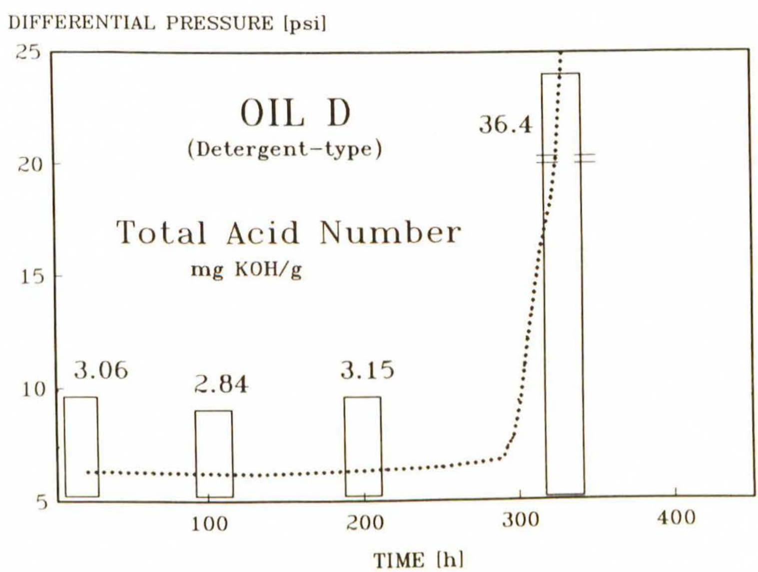
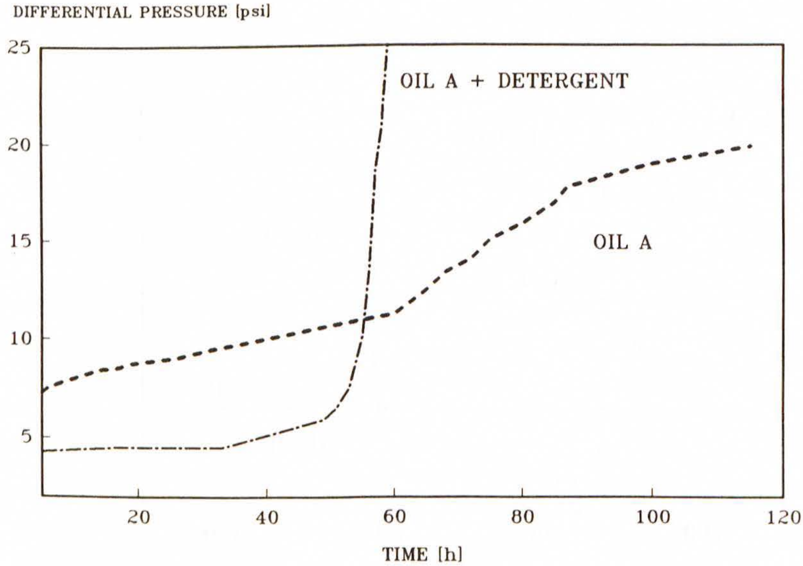


FIG. 3: Influence of detergents on the CBT



Comparison fresh oil – used oil (E.o.T.)

Viscosity increase (KV40), %	
OIL A	15
OIL A + DET.:	1500
Total Acid Number increase, %	
OIL A	50
OIL A + DET.:	2000

behaviour of a typical hydraulic oil whereas oil D represents a detergent type compressor oil (ISO VG 46). The first differential pressure measurements which were taken for this graph were recorded after 3 hours in order to allow the system to stabilize. The oils A,B and C exhibit similar performance. Oil E seems to be slightly better for preventing the formation of filter blocking substances. In Oil D the typical effect of a detergent can be seen. Once the detergent has been consumed the oil fails very rapidly (see also Fig.3). Oil F does not show any tendency to block the filter even after 475 hours. This behaviour had previously only been seen with PAO based lubricants /6/.

In all tests TAN and KV40 measurements were carried out. Figure 2 shows that the TAN increases when the differential pressure rises. However, this example demonstrates that a routine check would not have predicted the sudden failure of the oil, and therefore damage to the compressor could not have been avoided. The effect of a detergent can also be seen in Figure 3. The addition of a detergent to OIL A (mineral oil based compressor oil) caused a rapid failure after approx. 60 hours, whereas the "base oil" (OIL A) only slowly blocked the filter. The viscosity increase and the increase of the total acid number was also much less "dramatic" in this case.

6. CONCLUSIONS

The performance requirements and specifications for rotary screw air compressors were reviewed.

Test methods for the evaluation of thermal and oxidation stability were discussed.

The Coalescer Blocking Tendency test was described as a method to evaluate compressor lubricants under field related conditions. It was demonstrated that it was possible to differentiate between the performance of various oils.

Well formulated mineral based compressor oils have shown extended life-times comparable to synthetic (PAO-) based products.

Detergent type oils appear to offer no benefits in terms of the prevention of a filter blockage due to sludge formation.

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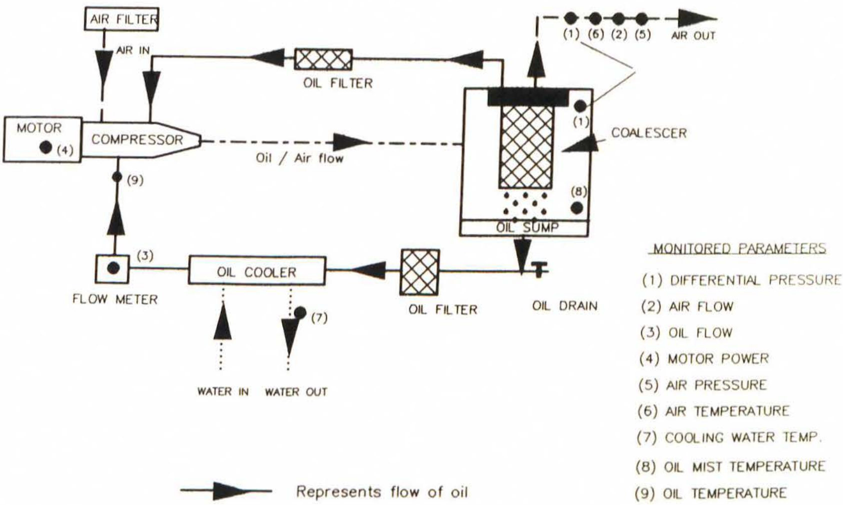
APPENDIX A

FIGURE 4: Test Set-Up Coalescer Blocking Tendency



The numbers indicate the positions of the primary computer controlled elements. The information is transferred to an IBM-PC which controls and monitors the whole test run.

Table 6: Details of the CBT Conditions

PARAMETER	LEVEL/DESCRIPTION
Rotary Screw Compressor	Compair Broomwade 6007E
Electrical Motor Output	5.5 kW (7.5 hp)
Free Air Delivery Pressure	965 kPa (140 psi)
Air Flow Rate	0.4 m3/min
Coalescer Filter Size	1-2 micron
Coalescer Masking	85%
Air Discharge Temperature	114 deg C
Catalyst	Fe/Cu-naphtenate (50 ppm each)
Oil Sump Temperature	120 ± 1 deg C
Pressure Differential for blocked Filter	138 kPa (20 psi)