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LABORATORY TESTING UNDER CONTROLLED ENVIRONMENT USING A FALEX MACHINE

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ABSTRACT

According to one expert, inadequate control of the environment renders lubrication data "worse than useless". The paper describes a modified Falex Lubricant Tester, such that it provides a controlled environment in a pressure tight test chamber. The authors believe that data taken with the modified machine correlate with field performance. Repeatability of the test data and differences between air and dichlorodifluoromethane are discussed. Methods of evaluating lubricants and extreme pressure additives are described.

NEED FOR CONTROLLED ENVIRONMENT

"It is now coming to be realized ... "Essentially all lubrication data obtained before 1960 (and a good deal since) is worse than useless".

Dr. Alan Beerbower[1] says so in his scholarly review of the state of the art in Boundary Lubrication. The comment refers to the effect of the atmosphere surrounding a bearing/lubricant system, in particular to the effect of humidity in the laboratories. He continues, "Not only did the experiments fail to control the humidity in their laboratories, they seldom even bothered to record it."

If indeed, the uncontrolled and unknown changes in the humidity affect the lubrication data to render it "worse than useless", then how can we expect data in air to apply to other environments - in our case to fluorocarbon refrigerants - no matter how good the data in air may be.

Of course, much before Dr. Beebower's review researchers had demonstrated the futility of predicting the lubrication behavior in refrigerant from data in air. In 1958, for example, Divers[2] tested several oils in a Falex machine, and reported that oils, which for years had been successfully used in refrigerant compressors performed poorly in the Falex tests in Air. More recently Klaus[3], et al., using a Shell fourball machine, have shown that R12 is beneficial for boundary lubrication, and Huttenlocher[4] has reported a similar effect of R22 in comparison to that of air and nitrogen with the use of a Falex machine.

METHODS OF CONTROLLING THE ENVIRONMENT

Since the desirability of obtaining laboratory data in the appropriate environment is recognized, the only question is how one obtains that environment. Both Klaus and Huttenlocher bubbled refrigerant vapor through the oil sump before and during the experiment and depended upon the blanket of refrigerant to exclude air from the oil. Also by analyzing the oil, Klaus has shown that the bubbling procedure effectively displaces the dissolved oxygen and air from the oil, particularly when the gas is highly soluble in oil as is the case with R12.

The bubbling procedure is most convenient because it involves a minimal modification of the equipment. At Tecumseh, however, our efforts led us to an alternative method which would duplicate more closely the conditions in a hermetic compressor i.e., a sealed pressure tight, test chamber. One reason for this route, was that over the years we have learned that a setup which suits one laboratory does not necessarily suit others. We also realized that the modification of a test machine was not such a major task.

TEST MACHINE AND MODIFICATIONS

Lubricant testers are expensive, and with the type of modifications we desired, they become even more so. For example, a Shell four ball machine equipped with a pressure tight chamber, temperature control and variable speed drive was commercially available for about $20,000.00 when we first investigated. Moreover, the interpretation of the test results and the utility of the data for practical applications was very much an unknown factor.

Under the circumstances, the decisive factor in the choice of the machine was its cost. The Falex tester is perhaps the least expensive among the various test machines. The test specimens are also cheaper, have a simple geometry and can be readily machined in house. This was also an important consideration because we wanted to have the capability of testing the precise materials used in hermetic compressors.

Modifications to obtain a sealed chamber turned out to be fairly simple. They included addition of three seals, one at the rotating shaft and the other two at the movable jaw arms. The seals were incorporated in a flat plate, which formed the cover for the test chamber. An inlet and an outlet for refrigerant were provided through the flat plate and a groove was machined on the underside. A special oil cup was made to fit in the groove, and held closed with two clamps. Other conveniences were a thermocouple and a cooling coil brazed to the oil cup.

A close up of the test chamber open and closed is shown in figures 1 and 2 respectively.

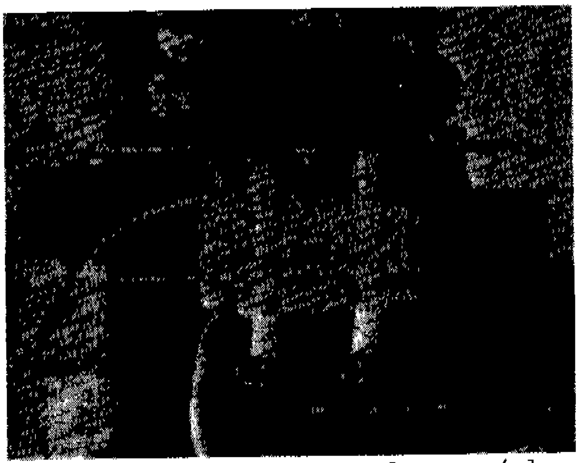

Fig. 1 Close up of test enclosure (closed)

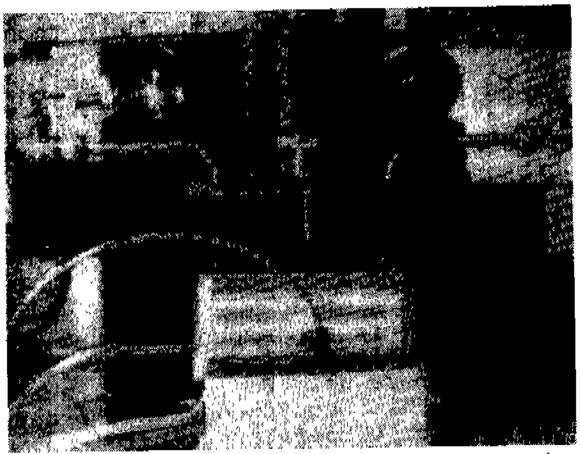

Fig. 2 Close up of test chamber (open)

EXPERIMENTAL TECHNIQUES

Saturation of Oil

The prime requirement for the experimentation is to have the oil saturated with refrigerant at the start of a test run and to assure that it remains so during the test itself. Saturation of the oil can be achieved by bubbling refrigerant through it. A simpler way, however, is simply to add liquid refrigerant to the oil. The liquids mix readily and the oil will retain only a a fixed amount of refrigerant depending on the temperature and pressure. During the test a small stream of refrigerant vapor is fed over the oil sump in the closed test chamber.

For experiments with other environments, air for example, the oil is degassed under vacuum and backfilled with air and a small stream of air is passed over the oil sump during the test.

Temperature Control

This is friction testing, so that the temperature of the oil rises during the test. The cooling coil brazed to the oil cup may be used to maintain the desired temperature. At times, it is desirable to start the experiment at an elevated temperature. This is easily done by a hot air gun.

Experimental Procedure

Several procedures or variations are described in the manufacturer's literature.[5] One is to increase the applied load until seizure occurs either by high torque or by the shearing of the locking pin. Another (ASTM D2670-67) is to apply a fixed load for a specified time and measure the rate of wear directly from the machine. Huttenlocher has used the weight loss of the pin as a measure of wear.

Regardless of the criterion one selects it is important that as complete a record as possible be kept of the test specimens, operating variables and the test results. In our case, each batch of the test specimens was inspected for surface finish, imperfections, hardness and microstructure. The pins were weighed before and after the experiment. The V-blocks were checked for the scar width and the finish on the worn surfaces of both test specimens was measured. The torque and the temperature were recorded during the experiment. The test specimens were protected against rust for future reference.

Experimental Results

Several questions are likely to crop up in the reader's mind at this stage. One would be the "repeatability" of results. Another would be the differences in the data in air vs data in refrigerant; and certainly whether this type of experimentation is useful for field application, be it for evaluation of oils or of bearing materials. We will briefly discuss these aspects in this section.

Repeatibility

We were aware that the Falex tester is not considered to be a highly precise instrument. Yet we were pleasantly surprised that the test results are quite repeatable. Of course, not every measurement say the torque, the scar width or the surface finish is precisely repeatable, but the general trend is quite consistent.

For example, one test may show seizure whereas a repeat test may not. Examination of the pin and the blocks will, in the second case, show severe wear and gouging and the torque on the recorder would be high, only not high enough to rip the relay.

Perhaps the repeatability of the tests is best explained with an illustration. In the early stages of our experiments, we were testing the effect of a conversion coating viz. phosphating of ferrous parts. The experiments were made with identical base materials having the same microstructure, hardness and with the same loading program. The conversion coating process was supposedly the same i.e., controlled per manufacturer's recommendation in terms of concentrations, time, temperature, etc.

Figures 3 and 4 show photographs of the test specimens having conversion coatings given at two different times. In figure 3 the worn surfaces are dark and smooth. The phosphate coating is burnished on to the surface and remains tightly adherent to the base metal. In figure 4, the worn surfaces are shiny white and the phosphate coating has worn away exposing the bare metal. Except for the presence or the absence of the coating, the other test data were not far different. The scar width is about the same and the torque, temperature, etc., were not much different. Repeating of the test gave identical results for the two batches.

Investigation of the surfaces later showed that the crystal size of the phosphate was

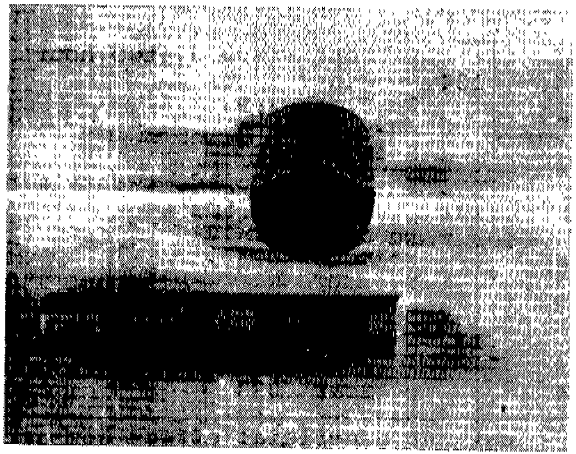

Fig. 3 Specimens after testing showing the presence of phosphate surface coating.

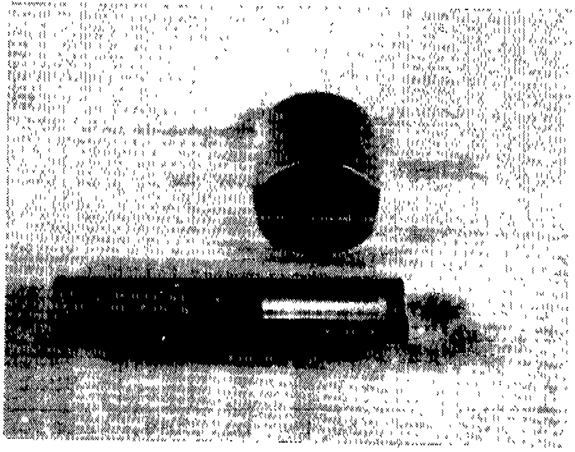

Fig. 4 Specimen after testing, showing that the phosphate conversion coating wore away, exposing the bare metal.

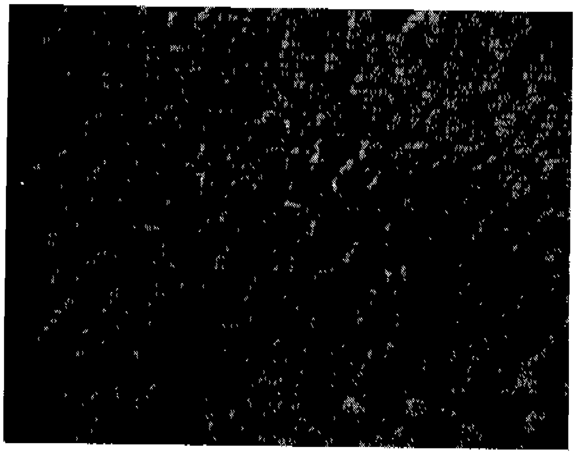

Fig. 3a Photograph (2400x) of the phosphate crystals from test pin in Figure 3.

Fig. 4a Photograph (2400x) of the conversion coating from test pin in Figure 4.

TABLE I

Comparison of Atmosphere - Air vs R12

Test Description	Test No.	Results in air	Test No.	Results in R12
Pin steel 3135 V-Blocks steel 1137 Oil A, 200 # Load Four hours	26	Seizure, 25 min.	5	No seizure Pin 160 Block 100 Scar width .02"
Pin Cast iron Rc 55 V-Blocks 1137 steel Oil A, 200#Load Four hours	25	Pin 130-150 rms Block 90-100 Scar .03	24	Pin 19-25 rms Block 13-20 Scar .017
Pin Cast Iron R_B 96 V-Blocks Cast Iron R_B 88 Oil A, 200 # Load Four hours (Surfaces phosphated)	27	Pin 8-13 rms Block 13-17 Scar .023	30	Pin 18-20 rms Block 14-20 Scar .021
Pin steel 1095 Rc 55 V-Blocks steel 1137 Oil A, 750 # Load	122	30 min. life Pin 25-40 rms Block 45-55 Scar .035	133	30 min. life Pin 16-25 rms Block 30-40 Scar .032
Same as above plus a surface coating	127	90 min. life Pin 35-45 rms Block 50-60 Scar .033	134	Test stopped, two hours Pin 7-9 rms Block 7-9 Scar .025
Pin Steel 1095 Rc 55 V-Blocks Steel 1137 Oil B, 750 # Load	123	30 min. life Pin 35-40 rms Block 70-75 Scar .043	131	Test stopped, twenty minutes Pin 8-11 rms Block 10-12 Scar .025
Same as above White Oil	124	30 min. life Pin 50-70 rms Blocks 190-220 Scar .070	132	30 min. life Pin 11-15 rms Blocks 20-25 Scar .033

different for the two batches. Electron microscope photographs of the two are shown in Figures 3a and 3b.

Regardless of the explanation, we were convinced that the test machine does indeed have adequate repeatability.

Effect of Air vs. R12

This involves the comparison of parameters where one must guard against hasty judgements. We find that to make a valid comparison one should run a series of tests and compare a set of experiments involving several other variables. Table 1 shows a set of tests which we made to compare the effect of air vs. that of R12. Because of various extraneous variables, which affect the test results, this seems to be the best way of avoiding pitfalls. Referring to Table 1, if only tests no. 27 were used, R12 and air would appear equivalent and for that matter air may even appear superior. On the other hand, if only test no. 127 and 134 were used, R 12 would look vastly superior. When all the tests are taken together R12 shows a clear cut beneficial effect compared to that of air.

Effect of R12 vs. R22

We bring this up only because an impression exists in industry that R12 aids boundary lubrication whereas R22 does not. The impression stems from the early work by Murray[6] et al, involving only the refrigerants and no oil, which showed that R12 forms a lubricating film and gives a low coefficient of friction. With R22 the coefficient of friction was high and a lubricating film was not believed to form.

We made a few experiments of the type shown in Table 1, to compare the effects of R12 vs R22. The results indicate that the beneficial effect of R22 is comparable to that of R12.

Evaluation of Oils and Additives

One of the purposes of the Falex tester is to evaluate lubricants and the ASTM procedure

D-2670 is designed for that purpose.

We checked several test procedures before finding one which would differentiate between oils, and yet not be too severe. We would like to share the background of this work with the reader.

One procedure was to start at room temperature, apply a load of 200 lbs and run the test for four hours.

The scar width and the surface finish of the specimens were the figures of merit. This was a relatively mild loading program and we found that all the oils showed good performance. Even white oil, which is considered to be a poor lubricant, performs well when the test specimens are made of typical compressor materials and are given the normal surface preparation.

One interpretation of this phenomenon is that any oil would work satisfactorily in a refrigerant compressor provided the loads and temperatures are low. Alternately, one might also conclude that at low loads and temperatures the Falex test does not discriminate between oils.

With higher loadings, the oils show some differences. Of the two widely used domestic refrigeration oils, one consistently showed a slightly better performance than the other. However, we do not consider the small differences significant, because both the oils have for years been interchangeably used in refrigerant compressors without any apparent problems.

A higher initial oil temperature has the same type of an effect as the higher loading levels. For example, a set of test specimens and oil, would hold a 600 lb load for two hours when the operating temperature was maintained at 90°F throughout the test. The surface finish on the pin was 13-17 rms and on the block it was 26-28 rms. In a parallel experiment, the starting temperature of the oil bath was raised to 150°F and allowed to rise during the experiment. The test had to be stopped within one hour, because of high torque and the test pin showed 75-85 rms finish while the V-Blocks had 90-110 rms finish.

The procedure we now use for evaluating oils and additives consists of preheating the oil sump to 150°F and permitting the temperature to rise during the test. The test specimens are a hardened steel pin and the V-blocks are cast iron. The duration of the test is two hours. The ability to hold an applied load is the figure of merit.

With this procedure we can classify lubricants and additive formulations in three categories; acceptable, intermediate and excellent. Most nephthenic, additive free, 150 SUS refrigeration oils will hold a 250 lb load, but will fail at 350 lbs because of excess wear. With 2% Tricresyl phosphate, the same oils will hold 750 lb load, a vast difference from the 250 lb level. Among the several additive formulations tested, we have yet to find one which will match the performance of 2% TCP. Accelerated compressor tests have verified these findings from the Falex tester.

SUMMARY AND CONCLUSIONS

We have described a modification of the Falex Tester for evaluation of bearing materials, surface treatments and lubricants. Although our interest is in fluorocarbon refrigerants, the set up should be applicable for any environment. We have presented some raw data in order to emphasize that comparisons of variables should be made from sets of experiments rather than on the basis of two parallel experiments. The repeatability of the results is illustrated with photographs and an example. Methods of evaluating lubricating oils are described.

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