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Mineral oils for the lubrication of refrigeration compressors have been developed to a high level of performance and have served with distinction over a wide range of applications. However, in some cases, the demands of refrigeration systems have exceeded the ability of mineral oils to perform adequately. Two areas where mineral oils have been deficient are in good oil return with some refrigerants such as R-22, R-502, R-13, and R-503, and in high temperature stability. Good oil return is directly related to the solubility of refrigerants in the oil at low temperatures. High refrigerant solubility tends to keep the oil viscosity low and allow it to be moved out of the low temperature areas by the flow of refrigerant. A deficiency in high temperature stability results in coking, varnishing, sludging, and other evidences of oil breakdown.

Alkyl benzenes have been found to offer improved performance in refrigeration systems, both with respect to better oil return and better high temperature stability. Representatives of this type of oil have been in limited use in Europe for some time (1). Sanvordenker (2) has reviewed the properties of alkyl benzene oils as well as other synthetic materials of possible interest in refrigeration. Schwing (3) has studied the properties of polyisobutyl benzenes in the laboratory and found that they are very stable in the presence of R-12. Sealed-tube tests showed superior performance on the basis of chloride ion development, copper plating, and the production of dissolved copper.

It is the object of this paper to describe the properties of an alkyl benzene lubricating oil for refrigeration applications. The properties and performance characteristics of a typical naphthenic oil are also included as a frame of reference.

OIL PROPERTIES

Typical properties of an alkyl benzene oil are compared with those of a mineral oil with about the same viscosity in Table 1. Some properties are quite similar while others are greatly different. The viscosity at the standard reference temperatures of 100°F and 210°F is similar for both oils. In the example shown, the change in viscosity with temperature seems to be slightly less for the alkyl benzene than for the mineral oil but this difference is not considered significant. The molecular weight for the two oils is about the same. The pour point or temperature at which the pure oil does not readily flow is somewhat lower for the alkyl benzene but the difference is not great. Relatively small differences are also found in the specific gravity, flash point, aniline point, etc.

The greatest differences in the properties of alkyl benzene and mineral oils are found in the floc point and thermal stability. The floc point has long been used in the refrigeration industry to measure the likelihood of wax separation from solutions of oil and refrigerant. The test is made with R-12 and is not intended to indicate general solubility relationships but rather the possibility of the deposit of potentially harmful higher melting constituents of the oil. Solubility relationships for the two oils with other refrigerants are compared later.

TABLE 1. TYPICAL PROPERTIES OF OILS

	Alkyl Benzene	Mineral Oil
Viscosity, SUS 100°F	150	155
210°F	41.1	40.8
Molecular Weight	320	325
Pour Point, °F	-50	-45
Floc Point, °F	<-115	-68
Aniline Point, °F	125	160
Specific Gravity, 60/60	0.872	0.917
Dielectric Strength, KV	>34	>34

SOLUBILITY RELATIONSHIPS

R-12 is miscible in all proportions with alkyl benzene down to the lowest temperature measured, about -115°F. Since R-12 is also miscible with naphthenic mineral oils to about the same low temperature, little difference would be expected between the two oils as far as oil return is concerned.

The solubilizing effect of alkyl benzene for refrigerants is more evident with R-22. The consolute temperature is used to indicate the magnitude of mutual solubility of an oil and refrigerant. This point is the highest temperature at which separation into two liquid phases occurs. For R-22 and a typical naphthenic mineral oil, this temperature is about 35°F for a solution containing about 80% R-22 by weight. The consolute temperature has not been determined exactly for R-22 and alkyl benzene but is somewhere in the vicinity of -100°F. An even greater difference is found with R-502. With this refrigerant and a naphthenic mineral oil, two liquid phases exist at all temperatures up to the critical temperature of the refrigerant (180°F) for compositions ranging from about 50% to 90% R-502. With alkyl benzene, the consolute temperature is about -25°F at a composition of 58% R-502. At higher temperatures, the two liquids are completely miscible in all proportions.

Other solubility comparisons are illustrated in Table 2. The data is for saturated conditions. For example, in the first and second columns showing refrigerant solubility in oil, the addition of more refrigerant would lead to the formation of a second liquid phase. On the other hand, the addition of more oil to the conditions represented by the last two columns would cause the formation of a second liquid phase. It can be seen that both R-22 and R-502 are considerably more soluble in alkyl benzene than in mineral oil.

The solubility of refrigerant in oil is important in dry-type evaporators where all of the refrigerant is evaporated before reaching the evaporator outlet. In this condition high refrigerant solubility tends to keep the oil thin and less viscous and thus enables it to more easily be returned to the compressor.

Information on the solubility of oil in liquid refrigerant is of interest in flooded evaporators or liquid re-circulation applications. Oil solubility determines whether or not a separate oil layer is formed and what methods of oil separation and return are needed.

The solubility of refrigerant gas in oil is of interest in various parts of the refrigeration system such as the compressor crankcase, the suction line, discharge line, etc. Refrigerant solubility in alkyl benzene and a mineral oil is summarized in Table 3 for several conditions of temperature and pressure.

Experimental measurements of the vapor-pressure of refrigerant dissolved in alkyl benzene have demonstrated that this solution follows Raoult's law very closely, so the values reported in Table 3 have been calculated. Extensive measurement with mineral oils of various compositions have shown a positive deviation from Raoult's law for refrigerant solutions.

For the temperature range shown in Table 3, R-12 and R-22 are about 20% more soluble in alkyl benzene than in the mineral oil. On the other hand, R-502 is more than twice as soluble under similar conditions of temperature and pressure. This great increase in oil solubility for R-502 is especially striking in view of its very poor solubility in typical mineral oils.

STABILITY

One relatively common cause of trouble in refrigeration systems is the formation of coke and varnish from the decomposition of lubricating oil. It has been shown that breakdown of oil at the temperatures found in refrigeration systems is often caused by interaction with the refrigerant. (4). During the reaction, the refrigerant is reduced and one chlorine atom is replaced by a hydrogen atom. For example, R-12 CCl_2F_2 produces R-22, $CHClF_2$ R-22, $CHClF_2$, produces R-32, CH_2F_2 etc. The formation of reduced refrigerant has come to be used as a measure of oil/refrigerant stability in sealed tube tests. The test is usually made with R-12 and the oil in question sealed in glass tubes in the presence of copper, steel, and sometimes aluminum strips. The amount of R-22 produced shows the extent of reaction between the oil and refrigerant. The tubes are heated for two weeks at a temperature of 175°C (347°F). The results of such stability tests summarized in Table 4 show that alkyl benzene is distinctly superior to mineral oil in this important property.

Resistance to oxidation can also be used to judge the stability of lubricating oils. Of course, oxygen should not be present in a properly sealed and charged system, but sometimes it is. Centrifugal compressors used with high boiling refrigerants normally have inward leakage of air. In one test of oxidative stability (5), the oil is held at 115°C (239°F) in an open beaker for 96 hours in the presence of copper. The quality of the oil is judged by the development of color. In this test, alkyl benzene turns from colorless to pale yellow while a mineral oil of similar viscosity becomes black.

FOAMING

Oil foam is usually generated in the compressor crankcase when the compressor begins to operate, especially after not operating for a period of several hours or longer. Refrigerant tends to dissolve in the oil while the machine is idle and to be rapidly evolved when the compressor begins to run. This withdrawal of refrigerant tends to cause foaming. Loss of oil from the crankcase is thought to be directly related to the degree of foaming, but the exact mechanism is not clearly understood. To the extent that foaming is the cause of oil carry-over, it is bad. On the other hand there is some evidence that oil foaming tends to reduce noise in operating compressors and this is good. In any event, a much reduced tendency to foam is found in the alkyl benzene oil. For example, when R-12 is bubbled through liquid oil at a rate of 240 ml/min. a 16-inch layer of foam is generated on top of the mineral oil. Under similar conditions the foam above the alkyl benzene was about 1/2 inch, as shown in Table 5.

TABLE 2. SOLUBILITY RELATIONSHIPS OF REFRIGERANTS AND OILS AT SATURATION

		Solubility, Weight %			
		Refrigerant in Oil		Oil in Refrigerant	
Ref.	Temp°F	Alkyl Benzene	Mineral Oil	Alkyl Benzene	Mineral Oil
502					
	-50	32	16	18	0.2
	-30	46	18	34	1
	0	miscible	20	miscible	2
22					
	-100	40 (est'd.)	22	22	0.1 (est'd.)
	-50	miscible	29	miscible	1
	0	miscible	46	miscible	5

TABLE 3. PVT RELATIONSHIPS OF OIL/REFRIGERANT SOLUTIONS

			Solubility of Refrigerant, Weight %	
Ref.	Temp.°F	Pressure, Psia	Alkyl Benzene	Mineral Oil
502				
	140	200	28	14
		150	19	10
		100	11	6
	100	150	40	17
		100	21	9
		50	9	4
	60	50	18	8
22				
	140	200	26	23
		150	17	14
		100	10	8
	100	150	40	32
		100	20	16
		50	8	6
	60	50	17	11
12				
	140	150	44	38
		100	24	21
		50	10	9
	100	50	19	15
	60	50	45	35

TABLE 4. THERMAL STABILITY TESTS

	Percent R-22 based or Original R-12 after 14 days at 175°C (347°F)	Color[b] in Sealed Tube Test (5 days at 204°C) (400°F)	
		R-12	R-22[c]
Alkyl Benzene	0.027[a]	0	0
Mineral Oil	0.28[a]	5	1

a. Average of 3 tests
b. Color scale:

0 = colorless	3 = brown
1 = yellow	4 = black
2 = amber	5 = black with solids

c. After 16 days

TABLE 5. TENDENCY TO FOAM

R-12 bubbled through a 3-inch layer of oil at a rate of 240 ml/min.

	Foam Height, Inches	Foam Life, Minutes
Alkyl Benzene	0.5	-
Mineral Oil	16	5

TABLE 6. LUBRICITY OF REFRIGERATION OILS

Test	Refrigerant Present	Time, Hours	Alkyl Benzene	Mineral Oil
			Wear, mg.	
Falex	22	3	45	44
		4.5	65	60
			Scar Diameter, mm	
Shell Four Ball	-	1	0.323	0.334
			0.378	0.391
			0.360	0.389
			0.432	0.409
				0.381
				0.391
				0.425

LUBRICITY

The principal function of oil in refrigeration systems is to lubricate the compressor bearings. If the oil is lacking in this property it is of little use regardless of its other qualities.

The available evidence shows that alkyl benzene type oils provide satisfactory lubrication for refrigeration compressors.

Natural mineral oils contain many different kinds of hydrocarbon molecules. For refrigeration applications these molecules can be classified as saturates and aromatics (6). The saturates refer to all molecules where the maximum amount of hydrogen is attached to the carbon atoms including both chain and ring compounds. The aromatics are unsaturated ring compounds such as benzene together with attached side chains. Quoting from reference (6), "The saturates are noted for their excellent chemical stability, but they have poor solubility with refrigerants and are also poor boundary lubricants. The aromatics, on the other hand, are somewhat more reactive but have very good solubility with refrigerants and also have good boundary lubricating properties." In a sense, the alkyl benzene oils tend to combine the properties of both types of molecules -- good stability contributed by the alkyl side chains and good solubility and boundary lubrication by the aromatic nucleous.

A few studies of the lubricating properties of alkyl benzene have been reported. Steinle, in Germay, as reported by Sanvordenker (2), finds that alkyl benzenes have satisfactory lubricity and that they also have good resistance to coking. In 1963, Seemann and Shellard reported tests in hermetic reciprocating compressors operated continuously for three months and maintained at a temperature of 140°C in the motor windings. An alkyl benzene was used as the lubricant. At the conclusion of the test, they found score marks on the pistons and wear debris in the compressor housing. The oil was reported to have satisfactory chemical stability and no effect on insulation and compressor components. This test prompted Seemann and Shellard to recommend the addition of about 30% mineral oil by weight in order to improve the lubricity of the oil. Schwing (3) has studied the properties of an alkyl benzene oil in the laboratory. Lubricity tests were run on a "Four-ball fatigue test machine." He reports that ordinary mineral base stocks with a viscosity of about 500 SUS at 100°F would produce wear values near 0.6 mg for the lower three balls. In his test the alkyl benzene and a mineral oil with similar viscosities showed wear of about 0.1 to 0.2 mg.

As part of the evaluation of the particular fraction of alkyl benzenes described in this report, the lubricity was compared with a mineral oil of similar viscosity in laboratory screening tests. In one series of tests, the modified Falex procedure recommended by Huttenlocher (7) was followed. The principal modification is bubbling R-22 through the test oil before and during the test. A load of 400 lbs was used and lubricity was measured as a function of loss in weight of the pin. The average results of several tests are shown in Table 6. It can be seen that the lubricating property in this test is about the same for alkyl benzene as for a typical mineral oil.

Another series of tests was performed using the Shell Four-Ball test (8). The conditions of the test were 1800 rpm for one hour at 5 kg and a temperature of 70°C (158°F). On the average, the alkyl benzene showed up somewhat better than the mineral oil in this test. Average scar diameter was 0.37 mm for the alkyl benzene and 0.39 mm for the mineral oil.

In one series of tests, the coefficient of friction was determined for the two oils with the results shown in Table 7. Here again the alkyl benzene was equal to or slightly better than a comparable mineral oil.

TABLE 7. COEFFICIENT OF FRICTION

Velocity, Ft/Min	Alkyl Benzene	Mineral Oil
0	0.17	0.27
0.1	0.17	0.24
10	0.14	0.15

A great deal is known about lubricating oils from empirical and chemical studies and the contribution of various molecular species to the lubricity function seems reasonably well defined. Still the best method of demonstrating adequate lubricity is in an operating machine. This conclusion is implied in one discussion of lubrication (9), "In popular terms, the action of a lubricant in preventing failure is described as depending on its film strength or its extreme pressure properties . . . . The nature of the agents suitable for each type of service is evidently such as to interpose between the working surfaces something stable enough to survive the conditions."

The alkyl benzene oil described in this report has been used in a number of refrigeration systems in order to demonstrate its utility as a lubricant. It has been possible to observe the performance of the oil in some detail in several different units. The results of these tests are summarized in Table 8.

The refrigeration systems described in Table 8 had been in operation for various periods of time, ranging from 2 months to 8 years, using other types of oils. In general, when changing to the alkyl benzene oil, the old oil was drained out and the crankcase flushed twice with the new oil. This procedure removed most of the old oil although some remained in other parts of the system. All of the units reported in Table 8 are still operating with the original charge of alkyl benzene oil - a period of nearly 4 years in some cases. Maintenance is reported to be significantly lower than when other oils were used.

TABLE 8. USE OF ALKYL BENZENE OIL IN REFRIGERATION SYSTEMS

			Oil Analyses			
Unit	Ref.	Evap. Temp. °F	Time, Months	Viscosity, SUS at 100°F	Acid* Number	Color, Gardiner
Trane Recip. Direct Drive 20-Ton	12	28	0	149	0.01	1
			7	148	0.02	2
			14	147	0.02	3
			19	147	0.02	4
			45	148	0.01	4
American Standard Hermetic 40-Ton	22	35	0	147	0.01	1
			2	144	0.02	2
			14	139	0.02	3
			19	142	0.03	3
			45	142	0.01	3
General Electric Belt Drive 3-Ton	12	-20	0	146	0.01	1
			6	149	0.03	4
			13	151	0.05	5
			18	149	0.07	5
			44	150	0.01	6
General Electric 2-Stage Recip. 3-Ton	22	-50	0	143	0.03	4
			6	141	0.05	5
			11	148	0.06	5
			37	-	0.01	5
York, 16 cyl. 75 Hp	22	-60	0	148	0.01	2
			6	154	0.01	3.5
			11	154	0.01	4
			36	150	0.01	6
York, 16 cyl. 75 Hp	22	-60	0	147	0.01	2
			6	150	0.01	3.5
			11	149	0.01	3.5
			36	166	0.01	4
Carrier Recip** 10-Ton	502	-10	1	146	0.04	8
			26	164	0.44	-

*The most recent acid analyses seem suspiciously low and are being rechecked.

**This unit had a history of poor operation and major maintenance. No maintenance has been needed since changing to the alkyl benzene oil although the oil is now black and quite acid.

REFERENCES

1. W. P. Seemann and A. D. Shellard, "The Lubrication of Refrigerant 22 Machines", No. III - 7, XI International Congress of Refrigeration, 1963.

2. K. S. Sanvordenker, "A Review of Synthetic Oils for Refrigeration Use", ASHRAE Symposium, Nassau, June 29, 1972.

3. R. C. Schwing, "Polyisobutylbenzenes as Refrigeration Compressor Lubricants", ASHRAE Semiannual Meeting, Columbus, Ohio, February 5-8, 1968, ASHRAE Transactions Vol. 74, Part I, III .1.1.

4. H. O. Spauschus and G. C. Doderer, "Reaction of Refrigerant 12 with Petroleum Oils", ASHRAE Transactions, Vol. 67, page 237, 1961.

5. ASTM D1934

6. ASHRAE Guide and Data Book, Systems Volume, page 435, 1970.

7. D. F. Huttenlocher, "A Bench Scale Test Procedure for Hermetic Compressor Lubricants", ASHRAE meeting, Lake Placid, N.Y. June 1968.

8. ASTM D2266.

9. W. A. Gruse and D. R. Stevens, "Chemical Technology of Petroleum", Third Edition, 1960, McGraw-Hill, New York, N.Y.