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LOW TEMPERATURE CRANKCASE LUBRICANTS

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ABSTRACT

The diluent action of gasoline and a group of aliphatic diesters on a number of petroleum and synthetic oils has been investigated. It was found that these diluents are not effective pour point depressants for paraffin-base oils as they are poor solvents for wax and therefore do not greatly lower the temperature at which it precipitates. They are much more efficient pour point depressants for the synthetic polyalkylene glycol and polyethylene oils and naphthene-base petroleum oils as they are free from waxy material. The effectiveness of diluents in lowering the pour points and viscosities of these oils is inversely proportional to the viscosity and directly proportional to the concentration of the diluent.

Though not as efficient as gasoline in lowering the viscosity and pour point of these lubricants, the diesters have the advantage of permanency, in some instances they improve the V.I., and they do not increase the fire hazard. The utility of such blends for many low temperature applications is discussed.

The diester diluents are especially valuable for improving the V.I. of the polyglycol ethers such as the "Ucon" fluids. Blends with V.I.'s greater than that of either component have been prepared which are superior in this respect and in pour point to the unmodified fluid of comparable viscosity. The viscometric and low temperature properties of di(2-ethylhexyl) adipate and the homologous sebacate indicate their possibilities as automotive crankcase lubricants for extreme low temperature applications such as may be encountered during the Arctic winter. Small scale engine tests of 300 hours duration in a one cylinder Onan 10-LS air cooled engine loaded to 65 percent of its rated capacity, revealed that these low viscosity diesters are satisfactory lubricants for this engine. The oil consumption was the same as for SAE 20 petroleum oils and the engine was in much better condition. All the rings were free, there was very little lacquer or varnish, and no sludge deposited on the engine parts.

PROBLEM STATUS

This is an interim report, work is continuing on the problem of low temperature lubricants.

AUTHORIZATION

NRL Problem Nos. C02-01 and C02-06 (BuAer No. P-129).

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LOW TEMPERATURE CRANKCASE LUBRICANTS

INTRODUCTION

Statement of the Problem

Commercially available petroleum crankcase lubricants are not suitable for use at the sub-zero temperatures encountered during the Arctic winter. Ambient temperatures prevailing during the winter are much below the pour points of available lubricants, therefore cold motors cannot be turned over and started. Neither can the lubricants be removed from containers for relubrication and addition purposes at temperatures much below their pour points. This creates a supply and maintenance problem which is particularly difficult for motive vehicles in the field. Similar problems are encountered with gear and transmission lubricants at the low temperatures prevailing in the Arctic. In some instances the wheels of automotive type vehicles could not be rotated.

There is evidence that the crankcase temperature decreases with decreasing ambient temperature. Thus, less viscous lubricants may be used for vehicular lubrication under these conditions. In aeronautical applications the low temperature starting of the engines constitutes the greatest lubrication problem. It has been claimed that crankcase temperatures of aeronautical engines are nearly the same in the Arctic and in temperate regions at high altitudes. To insure effective lubrication, lubricants are required for these applications having low pour points and low viscosities at starting temperatures and adequate viscosities at operating temperatures.

Known Facts Bearing on the Problem

Much of the military equipment exposed to field tests in Alaska and Northern Canada in the winter of 1946-47 became inoperable at the temperatures encountered.¹ This was not surprising since the freezing points or pour points of these lubricants were above the ambient temperatures encountered. Other lubricants were so viscous at these temperatures that the mechanisms could not function properly. Air Force experiences with the conventional lubricants were similar during operations in the Aleutians in 1941-42 where it was necessary to keep each plane warmed up every few hours because of the difficulties of starting cold engines.

Conventionally refined petroleum crankcase lubricants have relatively high pour points, becoming solid at Arctic temperatures. The pour points of many of these oils range from zero to 20°F; while those of some of the lighter oils may be as low as -20 to -30°F. As temperatures of -65°F are sometimes encountered on the ground in the Arctic it is apparent that these lubricants will not be satisfactory. The use of polymeric materials as pour point

¹ Observers' Report, "Task Force Frigid," Ladd Field, Fairbanks, Alaska, Section I.

depressants and as a means of preventing crystal formation in high wax content oils is a common practice. Since these materials are satisfactory in lowering the pour point only to the extent of perhaps 20° - 30° F, they are not able to lower the pour point of conventional oils to the temperature necessary in the Arctic. Pour point depressants would be advantageous in that their use would permit removal of the oil from containers at lower temperatures. As these materials do not materially alter the low temperature viscosities of the lubricant to which they were added, they would not facilitate starting at low temperatures. It is reported that a cranking speed of approximately 50 rpm is necessary for effective starting of most automotive type engines.² Such a cranking speed at -65° F can be obtained with an oil having a viscosity of less than 11,000 centistokes. An SAE 20W oil has approximately this viscosity at 0° F. An SAE 10W oil, the lightest commercial grade available, would exceed these viscosity requirements at temperatures only slightly lower. Reports of a test during the winter of 1946-47, when the ambient temperature ranged from +4° F to -37° F, revealed that an SAE 10W oil solidified at the lower temperature.¹

The maximum cranking torque permissible for the R-3350-24 aircraft engine using the type "C" starter is fixed by Specification AN-S-54a at 750 pound-feet. The temperatures at which this cranking torque was attained using "Ucon" lubricant LB-550 and several blends of this lubricant has been determined by NAMC.³ Reference to the viscosity vs temperature graphs of these lubricants reveals that the temperature at which the cranking torque reached 750 pound-feet corresponded to a viscosity of approximately 20,000 centistokes.

One of the more common current practices to alleviate starting problems in aircraft and motorized equipment during Arctic operations is dilution in the field of operation. Gasoline is used in proportions up to about 30 percent by volume depending upon the weather.^{1,4,5} As gasoline is a temporary diluent it must be added to the crankcase at the conclusion of each operating period, the engine being allowed to run long enough to insure complete mixing of the gasoline and oil. Gasoline depresses the viscosity of the crankcase oil sufficiently to attain high enough cranking speeds even after standing for several hours. Although this practice helps in starting engines at Arctic temperatures, there are several disadvantages. Since the volume of diluent to be used will vary with the expected temperature at the next operating period, it is difficult to predict the amount of dilution necessary. Thus there will probably be times when insufficient diluent will be used to obtain starts. Where there has been inadequate mixing of the diluent and oil, a layer of gasoline will be on top and solid oil in the bottom of the crankcase; consequently, the viscosity of the oil will not have been sufficiently depressed and cranking speeds can not be attained. The unmixed gasoline also creates a fire hazard, especially when external heat is supplied to help start the engine.

Auxiliary heating units have been commonly used in the past and they are still being included in Army winterization kits.^{1,2} Because of the inefficiency of the ordinary lead-sulfuric acid storage battery at low temperatures, it is necessary that heat be applied to keep the temperature of the battery well above -65° F. Although the efficiency of the battery

² Report on Tests of Fuels and Lubricants for Arctic Winter Operation of Automotive Material, by Office, Chief of Ordnance, Ordnance Research and Development Division, Research and Materials Branch, Fuels and Lubricants Section, 1 August 1947.

³ NAMC Report on Project TED NAM-04186 Cold Starting Tests on an R-3350-24 Engine, using "Ucon" lubricant LB-550 as an engine oil, dated 28 May 1947.

⁴ Goodale, R. Wayne, SAE: 55, 51-53, May 1947.

⁵ Forney, A. K., Weitzen, William, Dunn, Robert G. and Bleyle, George A. SAE: 55, 30-32, March 1947.

is rather low at 0°F, it is considered that a fully charged battery will give sufficient current for starting if warmed to this temperature¹, providing the viscosity of the oil does not exceed the 11,000 centistoke requirement. The use of auxiliary batteries was common during the winter operations of 1946-47 in the Arctic.^{1,5} Another common practice has been the continuous running or idling of motors to prevent "cold soaking" while the equipment is not in use. This means a high fuel consumption in an area where transportation is difficult.

Because of the inadequacy of commercially available petroleum lubricants for low temperature applications in the Arctic, the Army adopted for use in the winter of 1947-48 an automotive crankcase oil similar to the experimental oil REO-15-47 which has been tentatively designated as "Oil, Engine, Arctic Winter."² This oil is a light and highly dewaxed naphthene base petroleum fraction of 55 SSU (8.9 centistokes) at 100°F which is prediluted at the refinery with 10 percent of a gasoline fraction. The diluent is essentially a low freezing point unleaded motor gasoline from which the first 10 percent has been removed by distillation thus giving a product less volatile than conventional gasoline. The diluted lubricant has a viscosity of 2190 to 3280 centistokes at -65°F.³

The advantages of using such an oil are: (1) its cheapness and availability in large volumes, (2) necessary cranking speeds can be attained at all times, and (3) the low pour point of the oil makes it possible to pour it from containers at temperatures as low as -65°F for lubrication and replacement purposes.² The low flash point of the oil, however, constitutes a fire hazard in the handling and storage of the lubricant, but the overall hazards would not be as great as the old practices of dilution in the field of military operations. About five percent of the diluent is lost during operation, thus the flash and pour points will be raised.

Available petroleum base oils for transmission and differential gear lubrication have also been found unsatisfactory for Arctic winter use. Frozen transmissions were not unusual during the winter of 1946-47. It has been estimated that if the viscosity of the gear lubricant greatly exceeds 22,000 centistokes² the gears can be shifted only with difficulty. A channel point of -50°F is the lowest required by existing government specifications. As the viscosity exceeds 22,000 centistokes at the channel point, it is evident that this lubricant will be unsatisfactory. A low freezing point diesel fuel has been commonly used as a diluent for differential and transmission lubricants.^{1,2} Although the vehicles were made operable by this expedient, they required closer attention due to the high leakage rate, the increase in gear wear caused by the dilution of the extreme pressure additive, and the danger of reversion in the viscosity and pour point of the lubricant due to the evaporation of the lighter components from the diluent. The Army Ground Forces will use a gear lubricant tentatively designated as "Lubricant, Gear, Arctic Winter" for their 1947-48 winter maneuvers in Alaska. This oil is similar to the experimental oil RGD-28-47 and is a polymer thickened petroleum fraction containing the normal concentration of one of the types of extreme pressure additives approved in Army Specification 2-105B.

Theoretical Considerations

On mixing two liquids, the less viscous component generally exerts the greater effect on the viscosity of the mixture. Thus it is seen that the linear law of mixing does not apply to the viscometric properties of two-component mixtures. Bingham⁶ found that the fluidity (the reciprocal of the viscosity) of the mixture was equal to the sum of the fluidities of the components, but many exceptions to this rule are known. A well known empirical blending

⁶ Bingham, Eugene C., Fluidity and plasticity, New York, McGraw-Hill Book Company, 1922.

chart for estimating the viscosities of blends of hydrocarbons and other non-associated liquids has been based on part of the ASTM Viscosity-Temperature Chart (D341-43)⁷ and is described in the appendix of this ASTM method.

Gasoline and similar petroleum fractions of low viscosity, low freezing point, and large volume availability are common diluents for petroleum lubricants. Because of the low boiling range of these fractions a large amount of the diluent is evaporated during operation thus necessitating redilution before the next operating period. Such diluents are classified as temporary. Non-hydrocarbon materials having low viscosities and freezing points such as certain low molecular weight alcohols, ketones, esters, and ethers could also be used as temporary diluents for petroleum lubricants. Many of these compounds have freezing points and viscosities not greatly different from gasoline fractions and would therefore have approximately the same dilution characteristics. They would offer only slight advantages as regards permanency and safety against fire hazards. Many of these compounds are hygroscopic and the presence of moisture in the lubricant would increase rusting and in extreme cases could cause the separation of diluent and lubricant. Furthermore, these diluents are more expensive and less available than petroleum fractions and their use would constitute an additional supply problem. The use of low freezing point and low molecular weight halocarbons such as chloroform, chloroethylenes, and certain fluorocarbons would be advantageous in reducing the fire hazards.⁸ However, because of their adverse viscosity-temperature characteristics they would not be as good low temperature diluents. In addition, the hydrolytic instability of the chlorinated aliphatics and the corrosive nature of the acids formed makes their use objectionable. The fluorocarbons are as yet available only in research quantities and their possibilities for early large volume applications are not promising.

The use of low freezing point, higher boiling liquids as diluents for lubricating oils would alleviate the necessity of redilution after operating periods and would produce a less flammable mixture. However, as the viscosity generally increases with increasing boiling points, the more viscous high boiling liquids would not be as effective diluents as their low boiling homologues. Therefore, larger quantities of the more viscous diluents would be required to produce a blend with a given viscosity. Though a hydrocarbon with the requisite low freezing point and high boiling point could probably be prepared for use as a diluent there are none available at present for such applications. Other possible non-volatile diluents are ethers, ketones, alcohols, esters, and halocarbons. The higher boiling chlorocarbons, though advantageous for reducing fire hazards, have such adverse viscosity-temperature characteristics that even mixtures have pour points so high that they would not be satisfactory in depressing the pour point and low temperature viscosity of lubricating oils to the temperatures required in Arctic winter applications.

A large number of aliphatic diesters were investigated as possible lubricants.⁹ Several of these diesters have pour or freezing points sufficiently low to be of interest as diluents for low temperature lubricants. These diesters also have high boiling and flash points, therefore they would not evaporate nor would their use constitute an increased fire hazard. It is also possible that higher boiling alcohols, ketones, and ethers with low freezing points could be obtained that are soluble in lubricating oils for use as diluents; however, they are not available in the volume required for this application.

⁷ ASTM Standards on petroleum products and lubricants 1947.

⁸ Sullivan, M. V., Wolfe, J. K. and Zisman, W. A., *Ind. Eng. Chem.* 39; 1607-1614, 1947.

⁹ Bried, E. M., Kidder, H. F., Murphy, C. M., and Zisman, W. A., *Ind. Eng. Chem.* 39; 484-491, 1947.

EXPERIMENTAL

Fluids Investigated

The lubricants investigated are listed in Table I.

TABLE I
LUBRICANTS INVESTIGATED

Identification	Viscosity (Centistokes)			KVI	Pour Point (°F)	SAE Grade
	100° F	130° F	210° F			
Petroleum Oils						
Navy Symbol 2135	68.5	30.0	6.72	29	-10	20
Grade 1065 (Spec. AN-0-8)	111	51.5	11.9	104	0	30
Navy Symbol 3065	112	50.0	11.0	90	5	30
Navy Symbol 2250	169	60.0	9.78	-17	0	40
Grade 1120 (Spec. AN-0-8)	369	142	24.9	95	15	60
Synthetic Oils "Ucon" Fluids						
LB-140-X	30.4	16.8	5.96	148	-45	10
LB-550-X	122	63	18.7	139	-30	50
Polyethylene Oils						
SS-903	218	94.4	20.1	111	-20	50
SS-906	657	253	43.0	110	-10	70

The petroleum oils were all procured under existing government specifications and are typical of those recommended for a variety of naval uses as they cover a rather wide viscosity range. They are also representative of the extremes of high and low Viscosity Index petroleum oils. The low V.I. oils (2000 series) are considered to be naphthene base and the high V.I. as paraffin base or "Pennsylvania type" oils. The synthetic "Ucon" fluids of the Carbide and Carbon Chemicals Corporation are derivatives of the polyalkylene glycols.^{10,11,12} They are prepared in a variety of viscosity grades, the LB-140-X fluid being a low viscosity crankcase oil and the LB-550-X fluid an aeronautical engine lubricant. The "X" indicates that the fluid contains an oxidation inhibitor and the numbers (140 and 550) refer to the viscosity in SSU at 100° F. The Polyethylene oils designated as SS (Schmierstoff) 903 and 906 are German synthetic oils made by polymerizing ethylene. They were obtained by the U. S. Naval Technical Mission in Europe and some of their physical and chemical properties of interest as lubricants have been described.¹³ An unleaded aviation gasoline

¹⁰ Russ, J. M., *Lubrication Engineering* 2, 151, 1946.

¹¹ Russ, J. M., *Special Technical Publication No. 77, ASTM*, 3, 1947.

¹² "Ucon" Fluids and Lubricants, Carbide and Carbon Chemicals Corporation pamphlet 1947.

¹³ Murphy, C. M., and Saunders, C. E., *Pet. Ref.* 26; 111-116, May 1947.

(Grade 73 of Spec. AN-F-48) was used as the temporary diluent in this investigation. The permanent diluents were aliphatic diesters. The viscometric properties of the diluents are shown in Tables II, III and IV.

Experimental Methods

Mixtures of the lubricants listed in Table I were prepared containing 10, 25, and 40 percent by weight of the various diesters. The weight percent concentrations are approximately the same as the volume percent concentration as the densities of lubricants and diester diluents differ only slightly. Blends of the lubricants containing 5, 10, and 25 percent by weight of gasoline (Grade 73, Spec. AN-F-48) were also prepared for investigation. The volume percent concentrations for the gasoline blends are also shown in the tables as these differ from the weight percent concentrations due to the differences in density of lubricant and gasoline.

The pour points of the blends were determined by examining the samples after storage at appropriate temperatures for 96 hours in tightly stoppered cylindrical glass bottles of the same diameter as the jars used in the ASTM Pour Point Method D97-39.⁷ The storage method was used because it gives more reliable results than the ASTM Pour Point Method D97-39. The kinematic viscosities of the blends were determined in Cannon-Fenske modified Ostwald type viscometers according to the ASTM Method D445-42T.⁷ The viscosity determinations at low temperatures were determined in the apparatus previously described.⁸

Engine Tests

The lubricants were evaluated in an Onan 10-LS gasoline engine which is a single cylinder, 4 cycle, L-head, air-cooled motor with an aluminum cylinder head. It is directly coupled to a one kilowatt AC generator which serves as the variable test load. The engine has been described in a previous NRL Report.¹⁴ The fuel used was an 80 octane leaded motor fuel. The tests were of 300 hours duration and the load was 65 percent of the rated electrical output. The condition of the engine as well as that of the oil were used as criteria to evaluate the suitability of the lubricant.

DISCUSSION OF RESULTS

Effect of Diluents on Viscosity and Pour Points

From Tables II, III and IV it is seen that the diester diluents were less effective in lowering the pour points of the high V.I. petroleum oils (1000 and 3000 series) than the low V.I. petroleum oils and the synthetic oils. Increasing the concentration of the diesters from 10 to 40 percent by weight in the 1000 and 3000 series oils caused only a slight additional lowering of the pour point. The higher viscosity diesters caused as great a lowering in the pour points of these oils as did the same concentration of the less viscous diesters. Much greater depressions of the pour points of the synthetic and low V.I. petroleum oils were obtained upon dilution with diesters. The pour point lowering upon increasing the concentration of the diester from zero to 10-25-40 percent by weight averaged about 10° F for each step on the low V.I. and synthetic oils as compared to 5° F for the high V.I. petroleum oils. Increasing the viscosity of the diluent caused little decrease in the pour point depressant action of the diesters. This observation is rather surprising but can be explained. A wax-free oil will not flow under the conditions of the pour point procedure, ASTM

¹⁴ NRL Report No. P-1857 "The Onan gasoline engine installation at the Naval Research Laboratory for oil and gasoline tests." March 1942.

Comparison of Diester and Temporar

Permanent
Blends of 10%, 25%, 40%, and

Oil Used	Property Measured	Undiluted Oil	Di(isoamyl) Sebacate†				Di(2-Ethylhexyl) Adipate				Di "B-24" Adipate†			
			10%	25%	40%	100%	10%	25%	40%	100%	10%	25%	40%	100%
Grade 1085	Viscosity (Cstks.) at 210 °y	11.9	9.51	7.10	5.42	2.28	9.63	7.23	5.80	2.38	9.82	7.51	5.93	2
	130	51.5	36.0	23.5	16.0	5.0	37.0	24.3	17.0	5.34	38.0	25.0	18.6	6
	100	111.0	74.7	44.7	28.7	7.38	77.3	47.6	31.0	8.22	79.5	50.8	34.3	9
	32	1850	821	440	220	29.6	900	500*	280	37.0	925*	600	290	47
	0	12900		1408	940	80		2981	1187	107		4089	1512	157
	-20					182				260				430
	-40					504				807				1602
V.I.		104	112	125	124	122	110	119	129	144	110	118	125	114
Pour Point (°F)		0	-5	-10	-15	<-80	-5	-10	-15	-20	-5	-10	-15	-20
% Volume														
MS 3085	Viscosity (Cstks.) at 210 °y	11.0	8.77	6.49	5.07	2.28	8.87	6.73	5.21	2.38	9.06	6.97	5.53	2
	130	50.0	34.5	22.0	15.0	5.0	36.0	23	16.0	5.34	37.0	24.3	17.4	6
	100	111.6	73.1	42.3	27.2	7.38	75.4	45.4	29.3	8.22	78.0	48.9	32.8	9
	32	1700	900	396	196	29.6	1050	445	233	37.0	1100	508	281	47
	0		8000*	1950*	825*	80	7000*	2400*	1060*	107	7500*	2900*	1300*	157
	-20					182				260				430
	-40					504				807				1602
V.I.		90	101	114	122	122	99	110	120	144	98	109	115	114
Pour Point (°F)		-5	0	-5	-10	<-80	0	-5	-10	-20	0	-5	-10	-20
% Volume														
MS 2250	Viscosity (Cstks.) at 210 °y	9.78	7.59	5.57	4.34	2.28	7.97	5.87	4.45	2.38	7.88	6.0	4.8	2
	130	60.0	36.0	21.0	13.7	5.0	38.0	22.0	14.5	5.34	40.0	24.0	16.0	6
	100	169.1	90.1	43.8	25.8	7.38	93.8	47.0	28.1	8.22	98.2	52.4	32.2	9
	32	8000	2400*	600*	240	29.6	2600*	725	385	37.0	3000*	800	380	47
	0			4750‡	1307	80	6135‡	1757	107		8510‡	2559	12,800*	157
	-20				5,200*	182	35,000*	7,500*	260					430
	-40					504			807					1602
V.I.		-17	22	59	71	122	19	49	52	144	19	48	61	114
Pour Point (°F)		0	-10	-20	-45	<-80	-10	-20	-45	-80	-10	-20	-45	-80
% Volume														
MS 2120	Viscosity (Cstks.) at 210 °y	6.72	5.62	4.52	3.76	2.28	6.70	4.60	3.84	2.38	6.81	4.80	4.10	2
	130	30.0	21.0	14.5	11.0	5.0	21.5	15.0	11.4	5.34	22.0	16.0	12.5	6
	100	68.5	45.0	27.9	19.1	7.38	46.9	29.6	20.6	8.22	48.8	32.2	23.1	9
	32	1400	760	250	140	29.6	760	330	175	37.0	800	390	210	47
	0	15,000	5740‡	1707	630‡	80	8525‡	2165	907‡	107	7335‡	2742	1116	157
	-20			7000*	1500*	182	9600*	3500*	260		13,000*	4500*		430
	-40					504			807					1602
V.I.		29	52	67	85	122	50	61	75	144	48	60	74	114
Pour Point (°F)		-10	-20	-35	-45	<-80	-20	-35	-45	-80	-20	-35	-40	-80
% Volume														
Grade 1120	Viscosity (Cstks.) at 210 °y	24.9	17.6	11.3	7.69	2.28	17.9	11.7	7.97	2.38	18.2	12.2	8.53	2
	130	142	85	44	25.5	5.0	88	47	27.5	5.34	92	51	30.0	6
	100	369	199	92.5	48.6	7.38	208	99.2	53.3	8.22	216	109	60.1	9
	32	9000*	3500*	1100*	420*	29.6	3750*	1200*	500*	37.0	4100*	1400*	600*	47
	0					80				107				157
	-20					182				260				430
	-40					504				807				1602
V.I.		98	103	115	128	122	101	113	125	144	100	109	116	114
Pour Point (°F)		-15	-15	-10	0	<-80	-15	-10	0	-80	-15	-10	0	-80
% Volume														

* Extrapolated from ASTM Temperature Charts
 ‡ Approximate Viscosity - Non-Newtonian
 † Made from Sharples Diethyl Carbinol
 ‡ Trade name of Dupont product

TABLE II

Typical Diluents for Navy Symbol Oils

Diluents at 100% by Weight of Diluent	Diluent								Temporary Diluent Blends of 5%, 10%, 25%, and 100% by Weight of Diluent				
	Di(2-Ethylhexyl) Sebacate				Ditetradecyl Sebacate				Unleaded Gasoline				
	5%	10%	25%	40%	100%	5%	10%	25%	40%	100%	5%	10%	25%
0.84	10.1	8.01	6.49	3.32	11.0	9.95	8.98	6.53	8.5	6	3.0		
0.25	39.2	28.	20.6	7.96	46.0	39.0	34.0	22.4	30	19.5	7.	0.539	
0.87	82.1	54.5	38.1	12.6	99.1	84.2	71.8	44.4	61.8	36.6	10.6	0.780	
0.7	960*	600	310	60.9	1400*	1200	800	483	635	291	46.9	0.995	
		3637	1430	187		106341	57031	2680	46001	1347	122.5	1.195	
				445				10500			300	1.480	
				1410				65000*				1.92*	
	111	120	130	154	104	109	108	107					
	-5	-10	-15	-67	-5	-10	-15	-60	-5	-10	-30		
									6.05	11.95	28.95		
0.84	9.29	7.41	6.10	3.32	10.3	9.31	8.51	6.53	8.0	5.8	2.8		
0.25	38.0	26.0	19.0	7.96	44.3	38.6	33.0	22.4	29.5	18.4	6.4	0.539	
0.87	80.3	52.4	36.4	12.6	98.6	82.9	71.0	44.4	59.3	34.1	9.60	0.780	
0.7	1100	550	298	60.9	1600	1250	920	483	682	287	45.2	0.995	
	7000*	3000*	1400*	187	13000*	9000*	6000*	2680		1400*	110.1	1.195	
				445				10,500			250*	1.480	
				1410				65,000*				1.92*	
	100	111	123	154	91	96	98	107					
	0	-5	-10	-67	0	-5	-10	-60	0	-5	-30		
									6.05	11.95	28.95		
0.84	8.09	6.38	5.29	3.32	9.09	8.31	7.68	6.53	6.3	4.4	2.35		
0.25	41.0	26	18.0	7.96	46.0	40	34.0	22.4	28.0	16	5.0	0.539	
0.87	100.9	55.7	35.7	12.6	132.8	99.9	78.7	44.4	67.4	32.8	7.47	0.780	
0.7	3100*	800	380	60.9	3300*	2500*	1600	483	1669	442	32	0.995	
		76101	2368	187			160701	2680	20,4101	3390	101.3	1.195	
			10,000*	445				10,500		20,000*	280	1.480	
				1410				65,000*			11021	1.92*	
	22	58	84	154	8	34	55	107					
	-10	-20	-45	-67	-10	-20	-25	-60	-10	-30	-65		
									6.05	11.95	28.95		
0.84	5.97	5.12	4.40	3.32	6.63	6.48	6.38	6.53	4.8	3.15	1.90		
0.25	23.5	17.5	13.7	7.96	27.5	26	24.0	22.4	17.0	9.5	4.08	0.539	
0.87	50.5	34.7	25.9	12.6	63.1	56.7	52.0	44.4	35.5	17.7	6.06	0.780	
0.7	850	550	400	60.9	1280	1000	780	483	468	160	25	0.995	
	75001	29101	13001	187	140001	89451	6172	2680	27661	988	70.5	1.195	
		14000*	3500*	445		55000*	35000*	10,500		4514	182	1.480	
				1410				65,000*		30000*	459	1.92*	
	55	73	77	154	42	60	72	107					
	-20	-35	-45	-67	-20	-30	-40	-60	-10	-25	-65		
									6.05	11.95	28.95		
0.84	18.8	13.0	9.34	3.32	21.0	16.7	13.4	6.53	16.0	11.	4.4		
0.25	95	54	33.5	7.96	114	81	60	22.4	75	42	11.3	0.539	
0.87	222	116	66.2	12.6	282	193	136.0	44.4	166.3	86.2	18.5	0.780	
0.7	4500*	1500*	640*	60.9	6000*	3500*	2100*	483	2892	959	96.8	0.995	
				187				2680			326	1.195	
				445				10,500			850*	1.480	
				1410				65,000*				1.92*	
	102	112	122	154	26	22	101	107					
	+15	+10	0	-67	+15	+10	0	-60	+5 F	0	-30		
									6.10	12.0	29.0		

Oil Used	Property Measured	Undiluted Oil	Di (isoamyl) Sebacate ‡				Di (2-Ethylhexyl) Adipate			
			10%	25%	40%	100%	10%	25%	40%	100%
"Ucon" LB-140-X	Viscosity (Cstks.) at 210°F	5.96	5.37	4.61	3.98	2.28	5.37	4.65	4.04	2.38
	130	16.8	14.7	12.2	10	5.0	14.6	12.0	10.1	5.34
	100	30.4	25.9	20.6	16.6	7.38	26.2	21.2	17.2	8.22
	32	250	190	130	88	29.6	190	140	100	37.0
	0	1240	880	550	340	80.0	900	600	400	107
	-20	4988	3216	1791	1049	182	3352	2076	1278	260
	-40	30106	17079	8084	4182	504	18450	9783	5447	807
	-60			57000*	25000*			75000*	37000*	
	V. I.	148	150	158	163	133	149	154	157	121
	Pour Point °F	-45	-65	<-65	<-65	<-80	-65	<-65	<-65	-90
% Volume										
"Ucon" LB-550-X	Viscosity (Cstks.) at 210°F	18.7	15.2	11.2	8.29	2.28	15.4	11.4	8.43	2.38
	130	63	48.0	32.3	22.2	5.0	48.5	33	23	5.34
	100	122.0	90.1	58.9	38.7	7.38	92.1	61.1	40.7	8.22
	32	1260	900	480	260	29.6	960	520	300	37.0
	0	8900	5048	2301	1106	80.0	5525	2590	1309	107
	-20	52,361	20000*	8100	3500	182	24000*	9600	4400	260
	-40			39000*	15000*	504		50000*	20000*	807
	-60									
	V. I.	139	144	150	158	133	143	149	155	121
	Pour Point °F	-30	-40	-50	-65	-80	-40	-50	-65	-90
% Volume										

‡ Made from Sharples Diethyl Carbinol

* Extrapolated from ASTM Temperature Charts

† Trade name of Dupont product

Table III

Comparison of Diester and Temporary Diluents for Two Typical Oils "Ucon" LB Series

Permanent Diluent Blends of 10%, 25%, 40%, and 100% by Weight of Diluent							
Di "B-24" Adipate †				Di (2-Ethylhexyl) Sebacate			
10%	25%	40%	100%	10%	25%	40%	100%
5.45	4.79	4.24	2.64	5.55	5.01	4.58	3.32
16	12.7	11.0	6.25	15.3	13.6	12.0	7.96
26.9	22.3	18.7	9.87	27.4	23.4	20.3	12.6
210	155	120	47.7	205	170	125	60.9
1000	700	500	157	975	750	500	187
3718	2464	1681	430	3635	2536	1591	445
20937	12552	7854	1602	19700	11134	6729	1410
	100,000*	57000*			85000*	44000*	
146	152	154	114	148	161	161	154
-65	<-65	<-65	-90	-65	<-65	<-65	-67
15.6	11.8	8.92	2.64	15.8	12.9	9.46	3.32
49.0	35	25.0	6.25	49	36	26	7.96
94.4	65.1	45.0	9.87	95.2	66.1	46.4	12.6
1000	600	350	47.7	1000	575	350	60.9
5862	3122	1677	157	5617	2997	1626	187
25000*	12500*	6000*	430	25000	12000*	5600*	445
	67000*	30000*	1602		65000*	27000*	1410
142	147	152	114	143	151	155	154
-40	-50	-65	-90	-40	-50	-65	-67

Oil Used	Property Measured	Undiluted Oil	Di (isoamyl) Sebacate ‡				Di (2-Ethylhexyl) Ad		
			10%	25%	40%	100%	10%	25%	40%
SS-903	Viscosity (Cstks.) at 210°F	20.1	15.2	10.4	7.35	2.28	15.5	10.7	7.61
	130	94.4	63.0	36.5	23.0	5.0	65.0	39.0	24.0
	100	218	134	72.5	41.8	7.38	140	77.3	45.3
	32	3480	1700	675	280	29.8	1800	760	370
	0	25000	10150	3355	1301	80.0	11225	3968	1647
	-20		41500*	12000*	4000*	182	15000*	15000*	5500*
	-40			52000*	16500*	504			24000*
	-60								
	V. L.	111	118	127	138	133	116	125	134
	Pour Point °F	-20	-40	-50	-60	<-80	-40	-50	-60
SS-906	Viscosity (Cstks.) at 210°F	43.0	29.4	17.6	11.0	2.28	29.8	18.1	11.5
	130	253	150	70	38	5.0	150	75	41
	100	657	346	150	72.0	7.38	358	162	79.6
	32	15600	5800*	1600*	600	29.8	6000*	1800	700
	0			8800*	2750*	80.0		11000*	3400*
	-20					182			
	-40					504			
	-60								
	V. L.	110	115	124	134	133	114	121	130
	Pour Point °F	-10	-25	-40	-50	<-80	-25	-40	-50

- ‡ Approximate viscosity - Non - Newtonian
 * Extrapolated from ASTM Temperature Charts
 † Made from Sharpless Diethyl Carbinol
 ‡ Trade name of Dupont product

Table IV

Ester Diluents on Polyethylene Oils

40%, and 100% by Weight of Diluents

Diluent	Di "B-24" Adipate †				Di (2-Ethylhexanoate)	
	10%	25%	40%	100%	10%	25%
2.38	15.7	11.1	8.08	2.64	16.1	11.1
5.34	66.0	41.0	27.0	6.25	68.0	44.0
8.22	144	82.7	50.4	9.87	149.0	88.0
37.0	1900	880	430	47.7	2000	900
107	12150	4707	2081	157	12400	4800
260	49000*	18000*	7000*	430	50000*	17500*
807			31000*	1602		
144	116	123	131	114	116	124
-90	-40	-50	-60	-90	-40	-50
2.38	30.5	18.9	12.2	2.64	31.2	20.0
5.34	158	81	46	6.25	160	87
8.22	373	176.0	93.4	9.87	384	186
37.0	6500*	2200	1000	47.7	6700*	2500
107		12500*	5200*	157		16500
260				430		
807				1602		
144	114	120	124	114	112	121
-90	-25	-40	-50	-90	-25	-40

Dihexyl) Sebacate			Ditetradecyl Sebacate			
	40%	100%	10%	25%	40%	100%
8	8.85	3.32	17.7	14.7	12.3	6.53
0	29.0	7.96	80.0	62.0	50.0	22.4
7	55.7	12.6	180	138.0	106	44.4
	460	60.9	2700	1800	1360	483
	2145	187	18700 †	12065 †	8285	2680
	7000*	445	80000*	50000*	35000*	10500
	30000*	1410				65000*
	133	154	112	112	113	107
	-60	-67	-35	-45	-50	-60
0	13.3	3.32	34.6	25.5	18.9	6.53
	39	7.96	190	127	75	22.4
	97.4	12.6	475	300	195.0	44.4
	950	60.9	9000*	5000*	2750*	483
	4600*	187		37000*	18000*	2680
		445				10500
		1410				65000*
	129	154	110	112	113	107
	-50	-67	-20	-35	-45	-60

Method D97-39, if the viscosity exceeds a certain value. This limiting value has been observed to be approximately 1,000,000 SSU or 220,000 centistokes. The pour point is by definition the temperature 5° F above the temperature where the oil does not flow. At temperatures approaching the pour point of an oil the viscosity may increase as much as 50,000 to 100,000 centistokes per 5° F. As the test temperatures are multiples of 5° F and these multiples will seldom correspond to the true temperature at which the oil does not pour, it is readily seen why the reproducibility of the test is $\pm 5^{\circ}$ F for the same operator using the same equipment and $\pm 10^{\circ}$ F for different operators in different laboratories. Such a lack of reproducibility is most probably the reason why no decrease in the pour point depressant action was observed for higher viscosity diesters.

Gasoline, like the diesters, caused a much greater lowering of the pour points of the low V.I. petroleum and synthetic oils than of the high V.I. petroleum oils. Also the decrease in the pour points with increasing dilution was much greater for the synthetic and low V.I. petroleum oils than for the high V.I. petroleum oils. Because of the much lower viscosity of gasoline, it was more effective in reducing the pour points than the diesters.

The greater susceptibility of the low V.I. petroleum oils and synthetic fluids to the pour point depressant action of diluents is attributed to differences in the nature and composition of the fluids. The high V.I. petroleum oils, being paraffinic, probably contain some wax. The low V.I. oils are naphthenic and contain little or no wax. The "Ucon" fluids are non-hydrocarbon materials and do not contain any waxy materials. The "Polyethylene" oils through hydrocarbons are essentially iso-olefins possibly containing some naphthene ring structures but no straight chain paraffins. The pour points of lubricants containing no wax is essentially a crude viscosity determination and is the lowest temperature at which the fluid will flow under specified conditions. The pour point of wax-containing oils is influenced not so much by the viscosity of the oil as by the temperature at which the wax precipitates, forming a lattice-like network that prevents the oil from flowing. Therefore, to depress the pour point of wax-containing oils effectively by the use of diluents, the diluent or solution of diluent and oil must have a high solubility for wax at low temperatures. If the diluent does not have this solubility for wax at low temperatures, increasing the concentration of the diluent will not markedly reduce the pour point. The viscosity of the diluent will not have a great effect on the pour point depression of wax-containing oils if the solubility characteristics for wax are equivalent. On the contrary the pour point of oils containing no waxy materials will be influenced by the viscosity and concentration of the diluents. The low solubility of wax in diesters and gasoline accounts for the poor pour point depressant action of these diluents on the high V.I., wax-containing petroleum oils.

Though a low pour point is desirable and is a necessary property of lubricants for many applications, this property alone will not insure a lubricant with the necessary low temperature characteristics. The viscosity at the pour point of wax-free oils is approximately 200,000 centistokes and this is above the maximum viscosity at which internal combustion engines can be started with conventional equipment because of the excessive drag of the lubricant. Therefore, the viscometric properties of the lubricant at various temperatures must be known to characterize properly a lubricant's suitability for low temperature applications. The results given in Tables II, III and IV show that the less viscous diluents are the most effective in lowering the viscosity of the resultant blend, whether the base oil is petroleum or synthetic. This result was predicted as it is known that the less viscous component exerts the greater effect on the viscosity of a blend of two components. Increasing the concentration of the diluent caused a progressive diminution of the viscosity of the blend as was expected.

A comparison of the predicted viscosities (ASTM Method D341-43) and the observed viscosities of blends of petroleum and synthetic oils with diisooamyl sebacate and also with

gasoline are shown in Table V. It will be seen that the predicted viscosities of the diester petroleum blends were in general greater than the observed viscosities and that the discrepancy generally increased at the lower temperatures. The predicted and observed viscosities of the diester diluted "Ucon" LB-140-X fluid and also of the "Polyethylene" SS-903 fluid showed the best agreement of any of the blends investigated. The predicted viscosities of the diluted "Ucon" LB-550-X fluid were lower than the observed viscosities at the higher temperatures and agreed very well with the observed viscosities at the lower temperatures. The differences observed between the predicted and actual viscosities of the "Ucon" diester blends from that of the hydrocarbon blends may be due to differences in association. The predicted viscosities of petroleum oil-gasoline blends are low and those of the "Ucon" fluids high. The difference between the predicted and observed viscosities is greater for the gasoline blends. The reduced accuracy of the blending chart for gasoline blends may be attributed, in part, to the greater differences in the viscosities of the components. After all, the blending equation is empirical.

The V.I. of each of the various mixtures of oils and diesters is given in Tables II, III and IV. It was impossible to determine the viscosities of the gasoline blends at 210° F because of the volatility of this component, therefore the V.I.'s could not be determined. From these Tables it is seen that the V.I.'s of the diester blends increase with the increasing diester concentration. As would be expected, the V.I. improvement is greater for the low V.I. petroleum oils but there is an appreciable increase for the high V.I. oils. The V.I. improvement is so great that it cannot be attributed to the peculiarities of the V.I. scale. Some of the synthetic "Ucon" and "Polyethylene" fluid blends with diesters have V.I.'s higher than that of either component. Also the "Ucon" LB-550-X fluid when blended with 25 percent by weight of diisoamyl sebacate has much higher V.I. and lower pour point characteristics than the unmodified "Ucon" LB-300-X fluid of similar viscosity. A comparison of the properties of the blend with the unmodified fluid is shown below:

	"Ucon" LB-550-X + 25% Diisoamyl Sebacate	"Ucon" LB-300-X
Visc. (cs) at 210° F	11.2	11.0
" " 100° F	58.9	65.0
" " 0° F	2300.	4000.
" " -20° F	8100.	18500.
" " -40° F	39000.*	---
Viscosity Index	150	142
Pour Point° F	-50	-40

*Extrapolated Value

The other diester blends of this fluid also show an improvement in viscometric and low temperature properties as compared to the unmodified "Ucon" fluids of comparable viscosities.

The better blending characteristics of the diesters with the "Ucon" fluids than with petroleum oils is evident from the comparison of the observed and predicted viscosities shown in Table V. A comparison of the diluent action of diisoamyl sebacate on Grade 1120 petroleum oil (Table II); "Ucon" LB-550-X (Table III) and Polyethylene oil SS-903 (Table IV) reveal that the diluent action of the diester is less at high temperatures on the "Ucon" than on petroleum or polyethylene oils. Thus a fluid with a flatter curve, or higher V.I., is obtained. The exceptional blending characteristics of the diesters is more pronounced on the higher viscosity "Ucons." This suggests the possibility of blending a diester with

Table V

Comparison of Observed and Predicted

Permanent Diluent (Diisoamy)									
Temp (°F)	Dilution (wt. %)	Grade 1120		Grade 1065		NS-2135		NS-225	
		Ac- tual Visc.	Pre- dicted Visc.	Ac- tual Visc.	Pre- dicted Visc.	Ac- tual Visc.	Pre- dicted Visc.	Ac- tual Visc.	
210	10	17.6	18.	9.51	9.80	5.62	6.0	7.59	
	25	11.3	11.5	7.10	7.20	4.52	5.0	5.57	
	40	7.89	7.75	5.42	5.50	3.76	4.2	4.34	
100	10	199.	215.	74.7	78.0	45.	53.	90.1	1
	25	92.5	102.	44.7	48.0	27.9	36.	43.8	
	40	48.6	53.	28.7	31.0	19.1	25.	25.8	
32	10	3500	4000	821	1000	700	850	2400	37
	25	1100	1400	440	490	250	430	600	13
	40	420	530	220	255	140	235	240	5
0	10					5740	7500		
	25			2408	2700	1707	3000		
	40			940	1200	630	1250		
-20	10								
	25								
	40								
-40	10								
	25								
	40								
Temporary Diluent (Gas)									
100	5	168.3	160.	61.8	60.	35.5	40.	67.4	
	10	86.2	77.	36.6	34.	17.7	24.5	32.8	
	25	18.5	15.0	10.6	9.2	6.08	7.6	7.47	
32	5	2693	2800	635	650	468	500	1669	23
	10	959	900	291	280	160	220	442	8
	25	98.8	75.	46.8	39.0	25	34	32	
0	5			4600	4000	3766	4200		
	10			1347	1400	988	1400		
	25			122.5	120	70.5	120		
-20	5								
	10								
	25								
-40	5								
	10								
	25								

* Extrapolated from ASTM Temperature Charts

Viscosities (CSTKS)

1 Sebacute)

Pre-dicted Visc.	Ac-tual Visc.	Pre-dicted Visc.	Ac-tual Visc.	Pre-dicted Visc.	Ac-tual Visc.	Pre-dicted Visc.	Ac-tual Visc.
8.25	5.37	15.2	14.2	5.35	5.35	15.0	15.2
6.40	4.61	11.2	9.7	4.60	4.60	10.2	10.4
5.10	3.98	8.29	6.8	3.95	3.95	7.10	7.35
10.	25.9	90.1	85.	25.8	25.8	140.	134.
64.	20.6	58.9	52.	20.5	20.5	75.	72.5
38.	16.6	38.7	32.5	16.4	16.4	46.	41.8
00	140	900.	800	130	130	1900	1700
00	73	480	420	72	72	775	675
00	20	260	230	19	19	350	280
	800	5048	5000	900	900	12000	10150
	550	2301	2200	575	575	4200	3355
	340	1106	1000	375	375	1600	1301
	3216	20000*	25000	3400	3400		
	1791	8100	9000	1975	1975		
	1049	3500	3600	1150	1150		
	17079	18500		18500	18500		
	8084	8500		8500	8500		
	4182	5000		5000	5000		
85.0	20.9	74.6	62.0	20.1	20.1	95.0	74.6
46.	14.7	47.6	36.	13.8	13.8	46.	47.6
11.	6.28	15.6	9.5	5.5	5.5	11.	15.6
00	190	200	530	200	200	00	530
00	130	140	230	140	140	00	230
70	88	100	36	100	100	70	36
	589	540	3000	540	540		3000
	258	260	1100	260	260		1100
	47.3	45.0	100	45.0	45.0		100
	2000	1900	13000	1900	1900		13000
	750	750	4000	750	750		4000
	100	95	240	95	95		240
	8935	9500		9500	9500		
	3227	3300		3300	3300		
	256	270		270	270		

one of the more viscous "Ucon" fluids such as LB-650 or LB-1200 to produce an aeronautical engine oil with even more desirable viscosity-temperature characteristics and pour points. Such blends, if satisfactory lubricants, could be used over a much wider temperature range than currently available lubricants.

The Army Ground Forces used an experimental oil designated as "Oil, Engine, Arctic Winter" for the winter maneuvers (1947-1948) in Alaska. This oil is prediluted at the refinery with 10 percent of a gasoline fraction and has a viscosity of 2200 to 3300 centistokes at -65°F . Several of the diesters used as permanent diluents have viscometric and low temperature properties not too greatly different from the Army engine lubricant. One of the "Ucon" fluids DLB-50-BX is also in this range. The viscometric and low temperature properties of these oils are shown in Table VI. The diisoamyl sebacate closely approximates the viscometric requirements of the Army oil at low temperatures and is more viscous at the higher temperatures. In addition, its use as an engine lubricant would not cause a fire hazard as its flash point is 380°F . Neither would there be danger of an increase in the low temperature viscosity or pour point due to evaporation of the diluent. The other two diesters, di(2-ethylhexyl) adipate and sebacate, and the "Ucon" fluid have higher viscosities at -65°F , 5000 to 8000 centistokes. The higher viscosities at the low temperatures would be acceptable if more efficient batteries or starting methods were available. It is most probable that dilution will occur in service at subzero temperatures and this would lower the viscosities. It is estimated that approximately 5 percent of gasoline dilution would lower the viscosity of the "Ucon" DLB-50-BX and the di(2-ethylhexyl) sebacate to 3300 centistokes, the upper range allowed for the Arctic Winter Oil, and approximately 2.5 percent dilution would be required to reduce the viscosity of di(2-ethylhexyl) adipate to this figure.

TABLE VI

COMPARISON OF PROPERTIES OF EXPERIMENTAL OILS WITH ARMY LUBRICANT "OIL, ENGINE, ARCTIC WINTER"

Property Measured	Oil, Engine, Arctic Winter	"Ucon" DLB-50-BX	Diisoamyl Sebacate	Di(2-Ethylhexyl) Adipate	Di(2-Ethylhexyl) Sebacate
Viscosity (Centistokes)					
210 $^{\circ}\text{F}$	1.75*	2.51	2.28	2.38	3.32
100 $^{\circ}\text{F}$	5.5	8.58	7.38	8.22	12.6
32 $^{\circ}\text{F}$	22.	38.	29.6	37.	60.9
0 $^{\circ}\text{F}$	65.	110	80.	107.	187.
-20 $^{\circ}\text{F}$	150.	280.	182.	260.	445.
-40 $^{\circ}\text{F}$	450.	906.	504	807.	1410.
-65 $^{\circ}\text{F}$	2500.	7500.*	2800.	5000.	8000.*
V. I.	92*	132	133	121	154
Pour Point ($^{\circ}\text{F}$)	≤ -70	-80	≤ -80	≤ -80	-67

*Extrapolated and hence approximate.

Engine Test Results

To obtain some idea as to the suitability of the various experimental oils as crankcase engine lubricants, tests of 300 hours duration were made in the Onan 10-LS engine as described under "Experimental." The oils tested were the "Ucon" LB-140-X and DLB-50-BX fluids and the diesters, diisoamyl sebacate and di(2-ethylhexyl) adipate and sebacate. The diesters were inhibited against oxidation with 0.35 percent phenothiazine. These tests revealed that the oil consumption of the low viscosity diesters was the same as that of non-additive petroleum oils; one quart per 100 hours of operation.¹⁵ The diester oil remaining after these 300-hour tests was in much better condition than the non-additive petroleum oils. The di(2-ethylhexyl) adipate and sebacate had a neutralization number increase of 0.5 or less and their precipitation number was 0.1. There was only a slight drop in the viscosity of these oils after the test and as the odor of gasoline was evident, the viscosity change observed is attributed to dilution. The diisoamyl sebacate had a neutralization number increase of 1.5 after the test indicating that it is less stable than the other two diesters. It also showed a slight viscosity decrease which is attributed to fuel dilution. The "Ucon" fluids had neutralization number increases of 1.0 and 0.65 respectively for the LB-140-X and DLB-50-BX. Their precipitation numbers were also 0.1. The LB-140-X, like the diesters, decreased slightly in viscosity after the test. The DLB-50-BX showed a slight increase in viscosity. The odor of gasoline was also evident and the dilution may have masked the viscosity changes observed. In general the diesters and "Ucon" fluids showed less changes attributable to oxidation than non-additive petroleum oils and compare favorably with the detergent type oils of Navy Symbol 9000 Series oil.

The engine was in excellent condition after the tests using diesters as lubricants. The rings were clean and free and there were no lacquer deposits in the engine. By contrast, when a naphthene base oil, Navy Symbol 2135, was used, there were lacquer deposits on the pistons and valves, the rings were stuck and the oil sump was dirty. When 100 V.I. paraffin base SAE 20 oil was used, the piston seized after 102 and 150 hours of operation respectively, for duplicate runs. The rings were stuck and valve stems covered with lacquer. When the "Ucon" LB-140-X was used as the lubricant, the oil ring was stuck and there was some lacquer on the piston skirt. When the "Ucon" DLB-50-BX was used as the lubricant, the rings were free and there was no lacquer on piston skirt or valve stems but the connecting rod bearing was tight due to the formation of lacquer. The engine condition after using the diesters as lubricants compares favorably with that observed when a detergent oil of Navy Symbol 9000 Series was used. When the "Ucon" fluids were used as lubricants the engine condition was not quite as good but it was in much better condition than when non-additive petroleum oils were used as lubricants.

CONCLUSIONS AND RECOMMENDATIONS

The pour point depressant action of gasoline and a number of aliphatic diesters on petroleum and synthetic lubricating oils show that these diluents are less effective for paraffin base, or Pennsylvania type oils, than for the naphthene base or the synthetic oils. The lack of effectiveness of the diluents in reducing the pour points of the paraffin base oils is attributed to the presence of wax. As these diluents are not good solvents for wax, a lattice-like wax structure forms at approximately the same temperature regardless of whether the diluent is present, thus preventing the oil from flowing. The slight pour point

¹⁵ Fitzsimmons, V.G., Millitz, R. O., "Small scale gasoline engine tests using the Carbide and Carbon Chemical Corporation's new synthetic lubricant 250-B-0-100," NRL Report No. P-2320, June 1944.

lowering observed is due to the diminution in the wax content of the resultant blend, thus neither the viscosity of the diluent nor its concentration markedly affects the pour point. On the contrary, the pour point lowering of petroleum and synthetic oil blends containing no waxy material is an inverse function of the viscosity of the diluent and is proportional to its concentration.

Similarly, the less viscous diluents are more effective in reducing the viscosities of blends of these oils. Increasing the concentration of the diluent causes a progressive decrease in viscosity of the blend. The diesters, though less efficient as diluents than gasoline, offer advantages for many low temperature applications. These high boiling compounds are permanent diluents; i.e., redilution after each operating period will not be required and their use would not constitute a fire hazard as their flash points are high; above 300° F. Also, they improve the viscosity-temperature characteristics of the blend over that of the base oil as evidenced by the increase in V.I. The blending characteristics of the diesters with the synthetic "Ucon" fluids are exceptional. Blends of "Ucon" fluids and diesters were prepared having V.I.'s higher than that of either component. The resultant blends had superior V.I.'s and pour point characteristics than the unmodified fluid of similar viscosity.

Diester blends of the higher viscosity "Ucons" are suggested as possible aeronautical crankcase lubricants having a much wider temperature of operation than conventional oils. Diester blends of petroleum and synthetic oils may also prove useful as base oils for the incorporation of additives in preparing transmission and gear lubricants for Arctic operation.

The viscometric properties of diisooamyl sebacate and di(2-ethylhexyl) adipate and sebacate and the "Ucon" DLB-50-BX compare favorably with those of the Army Arctic Winter Oil. Small scale engine tests revealed that these oils gave adequate lubrication as the engine wear was not excessive. The engine was in better condition when these oils were used as lubricants than when non-additive petroleum oils were used. The engine cleanliness after the use of these synthetic lubricants compared favorably with Navy Symbol 9000 Series detergent oils. The oil consumption, using these light lubricants, was no higher than with an SAE 20 petroleum oil. These small scale engine tests indicate that light oils such as the diesters di(2-ethylhexyl) adipate and sebacate and "Ucon" DLB-50-BX may be used as crankcase lubricants at subzero temperatures.

It is recommended that these oils be given full scale tests in heavy duty equipment to determine their suitability for low temperature applications as they offer the advantages of permanency as regards viscosity and pour points and their use would not create additional fire hazards which are inherent with the use of gasoline diluted lubricants.

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