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A LABORATORY EVALUATION OF LOW-TEMPERATURE LUBRICANTS FOR AUTOMOTIVE AND DIESEL EQUIPMENT

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NAVAL RESEARCH LABORATORY
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ABSTRACT

Satisfactory operation of automotive and diesel equipment during the Arctic winter cannot be attained without suitable lubricants. In addition to the usual requirements of lubricity, oxidation stability, and detergency, crankcase oils are required with pour points below -65°F having viscosities sufficiently low (maximum 4500 cs) to allow easy starting at temperatures down to -65°F yet capable of maintaining an adequate lubricating film (minimum 4.75 cs at 210°F) at operating temperatures.

Of the six crankcase oils tested at the Arctic Test Station, no single oil satisfied the viscometric requirements at both high and low temperatures. Bis(2-ethylhexyl) adipate, though sufficiently fluid at -65°F, was too light to prevent excessive wear in heavy-duty engines at operating temperatures. The REO-15-47 oil and Keystone 20W containing 40 percent Velo A upon the loss of the volatile diluent tended to revert to the high viscosities and pour points of the base oil and were unsuited for such applications. REO-72-49 and Ucon LB-140X give adequate lubrication at operating temperatures but require starting aids at temperatures of approximately -35°F and -25°F respectively. The pour point of the Ucon LB-140X makes it unsuitable for use where temperatures below -45°F are encountered. The RPM 5W oil will allow starts down to approximately -30°F but excessive wear is reported at operating temperatures.

No oils are available having the viscometric properties desired in a crankcase oil, therefore a compromise is required. A suitable compromise oil should have a maximum pour point of -65°F and be viscous enough at operating temperatures to prevent excessive wear. Its viscosity at subzero temperatures should be as low as possible consistent with the viscosity requirement at operating temperatures. The REO-27--49 or MIL-0-10295(Ord) oils are such a compromise. Oils with lower viscosities at subzero temperatures can be obtained if a large proportion of synthetic oils are used in their formulation.

Arctic gear oils must have maximum pour and channel points of -65°F, and be able to support the loads developed by the gears. Additives used in their formulation should not separate in use or in storage. Seven gear oils were tested at the Arctic Test Station. Ensign 561 and Navy Symbol 9500 have too high pour points to be considered for this application, and the Ucon LB-140X and LB-400X oils fail to support the loads developed by the gears. Keystone 78-6 and Ucon LB-140X-60 are useful to approximately -40° to -50°F but the former showed indications of additives separation at low temperatures. The RGO-28-47 or MIL-L-10324 (Ord) gear oils performed satisfactorily in all equipment over temperatures of +30°F to -50°F. This oil should be satisfactory down to -65°F since it is fluid at this temperature.

PROBLEM STATUS

This is a final report; the problem has been closed.

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A LABORATORY EVALUATION OF LOW-TEMPERATURE LUBRICANTS FOR AUTOMOTIVE AND DIESEL EQUIPMENT

INTRODUCTION

Conventional lubricants are not suitable for use in vehicles and engines at the temperatures encountered during the Arctic winter because of their high pour points and excessive viscosities. Since it is unlikely that military supplies can be housed in heated buildings, it is necessary that the pour point of the lubricants be as low or preferably lower than the lowest temperature likely to be encountered, generally accepted as -65°F. Unless the oil has a pour point as low as the ambient temperature it cannot be transferred from its container to the equipment in need of lubrication.

Another property desired in Arctic winter crankcase oils is that their viscosity be sufficiently low so that adequate cranking speeds for starting may be attained. Since battery efficiency decreases with decreasing temperature and ignition difficulties increase because of decreased fuel volatility and flammability, the limiting viscosity of the crankcase oil also decreases (1). However, a value of 4,500 centistokes (cs) or 20,000 Saybolt Universal Seconds (S.U.S.) is a reasonable approximation of the limiting viscosity of an automotive crankcase oil at temperatures of 0°F and below. Though less information is available for diesel engines, it is believed that the limiting crankcase oil viscosity is of the same magnitude as that for automotive engines. At temperatures below -25°F the efficiency of lead-sulfuric acid batteries decrease so rapidly that they are incapable of turning the engine at sufficient speeds to obtain starts, regardless of crankcase oil viscosity, unless the battery is warmed to temperatures above -25°F.

Two methods of obtaining low-viscosity oils are apparent. Diluents, such as gasoline, kerosene, or diesel fuel, may be used to lower the viscosity of conventional motor oils. Lower molecular weight and less viscous compounds or petroleum fractions may be used as lubricants. The lower the viscosity of the diluent, the more effective it is in lowering the viscosity of the oil (2). Pour points of motor oils containing appreciable quantities of wax are not effectively lowered by the diluents unless the wax is soluble in the diluent. As the volatility of a diluent increases with decreasing viscosity, the diluent most effective in reducing the viscosity of the oil is the least permanent and will require constant replacement. Consumption will therefore be high. The use of low-viscosity diluents such as gasoline also increases the fire hazard in vehicles.

A satisfactory Arctic winter crankcase oil must also provide adequate lubrication at operating as well as at starting temperatures. Under "short haul" and idling conditions in very cold weather, crankcase temperatures are much below normal and cases of the lubricant congealing in the crankcase have been reported. Therefore, the viscosity of the lubricant must not be so great that it cannot be pumped to the moving parts of the engine. During long hauls and on warmer days the crankcase temperatures are essentially normal and the oil must have the lubricating ability of SAE grade 20 or 30 oils. If an oil of too low a viscosity at normal crankcase temperatures (ca 175^{0} F) is used, it will be impossible to attain normal oil pressures, and insufficient lubricant will be supplied to the moving parts. There is also the possibility that a very low viscosity oil will not have the "body" to support the loads developed in the engine. Another possible difficulty with oils of low viscosity and low molecular weight is that they may be volatilized on hot surfaces such as cylinder walls and that insufficient oil will remain for adequate lubrication.

In addition to the special properties required of an Arctic winter crankcase oil, it should also have the properties required of conventional oils. These include resistance to oxidation and to the formation of lacquer and other insoluble deposits. The oil should have the ability to prevent the accumulation of such products, commonly known as detergency. It should not be corrosive to bearing materials and should be able to protect ferrous metal parts from the rusting action of water. Neither should the oil foam badly or form stable foams.

Conventional grade transmission and differential gear oils are also unsatisfactory for Arctic winter use. Frozen transmissions and the inability to shift gears are common complaints when conventional grade lubricants are used. In an effort to prevent the congealing or freezing of the lubricant low freezing point diesel fuels have been used as diluents for gear oils. Though this expedient made the vehicles operable, the increased maintenance caused by higher leakage rates and increased wear made a better solution desirable.

Besides having adequately low pour and channel points (below -65^{0}F), the viscosity of the gear lubricant should not exceed 22,000 cs at -65^{0}F if excessive drag and difficulties in shifting gears are to be avoided. The gear oil should be able to support the loads developed by the gears and should not foam excessively. The additives used must be stable at the temperatures encountered and should not settle out of solution. The oil should not be corrosive to the materials it contacts and it is desirable that it prevent the rusting action of water on ferrous metal parts.

In an effort to find the most desirable lubricants for Arctic winter operation, a cooperative test program was inaugurated. The operational characteristics of a variety of experimental lubricants would be determined in Bureau of Yards and Docks equipment by the Arctic Test Station, Point Barrow, Alaska. Samples of oil after varying periods of use in the equipment were to be forwarded to the Naval Research Laboratory for analysis to determine the changes that had taken place during use. From the physical and chemical properties of the oils and the changes in these properties during service use, information as to their suitability for such operations and their approximate service life could be obtained. This information in conjunction with the information on operational characteristics was to be used as a guide in selecting the lubricants most suitable for Arctic winter use.

DISCUSSION OF RESULTS

The results of the analyses of the various experimental oils are given in Tables 1 to 11 inclusive. To facilitate discussion, the data are tabulated into groups according to the application and the oil used. These groups are further subdivided as to the vehicle or equipment in which the oil was used. Properties of the new unused oil are also shown so that the changes that took place during service may be more readily discernible. As a greater number of samples and analyses are available for study than were available in the previous reports (7) (8), it is possible to weigh the results and to draw more definite conclusions. The conclusions presented here may not therefore be the same as those based on a smaller number of observations in the previous reports.

Crankcase Oils

Properties of the crankcase oils are shown in Tables 1 to 4. Those of the synthetic polypropylene oxide derivative "Ucon LB-140X" are given in Table 1. This oil falls between SAE grades 5W and 10W at 0°F and is a SAE grade 20 at 210°F. It was used in the crankcases of jeeps, weasels, LVT(3)'s and a D-6 Tractor. Ambient temperatures ranged from +24° to -47°F with -12°F being considered as the average ambient test temperature. The pour points of the used oils varied within ±10°F of that of the new oil (-45°F) with but four exceptions. It is obvious from their viscometric properties that the two oils with pour points below -75°F (sample taken 9/29/48 from Jeep No. 1 and sample taken 12/18/48 from Weasel No. 2) were mislabeled or contaminated with a very light oil. The two oils with pour points of -65°F may be attributed to fuel dilution.

There was little change in the viscosities of the used oils as compared with those of the new oil at temperatures of 210° and 100°F. At -40°F, the viscosities of the used oils are approximately 50 percent greater than that of the new oil. Increases in the low temperature viscosities of the used oils are attributed in part to the solution of fuel and oil oxidation and polymerization products. Such changes in viscosities of used oils at subzero temperatures are considered about normal. No appreciable differences were noted in the viscosity characteristics of the oils used in different type engines. Evidence of the oxidation stability and extent of oxidative deterioration of oils may be obtained from the changes in their neutralization numbers. In general, the used Ucon LB-140X oils had neutralization number increases of 0.7 and this was attained after considerable service use. Such an increase is not unusual, and this oil is believed to have adequate stability.

Precipitation numbers are evidence of the presence of oil insoluble materials. Such products may be formed by oil or fuel oxidation or may be extraneous material such as road dust. In general, precipitation numbers increased with the length of oil use. However, the addition of "make-up" oil mashed this trend because of the diluent action of the new oil. Insufficient information is available to determine whether the increases in neutralization numbers were due primarily to oil oxidation or to the presence of extraneous materials.

The Ucon LB-140X oil appears to be in very good condition after use as a crankcase oil in the various engines, showing no evidences of excessive oxidation or other forms of deterioration. The Arctic Test Station reports (3) that wear

TABLE 1

Properties of Used Crankcase Oils Upon LB-140X

Vehicle	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil Qts.	Neutralization No.	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40 (a)	Pour Point, °F
Jeep No. 1	- - -	New Oil		- - - -	0.03	Nil	5.7	30.4	250	1,240	6,500	30,100	-45
	9/29/48	131	220	1	0.37	0.07	2.1	8.5	40	130	426	1,150	<-75
	10/21/48	278	- -	2 (b)	0.17	0.15	4.8	30.6	310	1,900	12,000	65,000	-45
	11/3/48	55	43	- -	0.61	0.10	4.9	31.0	300	1,700	10,900	50,000	-45
	12/8/48	155	155	- -	0.71	0.28	4.9	33.5	360	2,200	17,300	65,000	-50
	1/25/49	- -	590	3	0.62	0.66	5.4	35.8	360	1,970	11,540	63,000	-55
	3/17/49	- -	861	5 1/2	0.77	0.14	5.7	36.8	360	2,000	12,800	55,000	-50
	4/15/49	- -	1,115	6 1/2	1.13	0.35	5.6	37.3	360	2,200	14,400	52,000	-55
	6/14/49	403	241	- -	0.56	0.38	5.6	36.0	420	1,800	11,000	50,000	-60
Weasel	8/47	- -	1,035	- -	0.54	0.20	5.8	36.5	360	2,300	17,000	70,000	-45
	10/18/47	- -	2,073	- -	0.67	0.69	5.5	32.3	300	1,700	16,900	- - -	-40
	12/28/47	- -	370	- -	0.43	0.62	5.7	26.3	210	1,050	5,700	23,000	-55
	1/3/48	278	476	- -	1.76	1.03	5.6	29.6	300	1,900	12,000	65,000	-45
	4/5/48	430	1,150	18	0.52	0.45	6.2	32.8	280	1,500	9,000	- - -	-40
	5/15/48	261	615	11	0.51	0.50	6.1	34.3	320	1,300	11,00	- - -	-40
	6/15/48	177	396	12	0.36	0.20	6.1	32.6	260	1,600	9,000	40,000	-45
Weasel No. 2	12/11/48	104	117	1	0.16	0.07	4.6	28.3	260	1,400	8,040	35,000	-60
	12/18/48	35	47	- -	1.42	0.40	2.0	8.8	48	190	825	2,600	<-75
	5/27/49	101	193	6	0.78	0.25	5.4	35.6	360	2,100	13,800	60,000	-50
	6/11/49	128	157	1	0.31	0.25	4.7	29.0	250	1,180	7,720	28,000	-50
D-6 Cat. Tractor	12/29/47	217	- -	- -	0.51	0.15	5.4	32.6	330	2,000	17,000	65.000	-50
	2/9/48	137	- -	- -	0.31	0.08	5.6	29.5	250	1,400	9,000	35,000	-50
LVT(3) No. 1 Port Crankcase	10/5/48	40	- -	- -	0.44	0.17	6.0	35.3	270	6,300	crystals	- - -	-40
	10/15/48	110	- -	- -	0.54	0.21	4.2	24.5	225	1,160	6,500	25,000	-50
	2/7/49	24	- -	- -	0.34	0.10	4.9	28.9	270	1,400	7,720	35,000	-55
	3/16/49	24	- -	- -	0.25	0.15	5.3	33.4	325	1,800	10,800	50,000	-45
Starboard Crankcase	10/5/48	40	- -	- -	0.37	0.07	6.0	35.1	270	6,190	crystals	- - -	-40
	2/7/48	24	- -	- -	0.45	0.06	5.3	33.2	320	1,500	10,700	50,000	-50
	3/16/49	24	- -	- -	0.29	0.13	5.3	32.3	300	1,500	9,190	43,000	-55
LVT(3) No. 2 Port Crankcase	6/3/49	43	285	6 1/2	0.48	0.55	5.5	35.0	338	1,810	11,300	50,000	-45
Starboard Crankcase	6/3/49	42	285	6 1/2	0.61	0.15	5.3	33.1	310	1,600	9,100	40,000	-50

(a) Extrapolated value

(b) Oil changed and 2 qt. 20 W oil added and consumption with this oil were considered normal. Because of its high pour point and high viscosity at -40^{0}F (30,000 to 50,000 cs) this oil is not suitable for Arctic winter operations. It was somewhat more difficult to obtain engine starts when this oil was used than with lower viscosity oils. At -48^{0}F one and one-half (1-1/2) hours of heat application, using a 250,000-Btu Herman-Nelson heater, were required before it was possible to crank a jeep lubricated with this oil.

Properties of the used bis(2-ethylhexyl) adipate oils used as a crankcase lubricant for jeeps, weasels, LVT(3)'s and a D-8 tractor are given in Table 2. This synthetic diester oil was obtained from two sources, that from Dupont being identified as PSP-14 and that from Ohio Apex Company as Adipol 2EH. Properties of the oils from different sources are essentially identical. This oil has a viscosity of 110 cs at 0^{0}F and its viscosity at 210^{0}F of 2.4 cs is below the minimum viscosity of 3.88 cs (39 S.U.S.) for SAE 5W oils. It was selected for tests in order to obtain information as to the lubricating ability of low-viscosity oils under Arctic winter operating conditions and also for information as to the limiting viscosity for engine starting. Because of the relatively high boiling point of this diester as compared with petroleum oils of similar viscosity, the results would not be confused by high oil consumption or wear due to the evaporation of the oil from hot cylinder walls. Ambient temperatures ranged from +30^{0} to -50^{0}F during tests.

It is evident that the first used-oil sample from Jeep No. 2, taken on 9/29/48, is mislabeled or contaminated. Subsequent samples tend to approach the properties of bis(2-ethylhexyl) adipate because of the addition of "make up" oil. The sample taken 1/15/49 has properties almost identical with those of the new oil except for neutralization number. Samples taken from Weasel (Test No. 2) have viscometric properties similar to those of the new oil. There is some evidence of dilution in the samples taken 5/20 and 5/31/48 since their viscosities are lower than those of the unused oil. Some of the samples from the other weasels show evidence of even greater fuel dilution. A number of samples had rather high neutralization numbers. That taken from Weasel No. 1 on 5/16/49 after 455 hours and 731 miles of operation had a neutralization number of 3.09, and its precipitation number, 0.8 was also high. Several of the samples from the LVT (3) were also contaminated with other oils as evidenced by their viscosities.

In general, the laboratory evaluation of the used bis(2-ethylhexyl) adipate oils showed that the oils from the different vehicles and engines were in approximately the same condition. The neutralization numbers of some samples reached rather high values, a possible consequence of contamination with other oils. The samples from the heavy-duty diesel engine had lower neutralization numbers than did many of the samples after comparable service in automotive engines. With the exception of the neutralization number increases, this oil showed no other evidence of deterioration in service.

The Arctic Test Station reported (3) that oil consumption was normal and that this appeared to be a good crankcase lubricant for automotive engines. Though no lubrication failures were reported crankshaft wear occurred during idling periods when oil pressure was low. This seems to be a reasonable explanation, as it is known that oil pressures decrease with decreasing viscosity and this is a very low viscosity oil. Wear on the heavy duty diesel engines was high. Automotive equipment lubricated with bis(2-ethylhexyl) adipate cranked easily down to -48^{0}F (3,4). No starting aids or coolant heaters were necessary for starting at -30^{0}F

TABLE 2

Properties of Used Crankcase Oils
Bis(2-ethylhexyl) adipate

Vehicle	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil Qts.	Neut. No.	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40	-65	Pour Point, °F
		New Oil		- -	0.04	Nil	2.4	8.3	37	110	350	850	6,000 (a)	<-80
Jeep No. 2 (c)	9/29/48	121	52	- -	0.66	0.12	4.8	29.6	290	1,600	10,000	40,000	- - - -	-60
(c)	10/26/48	307	200	1 1/2	1.35	0.10	2.2	10.3	80	410	2,600	10,000	- - - -	-60
(c)	12/6/48	556	465	2 1/2	1.93	0.15	2.3	10.1	70	320	1,710	6,000	50,000	<-75
(c)	1/15/49	- -	14	- -	1.28	0.17	2.4	8.6	40	125	414	1,000	6,700	<-75
Weasel (Test No. 2) (c)	5/20/48	112	965	6 1/2	0.70	0.10	2.3	7.6	32	94	280	710	5,000	<-75
(c)	5/31/48	151	1,261	8	0.88	0.10	2.3	7.6	32	91	265	685	5,000	<-75
(c)	6/5/48	218	1,587	- -	0.97	0.12	2.3	8.1	35	106	320	819	6,000	<-75
Weasel No. 1 (c)	9/21/48	115	588	4	0.79	0.01	2.4	8.8	42	135	454	1,150	8,000	-70
(c)	10/6/48	218	711	5	1.31	0.02	2.4	8.8	42	140	431	1,050	- - - -	-60
(c)	10/19/48	306	1,005	6 (b)	1.37	0.07	2.4	8.4	36	110	323	750	4,000	<-75
(c)	11/20/48	170	144	3	1.13	0.07	2.0	7.2	34	110	343	850	5,500	<-75
(c)	2/4/49	- -	264	12	2.25	0.30	2.2	8.0	36	115	383	900	6,000	<-75
(c)	3/12/49	579	- -	4	2.53	0.31	2.4	8.0	33	94	275	600	3,300	<-75
(c)	4/7/49	773	- -	7	1.71	0.27	2.1	7.0	28	80	237	520	3,000	<-75
(c)	5/16/49	455	731	7	3.09	0.80	2.0	6.6	26	73	214	470	2,700	<-75
Weasel No. 2 (c)	9/27/48	125	339	2	0.75	0.10	3.5	20.2	185	1,100	7,000	28,000	- - - -	-65
(c)	10/9/48	206	475	5	0.86	0.02	2.4	9.5	39	120	393	920	6,200	-65
(c)	11/2/48	329	823	7	1.20	0.10	2.0	6.9	28	80	236	550	3,100	<-75
(c)	11/22/48	466	1,078	7 1/2	1.30	0.08	2.3	8.5	40	128	438	1,100	8,000	<-75
Weasel No. 4 (d)	12/22/50	59	134	10 (e)	1.02	0.09	2.2	7.4	31	90	270	640	3,750	<-75
LVT(3) No. 2 Port Crankcase (c)	11/9/48	116	- -	(b)	0.66	0.12	2.7	10.4	62	190	696	1,800	13,000	<-75
(c)	12/5/48	89	- -	1 1/2	1.35	0.10	2.3	8.3	38	115	373	900	6,000	<-75
(c)	2/4/49	144	- -	2 1/2	1.93	0.15	3.0	12.9	75	280	1,100	3,000	26,000	<-75
(c)	3/28/49	12[illegible]	- -	- -	1.28	0.17	2.8	10.7	60	185	666	1,800	14,000	<-75
Starboard Crankcase (c)	11/9/48	12[illegible]	- -	(b)	1.39	0.10	2.7	11.4	75	305	1,400	4,000	42,000	-50
(c)	12/5/48	94	- -	- -	1.18	0.16	2.2	7.7	33	100	311	750	[illegible],700	<-75
(c)	2/4/49	160	- -	1			sample	bottle	broken	in	transit			
(c)	3/29/49	107	- -	3	0.90	0.39	3.0	13.4	85	340	1,500	4,300	48,000	<-75
D-8 Tractor (d)	12/2/50	151	- -	- -	0.73	0.07	2.4	8.9	39	130	418	1,000	6,500	<-75
(d)	1/5/51	251	- -	- -	0.58	0.10	2.5	9.0	40	133	425	1,100	7,000	<-75
(d)	1/25/51	390	- -	- -			sample	bottle	broken	in	transit			

(a) Extrapolated value
(b) Oil Changed
(c) Oil designated as PSP-L4
(d) Oil designated as Adipol 2EH
(e) Consumption miles/quart

if the vehicles were in good condition. Ether capsules were used to start the diesel engines. At -30^{0}F, bis(2-ethylhexyl) adipate has a viscosity of 400 cs which is so much below the limiting crankcase oil viscosity of 4,500 cs that very little battery power would be required to overcome the viscous drag of the lubricant. This oil is regarded as a border line automotive crankcase lubricant because its low viscosity makes it impossible to maintain adequate oil pressure with conventional engines. If the oil pressure could be maintained it is possible that this oil would be satisfactory for automotive engines.

Properties of the Keystone 20W (60 percent) - Velo A (40 percent) oils are shown in Table 3. This is a 20W oil containing 40 percent of a gum and sludge solvent identified as Velo A. The resulting mixture is a SAE 10W grade oil. At subzero temperatures it is non-Newtonian liquid and the viscosity values shown are therefore approximate. Pour points of the used oil samples are variable, most of them being higher than the original mixture. The viscosities of the used oils are also greater than those of the original mixture. These phenomena are a manifestation of the vaporization of the less viscous Velo A component. Samples taken on 12/10/48, 2/4/49 and 3/28/49 from the D-6 tractor show a progressive decrease in viscosities at -40^{0}F. It seems probable that a low viscosity "make up" oil is being added as these oils have lower viscosities than the original oil. Low neutralization and precipitation numbers indicate little oil oxidation or deterioration but this is mashed to a certain extent by the large volume of "make up" oil added. The Arctic Test Station reported that consumption rates were high due to the evaporation of the light component (3). The variabilities in the properties of the used oils caused by changes in composition with evaporation of the Velo A and the high pour points make this mixture unsuited for Arctic winter use.

Army experimental oil REO-15-47 was also used as a crankcase lubricant. This oil is a dewaxed naphthene base petroleum fraction of 8.9 cs (55 S.U.S.) viscosity at 100^{0}F prediluted with 10 percent of a gasoline fraction. Its properties and those of the used oils are shown in Table 4. This oil has a lower viscosity than does bis(2-ethylhexyl) adipate and is therefore lighter than a SAE 5W oil. Samples received for analysis were all from a jeep. The greatest changes taking place in this oil with service were increased in viscosities and pour points due to the evaporation of the gasoline diluent. Neutralization numbers tended to approach a value of 1.0. The Arctic Test Station reported that consumption rates were excessive (3). Though the wear rates were not excessive in the jeep, concern as to the lubricating ability of this oil in heavy duty engines was expressed. Because of the high oil consumption, extra maintenance, variability in oil properties, and added flammability hazards, this oil is not considered suitable for Arctic winter use.

A new experimental oil was developed by the Army to replace the REO-15-47. This new oil identified as REO-72-49 is a petroleum oil composition containing a viscosity index improver and MIL-0-2104 type additives. It has been superseded by a similar oil covered by specification MIL-0-10295(ORD). The properties of the new REO-72-49 oil shown in Table 4 are those of a MIL-0-10295(ORD) oil as no sample of the former was received for analysis. REO-72-49 oils were used in the crankcases of a jeep, weasel and D-6 Tractor. The properties of the used oils are shown in Table 4.

Viscosities of the samples of oil taken from the jeep and that of the sample taken from the tractor in 1/20/51 are lower than those of the new oil at 100^{0}F

TABLE 3

Properties of Used Crankcase Oils
Keystone 20W (60 per cent)-Velo A (40 per cent)

Vehicle	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil-Qts	Neutralization Number	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40(a)	Pour Point, °F
		New Oil			0.02	Nil	5.7	33.8	290	1,400	14,000 a	- -	-35
Jeep No. 2	6/14/49	200	103	2	0.90	4.10	6.2	43.3	459	3,000	- -	- -	-10
D-6 Cat. Tractor	4/22/48	236	- -	6	0.19	0.05	6.6	43.2	630	- -	- -	- -	-10
	5/31/48	222	- -	9	0.23	0.04	5.9	36.4	440	- -	- -	- -	-15
	7/22/48	152	- -	5	0.42	0.05	7.5	53.4	577	-	- -	- -	+5
	12/10/48	305	- -	10	0.57	0.03	3.4	26.8	260	1,760	14,000	80,000	-45
	2/4/49	261	- -	15	0.60	0.04	4.3	26.1	240	1,330	5,800	30,000	-50
	3/28/49	118	- -	1/2	0.93	0.07	4.9	22.6	190	1,030	5,700	22,000	-55
	5/27/49	385	- -	28	0.62	0.07	6.8	48.7	545	3,200	- -	- -	-10
	6/4/49	56	- -	- -	0.61	0.06	6.5	58.0	799	- -	- -	- -	+5
D-8 Tractor	2/4/49	59	- -	4	0.68	0.04	6.2	42.7	445	- -	- -	- -	+5
	5/31/49	224	- -	13	0.90	0.06	6.5	48.0	516	- -	- -	- -	+5

(a) Extrapolated value

TABLE 4

Properties of Used Crankcase Oils

Vehicle	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil Qts.	Neut. No.	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40	-55(a)	Pour Point °F
						REO - 15-47 Oil								
		New Oil (b)				0.0	2.0 (a)	[illegible]	28	80	230	528	3,140	<-75
Jeep	1/10/48	113	1,500	- -	0.69	0.03	2.9	13.3	100	460	2,300	8,000	- - -	-65
	1/27/48	140	1,487	9 1/2	0.73	0.03	2.9	13.2	97	390	1,800	6,000	80,000	<-65
	3/3/48	520	1,900	20	1.02	0.08	3.2	15.5	110	500	2,350	8,500	- - -	-60
	4/26/48	510	523	17	1.03	0.13	3.5	13.0	145	800	3,750	13,500	- - -	-50
	6/2/48	222	263	7	0.93	0.05	2.7	11.9	83	360	1,650	5,700	70,000	<-65
	6/7/48	240	- -	8	0.79	0.06	2.8	12.9	85	350	1,620	5,300	65,000	<-65
						REO - 72-49 Oil								
		New Oil (MIL-L-10295)			- -	Nil	5.75 min.	50.	200 (a)	700 (a)	2,900(a)	8,500 max.	60,000 (a)	-65 max.
Jeep No.1	12/20/50	36 1/2	136	112 (c)	0.37	trace	4.0	18.5	110	405	1,626	4,400	38,000	<-65
	1/15/51	48	111	50 (c)	2.00	0.25	4.2	19.1	107	362	1,337	3,300	24,000	<-65
Weasel No. 5	1/3/51	128	381	47 (c)	0.51	0.15	7.3	43.2	315	1,224	5,300	17,000	- - -	-50
D-6 Cat. Tractor	11/30/50	120	- -	- -	0.48	trace	7.1	42.3	330	1,460	6,700	21,000	- - -	-55
	1/2/51	95	215	- -			sample bottle broken in transit							
	1/20/51	77	288	- -	0.22	0.35	4.5	26.5	255	1,220	6,700	26,000	- - -	-45
						RPM 9W Oil								
		New Oil				Nil	4.7	22.9	159	650	2,800	10,000(a)	- - -	-65
Jeep No. 2	1/9/51	88	256	23.3(c)	0.48	0.02	4.9	23.2	173	900	4,790	17,000(a)	- - -	-65
Weasel No. 1 (f)	1/19/51	129	283	10.8(c)	2.2	0.05	4.2	20.2	132	550	2,465	7,500(a)	- - -	-65
Weasel No. 3 (f)	1/10/51	75	300	14 (c)	1.9	trace	4.8	25.0	162	650	2,714	9,650(a)	- - -	-65
HD - 19	1/5/52	60	- -	- -	0.88	0.02	4.2	21.1	148	620	2,567	9,000(a)	- - -	-65

(a) Extrapolated value

(b) Viscometric properties as given in "Report on Test of Fuels and Lubricants for Arctic Winter Operation of Automotive Material" 1 August 1945, Office, Chief of Ordnance

(c) Consumption miles/qt.

(f) Report high oil consumption and high wear rates and 210^0 F. Samples from the jeep also have viscosities lower than that of the new oil at subzero temperatures. In contrast, the sample from the weasel and that from the tractor on 11/30/50 are considerably more viscous than the new oil over the entire temperature range. Dilution is not the cause of the low viscosities as the amount of dilution in both series of samples was low and of the same magnitude. Properties of the oils differ so greatly that contamination or mislabeling was suspected until the Arctic Test Station report was received commenting on the variabilities in the properties of different batches of new oils. With the exception of the sample taken from the jeep on 1/15/51 which has a high neutralization number (2.0), there is no evidence of excessive oxidation or deterioration of these oils. It was reported (4) that this oil had good lubricating properties. Engines could be started fairly easily at ambient temperatures as low as -35^0F without the use of coolant heaters or starting aids. Because of the variabilities in the properties of the new oil and the limited experience with this oil further testing is recommended with the oil in a variety of equipment.

The RPM 5W oil is a blend of approximately half and half of a synthetic polypropylene oxide derivative and petroleum oil (6). Properties of the new RPM 5W oil Table 4, are those given by Miller and Galindo (6) as no sample of the new oil was available. This oil is well below the maximum viscosity for a 5W oil, having a viscosity of 650 cs. at 0^0F as compared to the 870 cs maximum for 5W oils. Its viscosity of 4.7 cs at 210^0F is well above the minimum of 3.9 cs for 5W oils but is less than the minimum of 5.75 cs for MIL-0-10295 oils. It is presumed (6) that a detergent and probably other additives were incorporated in the oil.

Analysis of the used RPM 5W oils revealed that the oils from the weasels and HD-19 tractor had viscometric properties quite similar to the unused oil. The sample from the jeep was more viscous at low temperatures. All of the samples had pour points of -65^0 F. Neutralization numbers of the samples from the weasels were rather high, approximately 2.0 while those from the jeep and HD-19 tractor were much lower, less than 0.9. The small number of samples examined and variations in their properties makes it difficult to draw conclusions as to stability. The Arctic Test Station reported (4) that this oil tended to become very viscous at temperatures below -20^0F. Viscosity determinations reveal that these oils have approximately the same viscosity at -40^0F as do the MIL-0-10295(ORD) oils. In fact, they are intermediate in viscosity at this temperature to the extremes of the REO-72-49 oils. It was also reported that at operating temperatures (140^0 to 180^0 F) the oil lost body and the engine lost power. No lubrication failures have been reported.

Gear Oils

Properties of the gear oils are shown in Tables 5 to 11 inclusive. Table 5 lists the properties of the synthetic Ucon LB-400X oil used in the differential, transmissions, final drives, and transfer cases of jeeps, weasels, D-6 tractor and the Little Giant Tractor saw. The used oils changed little in properties from those of the new oil, only the sample from the differential of the tractor saw had a high neutralization number. Though the oils change little in physical or chemical properties with service several of the samples contained metal particles. Analysis of the metals present in the sample taken 2/3/49 from differential of the jeep revealed the presence of large amounts of copper, lead, and tin in addition to iron and nickel. It is evident that besides the abrasion of the steel gears the copper alloy bushings or bearings were badly worn. The same metallic

TABLE 5

Properties of Used Gear Oils
Ucon LB-400X

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make-up Oil-Qts.	Neutralization No.	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25(a)	-40	Pour Point, °F
			New Oil			Nil	Nil	14.1	95.6	900	5,668	40,000	- - -	-35
Jeep	Differential	- - -	- -	432	- - -	0.74	0.10	4.0	23.4	200	1,100	5,700	27,000 (a)	-45
	Front Differential	1/27/48	- -	269	- - -	0.15	0.04	14.7	74.7	775	4,369	38,000	- - -	-35
	Front Differential	2/3/48	- -	341	- - -	0.14	0.04	13.0	75.6	800	4,580	39,000	- - -	-35
	Rear Differential	1/27/48	- -	269	- - -	0.11	0.04	14.0	74.8	800	4,506	39,000	- - -	-35
	Rear Differential	2/3/48	- -	341	- - -	0.10	0.04	11.5	60.2	900	5,384	40,000	- - -	-35
	Transmission	2/3/48	- -	74	- - -	0.06	0.04	14.1	86.4	950	6,055	42,000	- - -	-30
	Transfer Case	1/27/48	- -	269	- - -	0.11	0.04	13.0	78.0	800	5,081	39,000	- - -	-40
	Transfer Case	2/3/48	- -	341	- - -	0.11	trace	14.1	86.1	950	5,833	42,000	- - -	-35
	Transfer Case	- - - -	- -	432	- - -	0.83	0.12	7.4	47.0	700	6,811	50,000	- - -	-45
Weasel	Differential (Test #1)	12/23/47	- -	370	- - -	0.4[illegible]	[illegible]	15.6	97.5	1,200	7,772	70,000	- - -	-35
	Differential	1/22/48	- -	3,023	- - -	0.12	0.50	14.0	88.0	950	6,168	65,000	- - -	-35
	Differential	1/31/48	- -	64	- - -	0.13	0.05	14.6	89.4	1,000	6,021	45,000	- - -	-45
	Transmission	6/22/47	- -	560 (b)	- - -	0.14	0.21	14.0	88.6	1,100	6,804	52,000	- - -	-50
	Transmission	12/28/47	- -	370	- - -	0.09	0.08	14.1	86.0	980	6,077	48,000	- - -	-50
	Transmission	- - - -	- -	419	- - -	0.17	0.08	12.7	78.2	900	5,941	43,000	- - -	-35
	Transmission	1/10/48	- -	15	- - -	0.14	0.04	13.7	85.8	980	6,070	48,000	- - -	-35
D-6 Cat. Tractor	Transmission and Differential	2/9/48	354	- -	- - -	0.15	trace	13.8	83.2	875	5,666	40,000	- - -	-35
	Final Drive	12/[illegible]/47	217	- -	- - -	0.23	0.02	12.1	81.7	975	6,446	50,000	- - -	-35
	Left Final Drive	2/9/48	354	- -	- - -	0.21	0.04	13.2	80.2	900	6,262	55,000	- - -	-35
	Right Final Drive	2/9/48	354	- -	- - -	0.21	0.04	13.7	84.3	1,000	7,210	60,000	- - -	-30
Little Giant Tractor Saw	Transmission	2/16/48	65	- -	- - -	2.09	0.25	4.81	31.2	380	2,581	25,000	- - -	-30

(a) Extrapolated value

(b) Second Draining

constituents were found in the sample from the differential and transmission of a weasel. The presence of these metals, in such large amounts, confirms the report of the Arctic Test Station that abnormally high wear rates were observed in the differentials and transmissions of equipment lubricated with the oil. Evidently the Ucon LB-400X does not have sufficient "load carrying capacity" to support the heavy loads developed by the gears and it is not recommended as a gear lubricant.

Properties of the Ucon LB-140X a lower viscosity grade oil than the 400X are shown in Table 7. There is evidence of the admixture of other oils in the sample from LVT(3) No. 2 taken on 2/4/49 as it consisted of two liquid phases. The higher viscosity Ucon oils are not completely miscible with petroleum oils. Though there is some variability in the properties of the used oils, possibly due to contamination with other oils, the used Ucon LB-140X oils were not badly oxidized while in service. There was visual evidence of metal particles in several samples of the used oils and this was confirmed by the report (3) of excessive wear in vehicles using the oil as the gear lubricant. High wear rates would be expected as the 140X grade has the same composition, though it is less viscous, than the Ucon LB-400X oil. It is not recommended as a gear lubricant.

The Ucon LB-140X-60 oil differs from the Ucon LB-140X in that the former contains an extreme pressure additive. This oil falls in the SAE 75 grade as a transmission oil, see Table 6. It was used in the differentials and transmissions of a jeep and weasels and in the transmission and final drive of a D-6 tractor. Samples taken during the winter of 1949-50 have somewhat lower viscosities than those in the winter of 1950-51. This is believed due to difference in production batches rather than to changes caus d by service use.

No appreciable changes in physical or chemical properties occured during service and the oils appeared to be in good condition. There was no evidence of unusal wear in the samples submitted for analysis. The Arctic Test Station reported (3) excessive wear of jeep and weasel transmissions lubricated with this oil and later (4) reported satisfactory operation in jeeps, weasels, and tractors. It is suspected that the high wear rates first reported were due to the use of the Ucon LB-140X which does not contain an extreme-pressure agent. Though this oil gave satisfactory performance at the lowest temperature encountered, -50°F, difficulties in shifting gears and excessive drag would become more apparent at lower temperatures. Because of its high pour point (-50°F) and viscosity, this oil is not suitable for use at temperatures down to -65°F.

Properties of the Ensign 561 gear lubricant are shown in Table 7. This oil does not conform to the new SAE requirements for transmission oils. It is less viscous than a grade 90 oil but it cannot qualify as a grade 80 oil as its pour point is above 0°F. Though no major changes in the properties of the oil due to service use were observed its high pour point, above 0° F, makes it unsuitable for Arctic winter use.

Navy Symbol 9500 oil is a heavy-duty crankcase oil, SAE grade 50. As a transmission oil it would be classified as SAE grade 90. The properties of the new oil shown in Table 7 are those of a typical oil conforming to the specification and are not necessarily those of the new oil used in these tests. There is a drop in the viscosity of the oil with service use. Oils from the final drive had lower viscosities than did those of comparable service in the transmission. However,

TABLE 6

Properties of Used Gear Oils
Ucon LB 140X-50

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make-up Oil-Qts.	Neutralization No.	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40(a)	Pour Point, °F
		New Oil					Nil	5.9	33.2	295	1,779	12,820	68,000	-50
Jeep No. 2	Front Differential	6/14/49	200	127	- -	0.40	0.05	5.0	32.7	340	2,000	12,800	50,000	-55
	Rear Differential	6/14/49	200	127	- -	0.83	0.05	5.0	32.4	310	1,800	11,900	40,000	-55
	Transmission	6/14/49	200	127	- -	0.40	0.13	5.0	32.4	340	2,000	13,100	50,000	-50
Weasel No. 2	Differential	5/27/49	231	777	2	0.47	0.08	5.0	32.2	310	1,800	11,800	40,000	-50
	"	6/14/49	343	976	2	0.65	0.07	5.1	33.5	340	2,000	12,400	47,000	-50
Weasel No. 4	"	2/2/51	46	299	299 (b)	0.59	0.07	5.6	29.9	265	1,550	11,000	55,000	-45
Weasel No. 2	Transmission	4/26/49	128	631	- -	0.58	[illegible]	5.0	32.1	310	1,800	11,900	40,000	-55
	"	5/27/49	101	193	- -	[illegible]	[illegible]	5.0	33.1	340	2,000	13,200	50,000	-55
	"	6/14/49	209	344	1/2	0.22	0.05	5.1	33.5	340	2,000	13,000	50,000	-50
Weasel No. 2 (V-8)	"	4/26/49	- -	653	- -	0.50	0.10	5.1	33.9	340	2,000	13,000	50,000	-50
Weasel No. 4	"	12/11/50	54	130	0 (b)	0.36	0.02	5.6	30.0	275	1,600	12,000	60,000	-45
D-6 Cat Tractor	Transmission	11/13/50	64	- -	- -	oil separated into two phases								
	"	11/29/50	100	- -	- -	oil separated into two phases								
	"	12/18/50	47	- -	- -	0.54	trace	5.7	32.7	285	1,700	13,000	65,000	-45
	"	1/2/51	94	- -	- -	0.40	trace	5.7	32.5	285	1,700	13,000	65,000	-45
	"	1/18/51	158	- -	- -	0.46	trace	5.7	32.7	300	1,700	13,000	65,000	-50
	"	1/25/51	212	- -	- -	0.59	trace	5.7	33.0	310	1,750	13,500	68,000	-45
	"	2/12/51	258	- -	- -	0.55	trace	5.8	33.5	300	1,700	12,500	62,000	-50
	Final Drive	11/13/50	64	- -	0 (b)	0.42	trace	5.7	32.2	285	1,650	12,000	55,000	-50
	"	11/29/50	100	- -	0 (b)	0.51	trace	5.7	31.8	290	1,650	12,500	64,000	-45
	"	12/18/50	162	- -	0 (b)	0.43	trace	5.8	33.1	290	1,600	11,500	53,000	-45
	"	1/2/51	214	- -	- -	0.45	trace	5.7	31.0	295	1,700	13,000	67,000	-50
	"	1/18/51	277	- -	- -	0.36	trace	5.7	32.2	300	1,750	12,500	64,000	-45
	"	1/25/51	331	- -	- -	0.40	trace	5.7	32.5	300	1,700	12,500	63,000	-45
	"	2/12/51	377	- -	- -	0.39	trace	5.8	32.9	300	1,750	12,500	63,000	-50

(a) Extrapolated value

(b) Consumption miles/quart

TABLE 7

Properties of Used Gear Oils

Vehicle	Application	Date Sample Taken	Operation		Make-up Oil-Qts.	Neutralization No.	Precipitation Number	Viscosity, centistokes at °F						Pour Point, °F
			Hours	Miles				210	100	32	0	-25	-40	
						Ucon LB-140X								
			New Oil			0.03	Nil	5.7	30.4	250	1,240	6,500	30,100 a	-45
D-6 Cat. Tractor	Transmission	7/20/48	507	- -	- -	0.56	0.06	3.8	21.5	195	1,050	6,690	25,000 a	-50
	Final Drive	7/20/48	507	---	- -	0.27	0.05	3.7	22.1	240	1,400	9,790	45,000 a	-50
LVT(3) No. 1	Port Transmission	10/3/48	40	- -	- -	0.69	0.07	5.3	33.1	340	2,000	13,900	50,000 a	-50
	Starboard Transmission	10/3/48	40	- -	- -	0.88	0.08	4.6	27.6	240	1,400	7,460	28,000 a	-60
	" "	11/1/48	124	- -	- -	0.93	0.13	5.4	33.9	340	2,000	12,700	50,000 a	-55
	" "	2/4/49	57	- -	- -	0.41	0.23	4.7	29.2	260	1,400	8,400	30,000 a	-60
	" "	3/3/49	206	- -	4	0.57	0.50	4.9	30.3	280	1,500	8,910	31,000 a	-55
LVT(3) No. 2	Port Transmission	2/4/49	74	- -	3	0.92	0.43	4.1	30.4	420	3,780	- -	- -	-30
	Starboard Transmission	2/4/49	67	- -	3	0.40	0.08	Oil separated into two phases						
						Ensign 561								
			New Oil			0.35	Nil	11.8	112.6	2,100	- -	- -	- -	>0
Weasel No. 1	Transmission	9/21/48	115	588	1/2	1.58	0.03	9.5	105.8	2,240	20,000 a	- -	- -	-15
	"	10/6/48	- -	711	1 1/4	1.11	0.03	9.1	113.1	2,520	30,000 a	- -	- -	-15
	"	10/19/48	- -	1,005	1 1/2	1.30	0.03	9.4	102.2	1,980	18,000 a	- -	- -	-15
	"	11/20/48	589	1,064	1 1/2	1.00	0.03	9.1	90.3	1,690	13,000 a	- -	- -	-15
	"	12/27/48	776	1,273	1 1/2	1.34	0.03	9.1	113.8	2,590	30,000 a	- -	- -	-15
	"	2/12/49	- -	264	- -	1.55	0.05	9.7	109.9	2,470	26,000 a	- -	- -	-15
	"	3/12/49	- -	945	1	1.49	0.04	9.0	111.7	2,990	37,000 a	- -	- -	-15
	"	4/7/49	- -	1,338	1	1.40	0.04	9.0	112.0	2,660	30,000 a	- -	- -	-15
	"	5/16/49	265	429	- -	1.13	0.03	9.0	117.2	3,130	40,000 a	- -	- -	-15
						Navy Symbol 9500								
			New Oil (b)			0.3(max)	Nil	18.5	235.0	5,000	- -	- -	- -	+15(max)
T-9 Tractor	Transmission	1/23/51	55	- -	- -	0.31	trace	16.7	182.2	3,500	28,000 a	- -	- -	-15
	"	2/10/51	104	- -	- -	0.40	Nil	17.0	203.1	3,700	30,000 a	- -	- -	-15
	Final Drive	1/23/51	55	- -	- -	0.37	0.05	14.9	144.6	2,100	14,000 a	- -	- -	-15
	"	2/10/51	104	- -	- -	0.22	0.05	13.6	150.8	2,500	25,000 a	- -	- -	-15

(a) Extrapolated value
(b) Approximate properties of Navy Symbol 9500 oil

the relatively high pour point, -15°F, of used oils, and the specification requirement of +15°F maximum pour point would eliminate this oil from consideration as an Arctic gear oil.

Properties of the RGO-28-47 gear oils are shown in Tables 8 and 9. This oil is now covered by specification MIL-L-10324(ORD). They are less viscous than the lightest oil covered by the SAE transmission classification, grade 75. Table 8 lists the properties of the oils used in differentials, transmissions, and transfer cases of jeeps. Table 9 gives the properties of oils used in the differentials, transmissions, and final drives of weasels and a D-8 tractor. Because of the non-Newtonian nature of these oils at low temperatures, the viscosities shown at subzero temperatures are approximate.

Properties of the used oils from the jeep are extremely variable. A number of samples have much higher viscosities and pour points than the new oil. It is possible that some increase in pour point and viscosity could be attributed to oil deterioration during use but the changes are so great that contamination with more viscous oils is suspected in a majority of instances. Additional evidence of contamination is that the changes in properties are not regular, i.e. there is no orderly increase or decrease in viscosity or pour point with use. For example, the samples from the differential of Jeep No. 1 after zero, 142, 231, 394, 590, and 881 miles of operation have the following viscosities in centistokes at 100°F: 12.3, 13.8, 17.6, 16.2, 13.8, and 15.0. At -40°F, their viscosities are: 2,400, 5,000, 10,000, 13,000, 6,000 and 6,500. Their pour points show a similar variability. Oils taken from the transmission of this jeep after comparable mileages show changes similar to those for the differential oils. Other used oil samples have properties closely approximating those of the new oil, as exemplified by samples from: front differential of Jeep No. 2 on 1/9/51, rear differential of Jeep No. 2 on 1/2/51, transmission of jeep (new) on 3/3/48, and transmission of Jeep No. 1 on 9/29/48. All of these samples had low precipitation numbers but there is some variability in their neutralization numbers. It is possible that difference in the neutralization numbers of different procurement batches of oil may be responsible for part of the variability observed.

Other samples of oil show very great changes in properties after comparable service, e.g. the sample taken from the front differential of the jeep on 6/7/48 after 165 miles of operation had a viscosity of 30.9 cs at 100°F and 15,000 cs at 0°F. Its pour point was -30°F. Six out of the 37 samples of used RGO-28-47 oils had pour points above -40°F. It is suspected that the used oil samples with physical properties greatly different from those of the new oil were caused by contamination or admixture with other oils. All of the used oils had low precipitation numbers and the neutralization numbers were relatively constant at about 0.8 to 0.9, evidence that the oil was reasonably stable and that the additive content had not changed appreciably.

Samples of RGO-28-47 from the weasels and D-8 tractor, Table 9, are not as variable in properties as those from the jeep, Table 8. The exceptions are samples taken in the winter of 1951 from the final drives of the D-8 tractor. These samples have viscosities of 21.6 to 43.2 cs at 100°F as compared to 12.5 cs for the new oil. Evidently they contain varying proportions of a more viscous oil. In general, the used oil samples from these vehicles do not differ greatly in viscosities and pour points from those of the original unused oil irrespective of their use, i.e. differential, transmission or, final-drive gear oils. None of the

TABLE 8

Properties of Used Gear Oils
RGO-2a-47

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil-Qts.	Neutralization Number	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40	-65(a)	Pour Point, °F
			New Oil (b)			1.5 max.	Nil	3.0	12.3	65	230	800	2,400	20,800	<-65
Jeep No. 1	Differential	9/29/48	131	142	- -	0.97	0.05	3.0	13.8	88	360	1,640	5,000	55,000	<-75
	Differential	10/21/48	- -	231	- -	0.79	0.07	3.5	17.6	130	600	3,000	10,000	- -	-60
	Differential	12/5/48	- -	394	- -	0.83	0.09	3.3	17.2	135	680	3,840	13,000	- -	-60
	Differential	1/5/49	- -	590	- -	0.82	0.09	3.0	13.8	90	380	1,920	6,000	75,000	<-75
	Differential	3/17/49	- -	881	- -	1.09	0.06	3.2	15.0	102	435	2,060	6,500	70,000	-75
Jeep No. 2	Differential	9/29/48	121	52	- -	0.48	0.06	4.1	22.2	177	820	4,300	15,000	- -	-45
Jeep	Front Differential	5/15/48	- -	1,028	None	0.68	0.04	3.4	25.2	360	3,000	- -	- -	- -	-35
	• •	6/7/48	- -	165	None	0.83	0.04	3.2	30.9	800	15,000	- -	- -	- -	-30
Jeep No. 1	• •	3/17/49	- -	881	- -	0.80	0.25	2.9	12.3	80	320	1,600	5,000	60,000	-70
	• •	4/13/49	- -	1,115	- -	0.94	0.08	2.8	13.0	87	375	1,800	5,900	65,000	-75
	• •	6/14/49	403	241	- -	0.75	0.07	4.2	19.6	114	418	1,500	- -	- -	-40
Jeep No. 2	• •	1/9/51	38	256	- -	0.43	0.02	2.5	10.9	62	220	906	2,800	23,000	<-65
Jeep	Rear Differential	5/15/48	- -	1,028	None	0.73	0.04	3.2	21.7	300	2,400	80,000	- -	- -	-35
	• •	6/7/48	- -	165	None	0.82	0.05	3.2	25.5	460	5,000	- -	- -	- -	-35
Jeep No. 1	• •	4/13/49	390	351	1/4	0.83	0.06	3.4	16.8	120	550	2,700	8,500	- -	-60
	• •	6/14/49	- -	1,115	- -	0.91	0.07	2.8	12.5	80	330	1,580	4,800	60,000	<-75
	• •	- -	403	241	- -	0.97	0.05	3.6	17.3	110	440	1,920	5,500	- -	-50
Jeep No. 2	• •	1/2/51	33	232	- -	0.42	trace	2.7	11.1	65	235	984	2,700	23,500	<-65
Jeep	Transmission (New)	3/3/48	- -	370	- -	1.55	0.10	2.8	11.5	63	225	830	2,300	22,000	<-75
	Transmission	6/7/48	- -	301	1	0.92	0.04	3.1	15.6	120	570	3,000	11,000	- -	-60
Jeep No. 1	•	9/29/48	131	142	- -	0.86	0.07	2.8	12.2	74	287	1,215	3,700	32,000	<-75
	•	10/21/48	- -	231	- -	0.84	0.07	3.7	18.6	130	550	2,620	8,000	- -	-60
	•	11/2/48	390	351	1/2	1.06	0.05	3.4	16.9	120	550	2,610	8,500	90,000	-70
	•	12/8/48	- -	394	- -	1.07	0.09	3.4	17.1	125	560	2,790	8,800	- -	-65
	•	1/15/49	- -	590	- -	0.96	0.14	3.1	[illegible]	100	415	2,190	6,600	70,000	-70
	•	3/17/49	- -	881	- -	0.91	0.20	3.4	16.8	110	460	2,070	6,200	55,000	-70
	•	4/13/49	- -	1,115	- -	1.06	0.16	2.9	13.0	86	360	1,700	5,500	60,000	-70
	•	6/14/49	403	241	- -	0.93	0.11	3.2	14.2	85	325	1,370	4,800	35,000	<-75
Jeep No. 2	•	9/29/48	121	52	- -	0.93	0.07	[illegible]	22.2	165	720	3,090	11,000	- -	-65
	•	1/9/51	38	256	- -	[illegible]	trace	2.5	11.8	90	430	2,453	9,000	- -	-55
Jeep No. 1	Transfer Case	5/15/48	- -	1,028	None	0.98	0.09	3.3	19.7	215	1,400	11,000	- -	- -	-35
	• •	6/7/48	- -	165	None	0.77	0.06	3.4	15.3	92	395	1,600	5,000	- -	-45
	• •	9/29/48	131	142	- -	0.75	0.05	3.7	22.5	230	1,400	11,200	- -	- -	-30
	• •	11/2/48	390	351	1/4	0.77	0.05	3.9	21.1	165	790	4,140	- -	- -	-45
	• •	4/13/49	- -	1,115	- -	0.97	0.09	3.0	13.9	93	395	1,870	5,900	70,000	-75
Jeep No. 2	• •	9/29/48	121	52	- -	1.09	0.04	3.8	19.4	147	650	3,160	10,000	- -	-65

(a) Extrapolated value

(b) Typical viscometric properties as given in "Report on Test of Fuels and Lubricants for Arctic Winter Operation of Automotive Material" - August, 1947, Office, Chief of Ordnance

TABLE 9

Properties of Used Gear Oils
RSO-28-47

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make Up Oil-qts.	Neutralization Number	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40	-65(a)	Pour Point, °F
		New Oil (b)				1.5 max.	Nil	3.0	12.3	65	230	800	2,400	20,800	<-65
Weasel	Differential	5/25/48	281	615	1 1/2	0.96	0.05	3.0	12.9	71	260	1,000	2,800	26,000	<-65
	"	6/15/48	- -	397	1	0.82	0.09	2.9	[illegible]	[illegible]	250	900	2,600	24,000	-80
Weasel No. 1	"	3/12/49	- -	997	- -	(c)	(c)	3.8	22.7	230	1,370	9,000	- -	- -	-45
	"	[illegible]	[illegible]	296	296(d)	0.36	trace	2.7	10.8	[illegible]	[illegible]	967	2,600	40,000	<-65
Weasel No. 3	"	1/30/51	65	583	583(d)	0.42	0.15	2.5	[illegible]	[illegible]	260	1,118	3,000	30,000	<-65
Weasel	Transmission	2/12/48	- -	165	- -	0.84	trace	3.2	17.2	[illegible]	600	- -	- -	- -	-35
	"	3/15/48	- -	[illegible]	- -	[illegible]	0.05	3.0	[illegible]	[illegible]	[illegible]	- -	-	- -	-35
	"	5/15/48	281	615	1 1/2	1.04	[illegible]	2.7	[illegible]	57	200	740	2,100	16,000	-80
	"	6/15/48	- -	397	None	1.12	0.01	2.8	11.1	56	200	700	1,900	- -	-60
Weasel No. 1	"	2/2/51	59	[illegible]	295(d)	[illegible]	trace	3.3	[illegible]	[illegible]	[illegible]	2,489	[illegible]	67,000	<-65
Weasel No. 3	"	6/16/50	5	45	- -	0.25	trace	3.1	[illegible]	81	300	1,221	[illegible]	30,000	<-65
	"	[illegible]	70	538	538(d)	[illegible]	trace	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3,000	25,000	<-65
D-8 Tractor	Transmission	11/13/50	56	- -	- -	[illegible]	trace	4.0	[illegible]	114	540	[illegible]	12,000	- -	-65
	"	[illegible]	106	- -	- -	[illegible]	trace	4.0	[illegible]	80	360	1,605	5,300	[illegible]	<-65
	"	12/15/50	11	- -	- -	[illegible]	trace	2.8	[illegible]	76	300	1,329	4,000	42,000	<-65
	"	[illegible]	65	- -	- -	0.39	0.02	2.8	[illegible]	75	290	1,245	[illegible]	38,000	<-65
	"	1/10/51	[illegible]	- -	- -	[illegible]	trace	2.7	11.5	70	260	1,123	[illegible]	30,000	<-65
	"	1/19/51	163	- -	- -	0.36	trace	2.7	10.9	[illegible]	250	1,132	[illegible]	30,000	<-65
	"	[illegible]	119	370	- -	0.50	trace	[illegible]	[illegible]	75	285	[illegible]	3,750	38,000	<-65
	"	2/5/51	282	- -	- -	0.41	trace	2.7	[illegible]	[illegible]	260	1,141	2,100	32,000	<-65
	Final Drives	11/13/50	[illegible]	- -	- -	[illegible]	trace	4.6	[illegible]	[illegible]	[illegible]	[illegible]	11,000	- -	-40
"	"	[illegible]	106	- -	- -	0.99	[illegible]	[illegible]	[illegible]	170	[illegible]	[illegible]	6,700	- -	<-65
"	"	12/15/50	158	- -	- -	[illegible]	trace	3.3	14.6	80	[illegible]	[illegible]	4,200	40,000	-45
"	"	12/30/50	116	62	- -	sample	bottle	broken	in transit						
"	"	1/10/51	264	- -	- -	0.38	0.01	5.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	<-65
"	"	1/19/51	327	- -	- -	0.66	0.15	5.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- -	-45
"	"	1/26/51	370	- -	- -	[illegible]	0.07	5.0	[illegible]	[illegible]	[illegible]	[illegible]	4,300	- -	-40
"	"	2/5/51	[illegible]	- -	- -	0.18	trace	9.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- -	-40

(a) Extrapolated value
(b) Typical viscometric properties as given in "Report on Test of Fuels and Lubricants for Arctic Winter Operation of Automotive Materiel" - 1 August 1947, Office, Chief of Ordnance
(c) Insufficient sample
(d) Consumption, miles/quart

samples had appreciable precipitation numbers but there is a greater variation in neutralization numbers. Samples taken during the winter of 1948-49 had neutralization number of approximately 0.9 while those from the winter of 1950-51 had a value of approximately 0.5. This is attributed to differences in the original neutralization numbers of the different lots. Possibly a lesser amount or a different extreme-pressure additive was used in the preparation of the oils.

Though the used RGO-28-47 oils show great variations in properties, this is attributed to the admixture of other oils rather than to oil deterioration. A sufficient number of the used oil samples have properties so similar to those of the new oil that it is beleived justifiable to conclude that the RGO-28-47 or MIL-L-10324(ORD) gear oils show no evidence of excessive deterioration during use in the various vehicles and applications. The Arctic Test Station reports satisfactory operation with this oil (3, 4), gears shifted easily, and there was no evidence of sluggish vehicle operation down to -50°F. No indications of excessive wear were observed.

Properties of the Keystone 78-6 Hypoid gear oil are shown in Tables 10 and 11. This oil has a viscosity of 817 cs at 0°F as compared to the maximum of 3,268 cs for a SAE grade 75 gear oil. It is considerably more viscous than the RGO-28-47 oil (817 cs as compared to 230 cs) and has a higher pour point. Table 10 gives the properties of the oil after use in differentials, transmissions, and transfer cases of jeeps and weasels. Viscosities of the oils taken from Jeep No. 2 are so much lower than that of the new oil that it is suspected that it has been contaminated with another oil, probably RGO-28-47. Pour points of the oils, except those that are obviously mislabeled or contaminated, vary from -45° to -60°F. The lowering of the pour points of the used oils may be a result of a better dispersion of the additive due to the shearing action of the gears. The Arctic Test Station reports (3) that some material settles out of this oil on standing. It is probable that the upper oil layer would have a lower pour point than the lower layer. Therefore, the lower pour points of the used samples could be due to the precipitation of the additive in the original container or while in the vehicles. The viscosities of the majority of the oils had changed very little. Precipitation numbers were generally around 0.1, which is not excessive, and neutralization numbers varied from 0.4 to 1.0. These variations may be a manifestation of the precipitation of the extreme pressure agent.

Properties of the gear oils used in LVT(3)'s, D-6 and D-8 tractors are given in Table 11. A number of samples in this series are evidently mislabled or contaminated since their viscosities at 100°F are much greater than that of the new oil. Several had viscosities of 73 cs at 100°F as compared to 20.7 cs for the new oil. Other samples had viscosities intermediate to these values. Samples with the high viscosities also had much higher pour points, up to -5°F. In general, the pour points of the used oils were approximately the same as that of the new oil, -45°F. A few samples had lower pour points, possibly due to the better dispersion of the additive or to its precipitation. About half of the used oils had properties similar to those of the new oil and showed little evidence of oxidation or deterioration.

Except for the precipitation of additives, the Arctic Test Station reports that this gear oil gave satisfactory performance in all vehicles and equipment down to temperatures of -50°F. No excessive wear was observed; gears could be shifted easily; and there was no appreciable drag on the vehicles. As this lubricant has

TABLE 10

Properties of Used Gear Oil: Keystone Hypoid 70-6

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make up Oil - Qts.	Neutralization Number	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40(a)	Pour Point, °F
		New Oil					trace	3.7	20.7	160	817	4,500	20,000	-45
Jeep No. 2	Differential	12/4/48	- -	409	- -	1.08	0.04	2.8	17.7	90	330	1,180	5,400	-50
	"	1/15/49	- -	558	- -	1.16	0.05	3.5	16.7	105	430	1,920	5,200	-55
	Transmission	12/6/48	- -	409	- -	0.99	0.07	3.0	13.2	85	340	1,540	4,600	<-75
	"	1/13/49	- -	558	- -	1.02	0.07	2.8	12.4	75	295	1,320	6,000	<-75
	Transfer Case	12/6/48	- -	409	- -	0.77	0.04	2.6	12.0	63	360	1,480	4,500	<-75
Weasel	Differential	5/25/48	- -	1,098	None	1.12	0.25	4.1	42.4	460	2,858	13,000	- -	-35
	"	6/5/48	- -	1,587	None	1.24	0.04	5.3	38.8	420	2,515	17,000	- -	-40
Weasel No. 1	"	9/21/48	115	585	- -	1.08	0.12	3.6	22.8	230	1,403	10,500	47,000	-60
	"	10/5/48	- -	711	- -	0.77	0.13	4.0	21.5	200	1,100	6,030	27,000	-50
	"	10/19/48	- -	920	(c)	1.03	0.12	4.0	20.3	195	1,050	6,330	23,000	-50
	"	11/20/48	170	444	- -	0.75	0.07	3.7	19.6	190	1,100	7,220	30,000	-60
	"	12/27/48	474	560	- -	0.69	0.09	4.1	22.7	200	1,150	7,050	25,000	-60
	"	2/12/49	- -	244	- -	0.77	0.15	3.8	20.5	185	1,000	6,000	22,000	-60
	"	4/7/49	- -	1,301	1 1/2	0.38	0.12	4.0	19.1	165	850	5,000	18,000	-55
	"	5/16/49	265	358	- -	0.44	0.06	5.4	27.4	210	1,050	5,500	18,000	-50
Weasel No. 2	"	9/29/48	125	339	- -	0.46	0.07	2.5	9.1	44	140	470	1,200	<-75
	"	10/9/48	- -	475	- -	0.87	0.10	3.7	21.1	190	1,020	6,370	22,000	-50
	"	11/2/48	- -	681	- -	0.75	0.09	3.7	20.8	190	1,020	6,400	22,000	-50
	"	11/22/48	- -	933	- -	0.48	0.04	3.5	23.4	230	1,390	9,000	40,000	-50
	"	12/14/48	- -	117	- -	0.55	0.07	3.5	20.5	178	920	5,900	- -	-40
Weasel No. 5	"	12/8/50	51 1/2	224	- -	0.07	0.03	3.4	16.5	127	600	3,200	13,000	-65
	"	2/3/51	124	724	724(d)	0.15	0.02	3.9	21.1	175	900	5,000	18,000	-60
Weasel	Transmission	5/25/48	- -	1,098	None	1.52	0.20	3.5	13.1	150	725	3,900	15,000	-45
	"	6/5/48	- -	1,587	None	1.38	0.09	3.0	12.5	95	434	2,200	8,500	-45
Weasel No. 2	"	9/29/48	125	339	- -	1.05	0.15	3.3	19.2	190	1,100	7,510	32,000	-60
	"	10/9/48	- -	475	- -	1.13	0.22	3.6	19.4	170	920	5,490	22,000	-60
	"	11/2/48	- -	681	- -	1.42	0.30	3.7	20.0	185	1,150	6,000	22,000	-55
	"	11/22/48	- -	933	- -	1.32	0.24	4.1	28.6	340	2,390	18,000	- -	-45
	"	12/14/48	117	- -	- -	0.21	0.06	4.9	27.2	220	1,040	5,270	13,000	-55
Weasel No. 5	"	12/18/50	51 1/2	224	- -	0.50	0.07	3.3	17.3	135	640	3,250	13,000	-60
	"	2/3/51	124	724	724(d)	0.33	0.06	3.4	13.4	150	740	4,050	15,100	-50

(a) Extrapolated value
(c) Oil Changed
(d) Consumption miles/quart

TABLE 11

Properties of Used Gear Oils
Keystone Hypoid 70-6

Vehicle	Application	Date Sample Taken	Operation Hours	Operation Miles	Make up Oil - Qts.	Neutralization Number	Precipitation Number	Viscosity, centistokes at °F 210	100	32	0	-25	-40(a)	Pour Point, °F
			New Oil				Trace	3.7	20.7	160	817	4,500	20,000	-45
D-6 Cat. Tractor	Transmission	9/22/48	162	- -	- -	0.57	0.06	3.5	19.7	170	800	5,390	- -	-40
	"	12/10/48	305	- -	- -	0.75	0.02	3.9	21.6	180	900	5,010	- -	-40
	"	2/4/49	261	- -	(c)	0.80	0.04	4.2	24.0	205	1,000	5,620	20,000	-65
	"	3/8/49	113	- -	- -	0.50	0.03	4.6	28.0	260	1,513	8,500	33,000	-50
	"	5/27/49	384	- -	2	0.50	0.01	4.2	22.7	180	867	5,000	- -	-45
	"	6/4/49	56	- -	- -	0.75	0.02	4.2	26.1	240	1,290	7,300	27,000	-55
	Final Drive	9/22/48	162	- -	3	0.75	0.07	3.5	19.3	165	810	4,860	18,000	-65
	" "	12/10/48	305	- -	1 1/2	0.66	0.07	3.5	18.6	165	750	5,000	19,000	-65
	Port Final Drive	2/4/49	261	- -	- -	0.71	0.11	3.5	19.2	170	910	5,480	21,000	-55
	" " "	3/28/49	118	- -	- -	0.39	0.02	6.7	73.0	1,470	23,000	- -	- -	-20
	" " "	5/27/49	385	- -	- -	0.61	0.01	3.6	21.9	170	879	- -	- -	-25
	" " "	6/4/49	56	- -	- -	0.55	0.08	5.2	38.2	490	3,410	23,000	- -	-30
	Starboard Final Drive	2/4/49	261	- -	- -	0.50	0.06	3.4	19.1	165	900	5,650	22,000	-70
	" " "	3/28/49	118	- -	- -	0.55	0.04	9.3	73.1	784	3,500	- -	- -	-20
	" " "	5/27/49	385	- -	- -	0.62	0.01	4.7	22.3	146	550	2,200	- -	-35
	" " "	6/4/49	56	- -	- -	0.70	0.10	4.5	30.0	320	2,040	13,000	- -	-45
D-8 Tractor	Transmission	11/1/48	50	- -	- -	0.64	0.05	3.6	20.9	185	1,000	6,260	26,000	-70
	"	2/4/49	120	- -	- -	0.41	0.04	3.6	20.6	185	1,000	6,420	26,000	-70
	Final Drive	11/1/48	50	- -	- -	0.43	0.04	3.7	22.6	230	1,200	9,800	45,000	-65
	Port Final Drive	2/4/49	120	- -	- -	0.57	0.06	4.8	22.6	210	1,180	7,310	28,000	-65
	Starboard Final Drive	2/4/49	120	- -	- -	0.51	0.06	4.8	22.5	208	1,200	7,920	31,000	-65
LVT(3) No. 1	Port Final Drive	2/7/49	50	- -	- -	0.86	0.04	2.9	19.5	270	2,490	27,000	- -	-45
	" " "	6/9/49	70	316	- -	0.53	0.02	3.7	20.8	170	950	5,330	20,000	-55
	Starboard Final Drive	2/7/49	50	- -	- -	0.44	0.05	4.6	34.0	460	3,470	- -	- -	-30
	" " "	6/9/49	104	745	3/4	0.74	0.09	5.2	38.5	500	3,310	- -	- -	-20
	Port Right Angle Drive	2/4/49	50	- -	- -	0.51	0.07	8.7	72.3	831	6,000	- -	- -	-5
	" " " "	6/9/49	104	745	3/4	0.56	0.01	3.8	21.6	175	844	- -	- -	-25
	Starboard Rt. Angle Dr.	2/4/49	50	- -	- -	0.58	0.05	6.5	59.7	1,250	13,100	- -	- -	-10
	" " " "	6/9/49	104	745	3/4	0.40	0.01	3.8	20.4	166	794	4,200	- -	-30
	P. C. B. T. O.	6/9/49	831	1,000	3/4	0.48	0.01	2.9	19.7	275	2,430	27,000	- -	-45
	S. C. B. T. O.	6/9/49	831	1,000	3/4	0.46	0.05	3.4	23.3	305	2,660	26,000	- -	-45
LVT(3) No. 2	Differential	12/4/49	16	- -	- -	0.60	0.02	3.6	19.5	165	769	4,000	- -	-30
	"	6/8/49	104	480	10	0.99	0.03	3.8	21.0	190	1,000	6,150	25,000	-50
	Port Transmission	10/25/48	- -	- -	(b)	0.96	0.06	3.8	21.2	187	1,000	6,730	24,000	-55
	" "	11/9/48	93	- -	- -	0.50	0.04	3.7	20.2	185	1,000	6,720	24,000	-50
	" "	12/4/48	185	257	1	1.02	0.05	3.6	19.3	180	1,000	6,060	24,000	-50
LVT(3) No. 2	Starboard Transmission	11/9/48	93	- -	- -	0.98	0.07	3.7	20.8	187	1,000	6,240	24,000	-50
	" "	12/4/48	185	257	2	0.69	0.01	3.7	20.7	187	1,000	6,690	24,000	-50
	Final Drive	11/26/48	- -	54	- -	0.61	0.04	5.9	40.1	500	3,310	- -	- -	-20
	Port Final Drive	2/4/49	21	- -	- -	0.88	0.03	3.9	21.5	185	950	5,420	20,000	-50
	" " "	6/8/49	104	480	1/4	0.88	0.07	5.2	34.5	380	2,430	17,000	- -	-30
	Starboard Final Drive	2/4/49	65	- -	- -	0.53	0.02	6.2	41.4	500	3,230	23,000	- -	-30
	" " "	6/8/49	104	480	1/4	0.27	0.04	5.4	34.5	400	2,550	18,000	- -	-30
	Port Rt. Angle Drive	2/4/49	16	- -	- -	0.27	0.06	4.0	23.7	240	1,500	11,000	45,000	-45
	Starboard Rt. Angle Dr.	2/4/49	16	- -	- -	Sample bottle broken in transit								
HD-19	Transmission	12/30/50	50	- -	- -	0.18	trace	3.8	22.0	296	1,100	6,750	29,000	-45
	Final Drives	12/30/50	50	- -	- -	0.21	trace	3.6	20.1	180	1,000	5,900	24,000	-45

(a) Extrapolated value
(b) Sample contaminated with "Arctic Winter Antifreeze"
(c) Oil changed
P. C. B. T. O. - Port Center Bearing Take Off
S. C. B. T. O. - Starboard Center Bearing Take Off

a pour point of -45^0F, difficulties with gear shifting, stiff axles and channeling would be expected at lower temperatures. This oil appears to be marginal as an Arctic winter gear oil.

SUMMARY AND CONCLUSIONS

The two crankcase oils containing volatile diluents, REO-15-47 and the Keystone 20W (60 percent) - Velo A (40 percent) show great variations in properties due to the evaporation of the diluent. The extra maintenance required because of the high oil consumption; the increase in low temperature viscosities and pour points make these oils unsuited for Arctic winter use. The synthetic Ucon LB-140X though giving satisfactory performance and lubrication at operating temperatures and startability at temperatures down to -20^0F becomes so viscous at temperatures below -30^0F that starting engines becomes difficult. Its pour point of -45^0F is also too high for satisfactory winter serivce where even lower temperatures may be encountered.

Bis (2-ethylhexyl)adipate oils, identified as PSP-14 and Adipol 2EH, are apparently on the border line of viscosity at operating temperatures for automotive engines. It seems probable that the oil pressure cannot be maintained at a level high enough to assure adequate lubrication. In heavy duty diesel engines, wear is much greater. Though this oil allows easier starting at subzero temperatures, its viscosity is too low at operating temperatures for the satisfactory lubrication of heavy-duty engines.

The used REO-72-49 or MIL-0-10295(ORD) oils were extremely variable in properties ranging from 4.0 to 7.3 cs at 210^0F and from 3,300 to 26,000 cs at -40^0F. Differences in dilution were not great enough to account for these variations (3, 4). The Arctic Test Station reports considerable differences in the properties of the new REO-72-49 oils which probably accounts for the variations observed in the used oils. This oil is considered the most suitable Arctic winter crankcase oil by the Arctic Test Station as engines could be started fairly easily at ambient temperatures as low as -35^0F without the use of coolant heaters or starting aids. Consumption rates were normal and less wear was observed in the heavy duty diesel engines using this oil. Some used oils had pour points as high as -45^0 and -50^0F which is above the maximum of -65^0F. It is possible that these high pour points were due to contamination with other oils.

Properties of the used RPM-5W oils were fairly consistent, all having pour points of -65^0F. Two of the samples had high neutralization numbers but there was no major change in physical properties. Because only four samples were available, two of which had much lower neutralization numbers, no conclusions can be made as to their oxidation stability. Low temperature viscosities of the oils do not bear out the Arctic Test Station report that this oil becomes very viscous at temperatures below -20^0F. The viscosity of the oils examined at -40^0F were intermediate between the extremes of the REO-72-49 oils. Viscosities at 100^0 and 210^0F revealed no unusal drop in viscosity as reported by the Arctic Test Station. Oil consumption was said to be high and adequate lubrication was not attained in diesel engines.

Three unusal requirements are asked of Arctic winter crankcase oils. I. They should have the lowest possible viscosity at subzero temperatures to facilitate starting with the least number of starting aids. Viscosities at -40°F and lower temperatures are desired that are comparable to those of a conventional oil at 0°F. II. Viscosities must be sufficiently high at operating temperatures which approximate normal operating temperatures, to maintain an adequate oil pressure and oil film to prevent excessive wear. III. The oil must have a boiling point high enough so that consumption will not be excessively high and so that it will not volatilize from hot cylinder walls leaving an inadequate oil film. No known oil, petroleum or synthetic, fills the requirements for such a crankcase oil. Therefore, a compromise must be made with some sacrifice at either operating or at starting temperatures.

REO-72-49, a petroleum base oil containing a viscosity index improver and MIL-0-2104 type additives, is a compromise oil. Some sacrifice in the low-temperature viscosities were made to obtain higher viscosities at operating temperatures. MIL-0-10295(ORD) oils have similar properties but this specification allows latitude as to composition in that oil may be petroleum or synthetic or a combination of the two. The RPM 5W oil is also a compromise, having a lower viscosity at operating temperatures than the REO-72-49 or MIL-0-10295(ORD) type oils but approximately the same low temperature viscosity characteristics. A crankcase oil having the viscosity of that of a MIL-0-10295 oil at 210°F but with lower viscosities at subzero temperatures could be prepared by using a larger amount of synthetic oil or a wholly synthetic oil. This would increase the cost, but if operational characteristics were improved sufficiently it would be warranted.

The Ucon LB-140X and Ucon LB-400X oils were unsatisfactory as gear oils because of their inability to support the heavy load developed by the gears. Excessive gear wear and failure were reported when these oils were used as gear lubricants. Navy Symbol 9500 oil and Ensign 561 are not suitable as Arctic winter gear oils because of their high viscosities and pour points. The former, a heavy-duty crankcase oil, probably would be unsuitable as a gear lubricant because of its inability to support the loads developed.

Ucon LB-140X-60 differs from Ucon LB-140X oils in that the former contains an extreme pressure agent. This oil showed no evidence of excessive oxidation or deterioration during service. Its operational characteristics were satisfactory down to -50° F, the lowest temperature encountered. Wear rates were normal and no lubrication failures were reported. Satisfactory operation with the Keystone 78-6 Hypoid gear lubricant was also attained down to -50°F with no evidence of excessive wear or lubrication failures. The decrease in pour points of the used oils could be attributed to the precipitation of the additive or to their better dispersion in service due to the shearing action of the gears. Though there was little evidence of oxidation instability or deterioration in the used oils the tendency of a component, probably the extreme pressure additive, to separate during storage could lead to trouble. Wear rates would increase as the concentration of the extreme pressure additive decreased. Both the Ucon LB-140X-60 and Keystone 78-6 gear oils have pour points of -45° to -50°F. At lower temperatures, excessive drag and difficulty in shifting gears would be expected. The channeling of the gears through the lubricant leaving them unlubricated also becomes probable. These gear oils are considered marginal for Arctic winter use because their pour points of -45°F are above -65°F, the lowest temperature expected.

The conclusions based on the results of the analyses of the used RGO-28-47 or MIL-L-10324(ORD) gear oils are obscured by mislabeled or contaminated samples. However, from the number of samples showing little changes in properties during service it appears that this oil is adequately stable. The Arctic Test Station reports that it has given satisfactory service in jeeps, weasels, and tractors at temperatures from +30° to -50°F. Consumption was low and wear rates normal. Because of its low viscosities at subzero temperatures and pour point of below -65° F, it appears to be the most suitable gear lubricant for Arctic winter use evaluated to date.

* * *

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