AD A

Low-Temperature Oil Pumpability Investigations in a 6.2L Diesel Engine

INTERIM REPORT
TFLRF No. 318

by

E.A. Frame
W.E. Likos
U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, TX

Under Contract to

U.S. Army TARDEC
Petroleum and Water Business Area
Warren, MI 48397-5000

Contract No. DAAK70-92-C-0059

August 2000

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E. C. Owens, Director
U.S. Army TARDEC Fuels and Lubricants
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13. ABSTRACT (Maximum 200 words)

Low-temperature engine oil pumpability investigations were conducted in a 6.2L diesel engine. The engine was installed in a cold box chamber, and investigations were conducted at temperatures as low as -33°F. Oil pumpability times were measured.

Borderline oil pumpability temperatures were defined for various petroleum and synthetic engine oils. The effects of soot in used engine oil on oil pumpability was determined.

14. SUBJECT TERMS

oil pumpability	6.2Ldiesel engine	low-temperature pumpability	
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EXECUTIVE SUMMARY

Problem: Low-Temperature operability is an important requirement for U.S. Army equipment. Adequate engine oil pumpability at low temperatures is essential for maintaining mobility readiness.

Objective: The objective of the project was to determine the low-temperature oil pumpability characteristics of future-generation synthetic high-temperature lubes, current-generation petroleum-based lubricants, and used diesel engine oils.

Importance of Project: In this project important issues concerning the low-temperature performance of petroleum oils, synthetic arctic oils, advanced high-temperature oils, and used oils were addressed and defined.

Technical Approach: Low-temperature engine oil pumpability investigations were conducted in a 6.2L diesel engine. The engine was installed in a cold box chamber, and investigations were conducted at temperatures as low as -33°F. Oil pumpability times were measured.

Accomplishments: Borderline oil pumpability temperatures were defined for various petroleum and synthetic engine oils. The effects of soot in used engine oil on oil pumpability was determined.

Military Impact: Low-temperature oil pumpability characteristics are important in setting the ambient temperature use limits of engine oils in military equipment. Adequate low-temperature oil pumpability insures Army ground mobility.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period February 1994 through September 1999 under Contract No. DAAK70-92-C-0059 (Work Directives 15, 19 and 39). The work was funded and administered by the U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan. Mr. Luis Villahermosa (AMSTA-TR-D/210) served as the TARDEC contracting officer's representative and project technical monitor.

The authors acknowledge and appreciate the following: the efforts of the TFLRF chemical and engine laboratory staff; and W.C. Mills for her careful attention to detail and editorial contributions.

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SYMBOLS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
BPT	Borderline Pumpability Temperature
CUCV	Commercial Utility Cargo Vehicle
GM	General Motors Corp
HMMWV	High Mobility Multipurpose Vehicle
HTL	High-Temperature Lubricant
MRV	Mini-Rotary Viscometer
Pa•S	Pascal • Seconds
SwRI	Southwest Research Institute
TARDEC	U.S. Army Tank-automotive RD & E Center
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility
TGA	Thermogravimetric Analysis
VII	Viscosity Index Improver

I. INTRODUCTION AND BACKGROUND

A. Introduction

Under cold ambient conditions, lubricants increase in viscosity to the point that they will not flow into the oil pump or through the oil galleries. This form of oil starvation is especially critical to engines that require prompt and copious lubrication to the turbocharger. The U.S. Army is concerned with heavy-duty diesel engine, low-temperature pumpability because the combat-tactical fleet, which is powered primarily by diesel engines, must be ready to operate immediately at a wide variety of ambient temperatures throughout the world.

B. Background

A history of low-temperature oil pumpability investigations was presented in the previous work.(1)* In more recent work, Margeson and Beimesch demonstrated the cold starting and oil pumpability benefits of a synthetic SAE 5W30 viscosity grade engine oil in heavy-duty diesel engines. (2) Heavy-duty diesel oil pumpability received increased attention during the 1990s, with studies conducted in both motored and fired engines. (3-7) Alexander et al. reported on low-temperature fired-engine evaluations of oil pumpability in Detroit Diesel Series-60, Caterpillar 3406B, and Cummins NTC-365 engines. (5) They reported significantly different pumpability characteristics for the different engine types for a given oil; however, they observed no pumpability problems for a wide range of commercial heavy-duty oils. (5) Machleder and O'Mara conducted studies in a Mercedes-Benz OM442A heavy-duty diesel engine and concluded that a Mini-Rotary Viscometer (MRV) limit of 30 Pa·s is higher than warranted by engine pumpability studies. (6) Alexander, May, and Smith conducted additional fired-engine tests using the same engines from Reference 5, with a variety of new and used multiviscosity oils of varying VII chemistry. (7) They found no evidence of oil pumpability problems, and there were good correlations between the MRV test oil viscosities and engine pumpability. (7) Other research investigated low-temperature viscosity test methods. (8-11)

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* Underscored numbers in parentheses indicate references at the end of the document.

II. OBJECTIVE/APPROACH

The objective of this program was to determine the low-temperature oil pumpability characteristics of both new and used fielded and experimental Army crankcase engine oil in a diesel engine. The approach was to determine low-temperature oil pumpability characteristics using a high-density diesel engine from the Army fleet. The investigations were accomplished by placing the subject engine in a cold box, charging it with test oil, then cooling it at prescribed conditions to the test temperature. The engine was then cranked (without firing), and the time to constant oil pressure was determined. The program included the following types of Army crankcase engine oils:

- baseline petroleum oil
- new and used experimental high-temperature oils
- candidate OEA-30 oils
- used oils from the 6.2L oil qualification test

III. EQUIPMENT/PROCEDURE

A. Test Engine

Low-temperature oil pumpability was investigated in the GM 6.2L engine used to power the U.S. Army High Mobility Multipurpose Vehicle (HMMWV) and Commercial Utility Cargo Vehicle (CUCV). All tests were run with the pistons installed. A description of the 6.2L engine is presented in Table 1. A schematic of the 6.2L engine lubrication system and the locations of the U.S. Army TARDEC Fuels and Lubricants Research Facility's (TFLRF) oil pressure instrumentation are shown in Figure 1. Gallery oil pressure was measured at the front of the right-side valve lifter gallery, i.e., the furthest point from the oil pump. Left-side oil pressure was measured at the port for the engine oil pressure gauges at the left rear of the engine. These same locations were used in the previous work. (1)

Table 1. Engine Specifications for the GM 6.2L Engine	
Model	**GM 6.2L**
Engine Type	Four-Cycle, Compression Ignition, Ricardo Comet V Combustion Chamber
Cylinder	8, V-Configuration
Displacements	6.217L (379 cubic inches)
Bore	10.1 cm (3.98 inches)
Stroke	9.7 cm (3.82 inches)
Compression Ratio	21.2:1
Fuel Injection:	Stanadyne DB-2 Fuel Injection Pump, Bosch Pintle Injectors
Rated Power	116 kW (155BHP) at 3600 rpm
Rated Torque	355 NM (262 lb-ft) at 2200 rpm

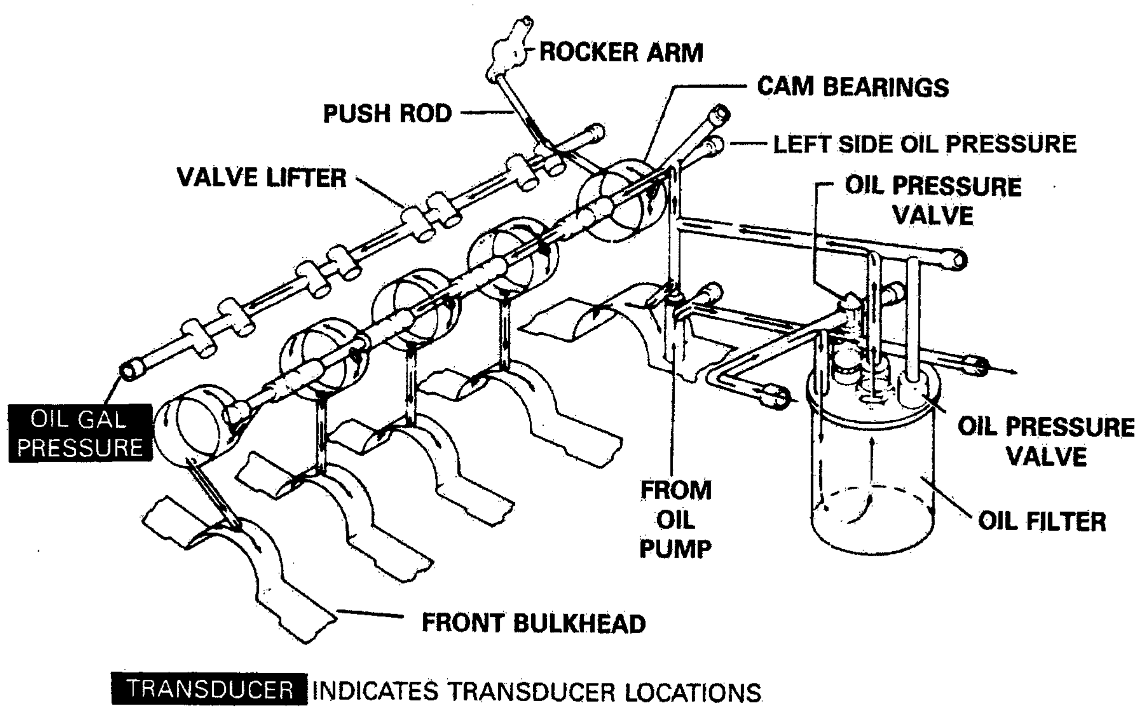

Figure 1. GM 6.2L Engine Lubrication System

B. Test Cell and Procedure

The 6.2L engine was mounted in a cold box, and the engine was cranked using an electric motor. Data for oil temperature and oil pressure were logged into a database on a personal computer. The engine was cooled overnight following a programmed fast-cooling cycle, and the oil pumpability test was conducted the next morning. Figure 2 shows a trace of engine cranking speed (95 RPM) versus time for a typical oil pumpability test. Figure 3 shows typical oil pressure traces obtained during a test. In the previous work (1), the engine was motored at idle speed (800 RPM) to determine oil flow characteristics assuming the engine was started. The limit was set at 30 psi min. oil pressure at the measuring point on the right side of the engine. In the current project, the engine was motored at 95 RPM, which is representative of typical low-temperature cranking speed. The borderline pumpability temperature was defined as the lowest temperature at which right-side oil pressure of 30 psi was achieved within 1.0 minutes.

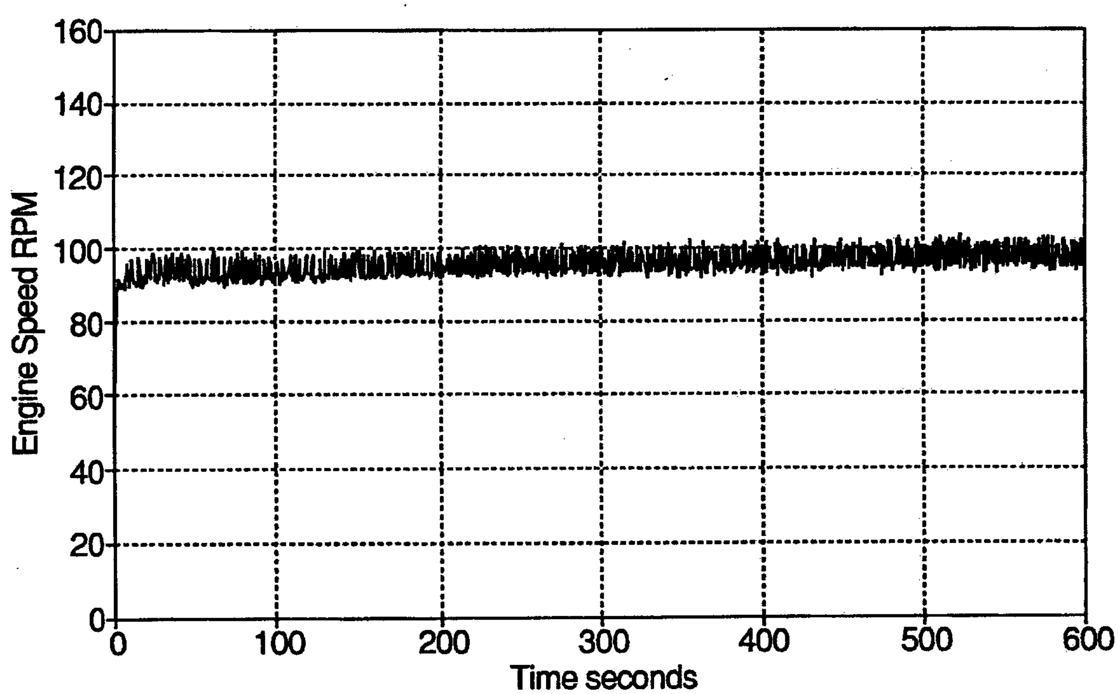

Figure 2. Typical Engine Cranking Speed

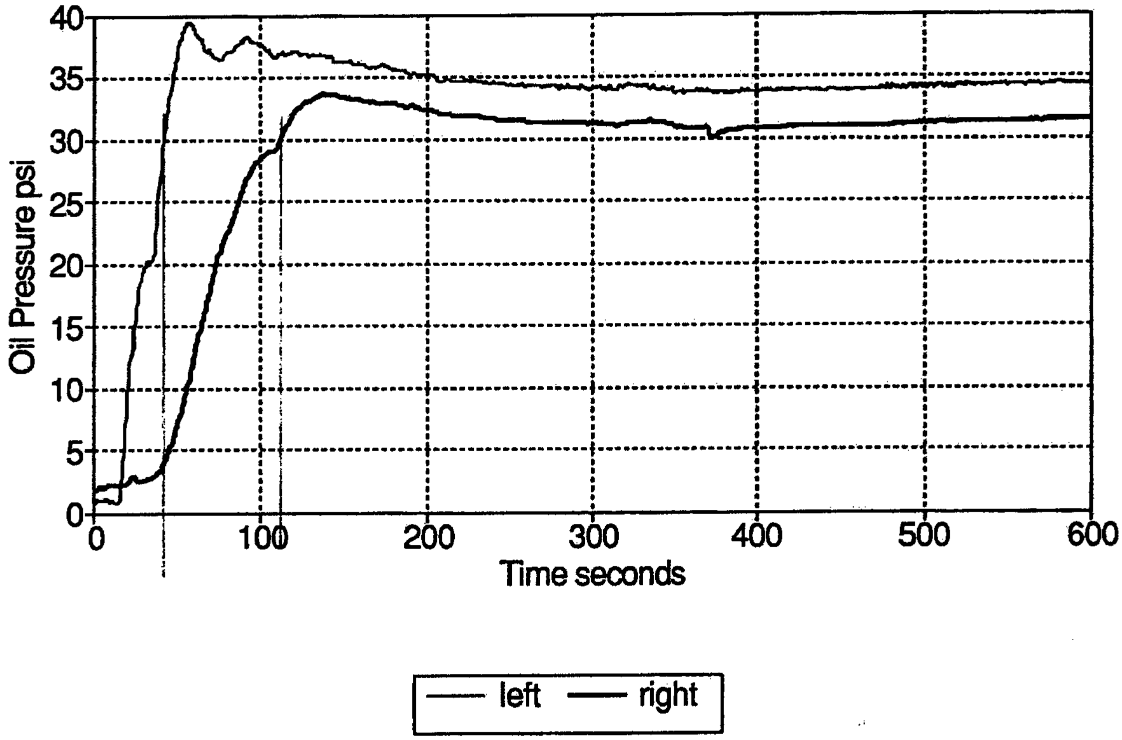

Figure 3. Typical Oil Pressure Traces

IV. RESULTS

A. Petroleum Oil Baseline

Four SAE 15W40 viscosity grade, petroleum-based engine oils were evaluated for low-temperature oil- pumpability characteristics to provide a baseline. Oils A (AL-14570) and B (AL-20222) were tested in the previous program (1), while oil C (AL-22999) was an Army Reference oil, and oil D (AL-23083) was a candidate oil.

In the previous work, borderline pumpability temperature (BPT) was defined as the temperature at which the oil pressure reached 30 psi on the right side of the engine after 1 minute of pumping. The engine was cranked at 800 RPM (typical idle speed). In the current program, the engine was motored at a typical engine cranking speed of 95 RPM. The effect of engine cranking speed on BPT is shown in Table 2. The lower cranking speed resulted in BPTs for two oils that were 2 to 8°F higher. No consistent correction factor was identified from this limited data set to allow a direct comparison with the results from the previous program. At the new BPTs, the oil pressure measured at the left side of the engine for both oil A and oil B reached 30 psi at approximately 0.5 minute. This illustrated that the right side of the engine receives oil pressure later at a given low temperature. Figures 4 through 7 show the oil pumpability characteristics of oils A and B for the right and left sides of the engine.

Table 2. Effect of Cranking Speed on BPT, measured at engine right side

	95 RPM	800 RPM
Oil A	-4°F	-12°F
Oil B	-9°F	-11°F

The BPT for oil C was –5°F, while the BPT for oil D was –7°F. Figures 8 through 11 show the oil pumpability characteristics for oils C and D. In summary, the four petroleum-based SAE 15W40 oils tested in this program had the following BPTs:

- Oil A -4°F
- Oil B -9°F
- Oil C -5°F
- Oil D -7°F

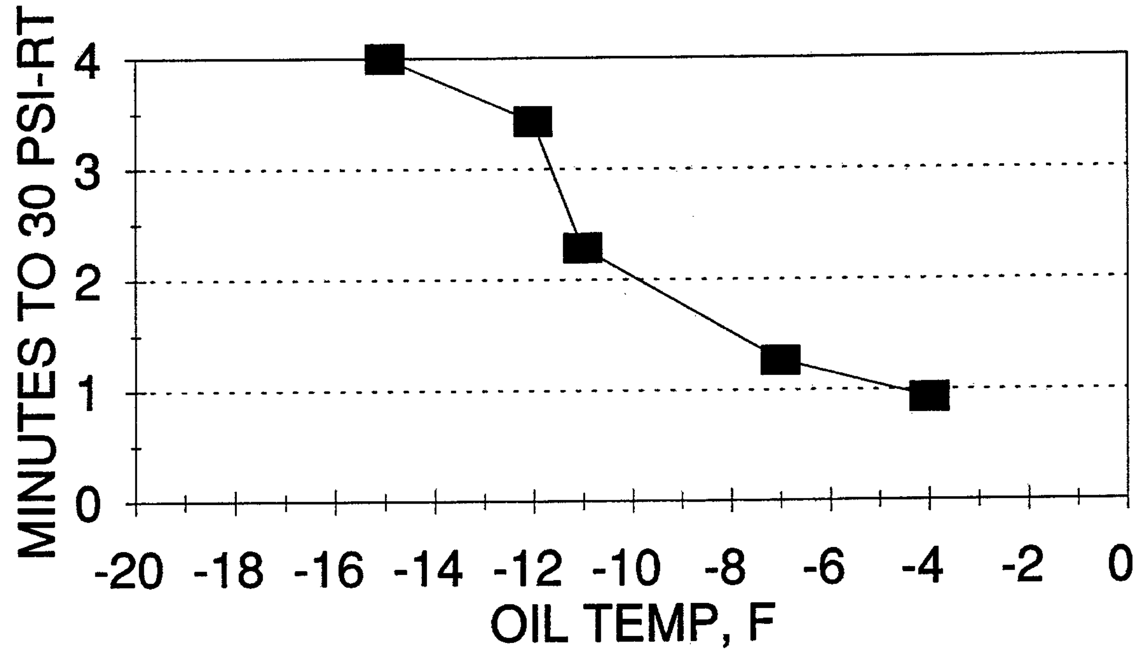

Figure 4. Oil A Pumpability, Right Side

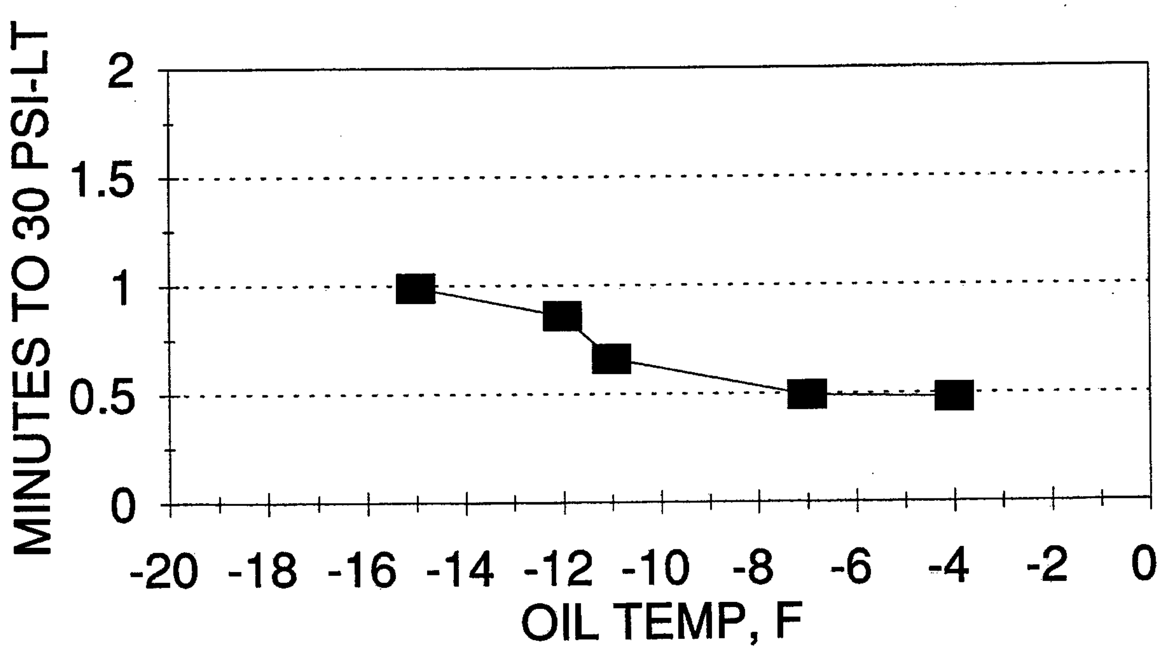

Figure 5. Oil A Pumpability, Left Side

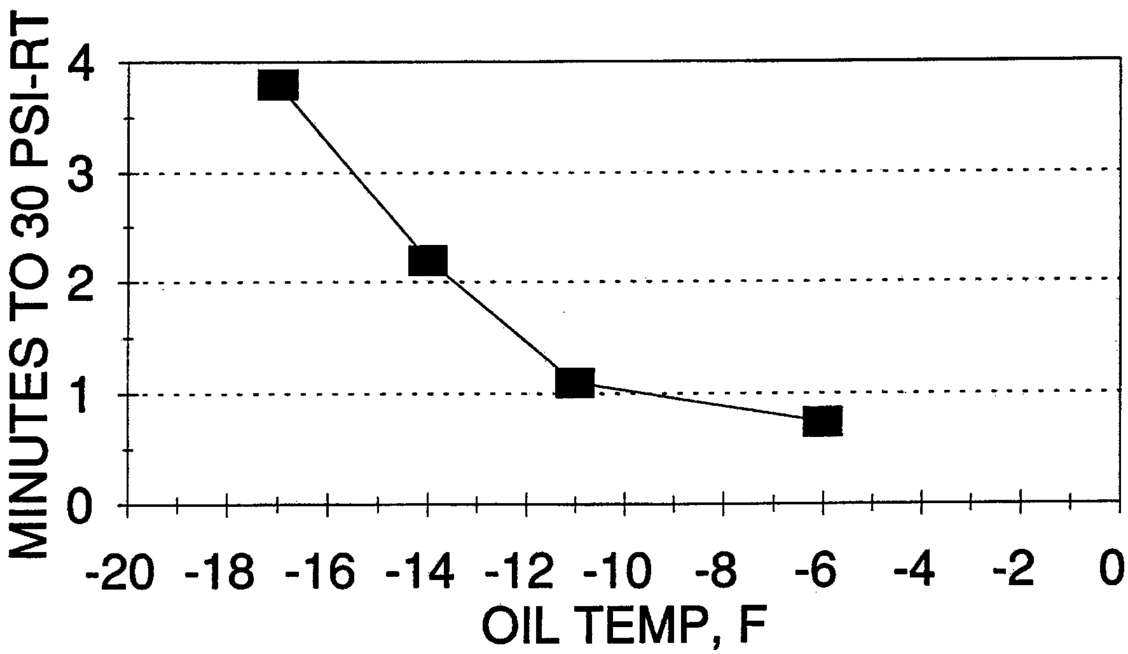

Figure 6. Oil B Pumpability, Right Side

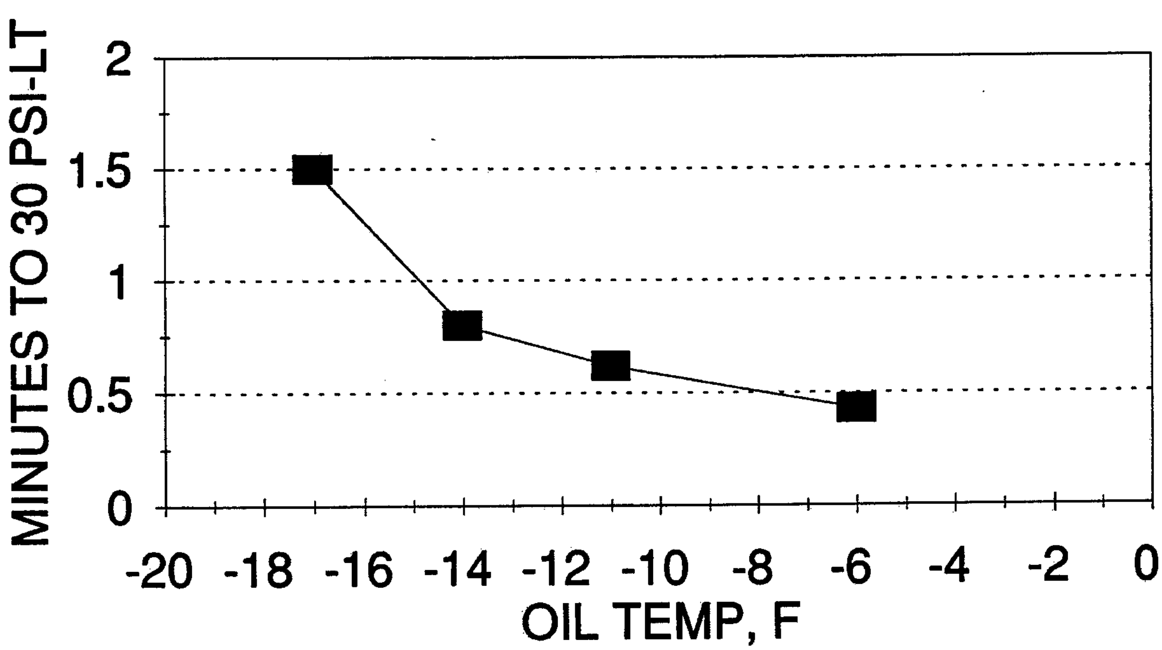

Figure 7. Oil B Pumpability, Left Side

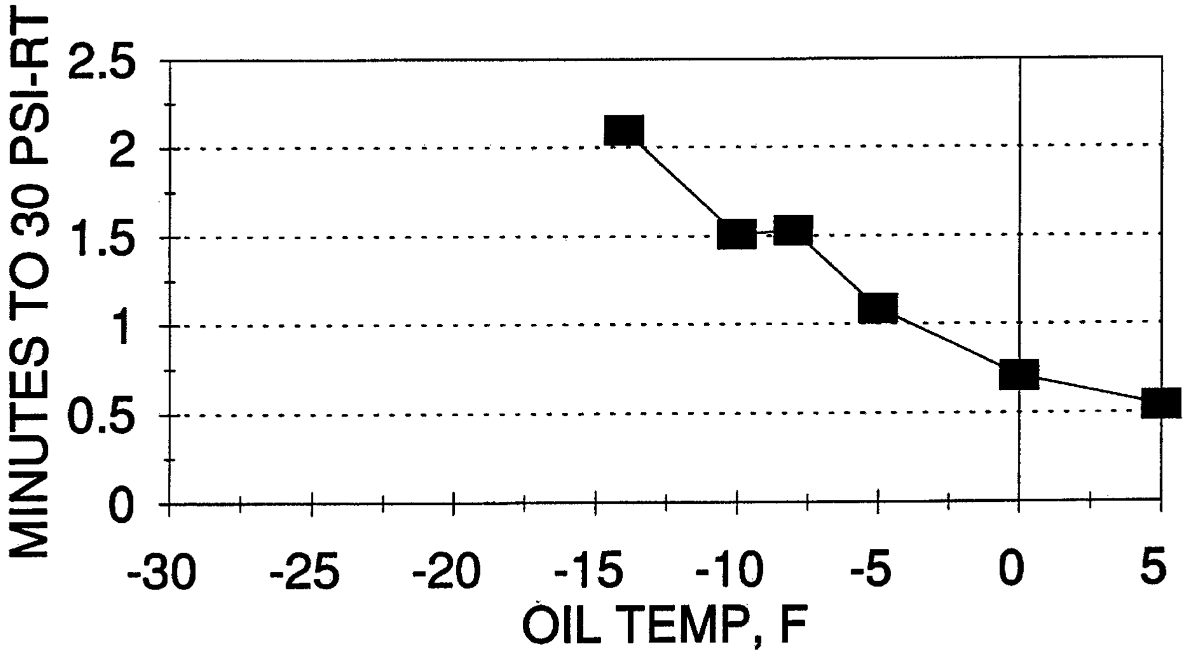

Figure 8. Oil C Pumpability, Right Side

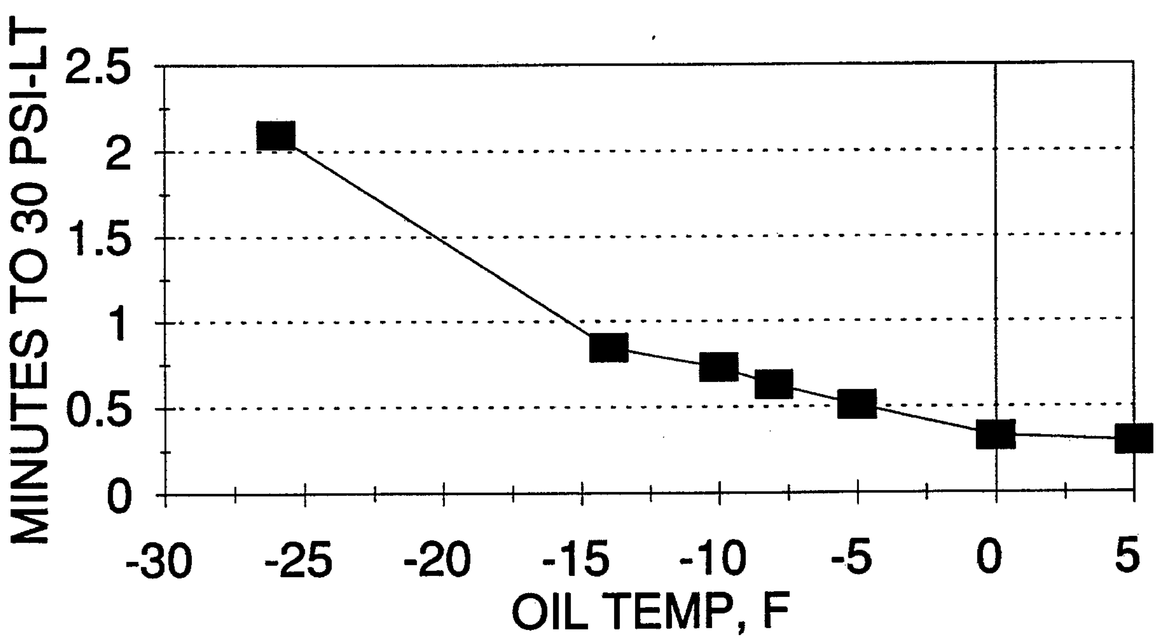

Figure 9. Oil C Pumpability, Left Side

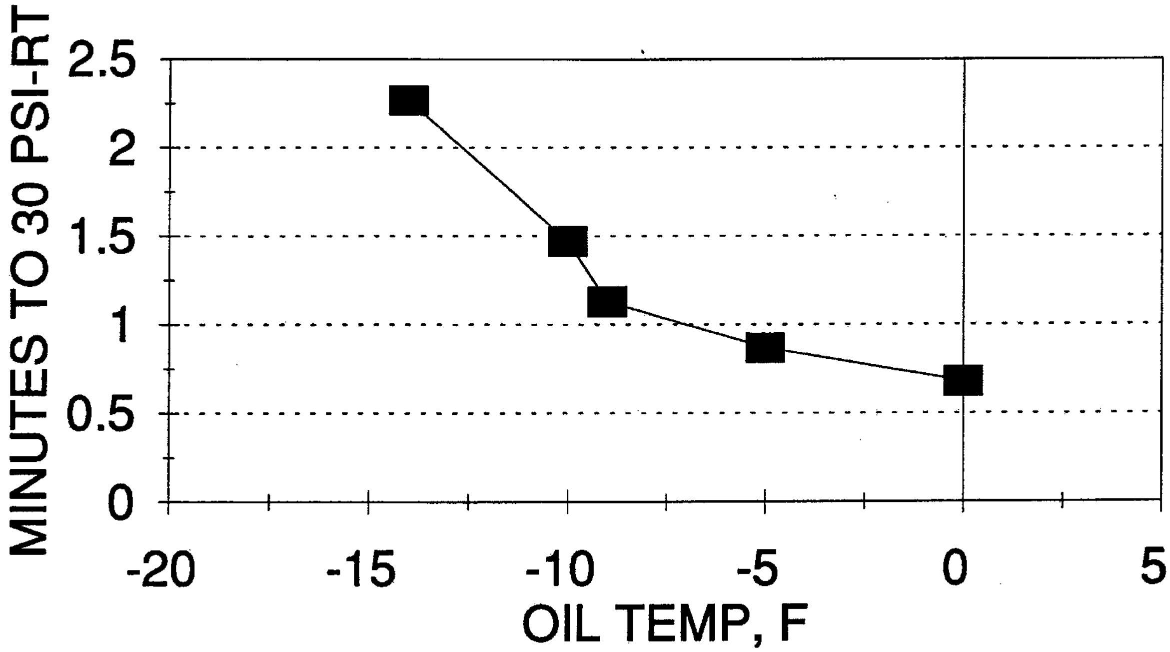

Figure 10. Oil D Pumpability, Right Side

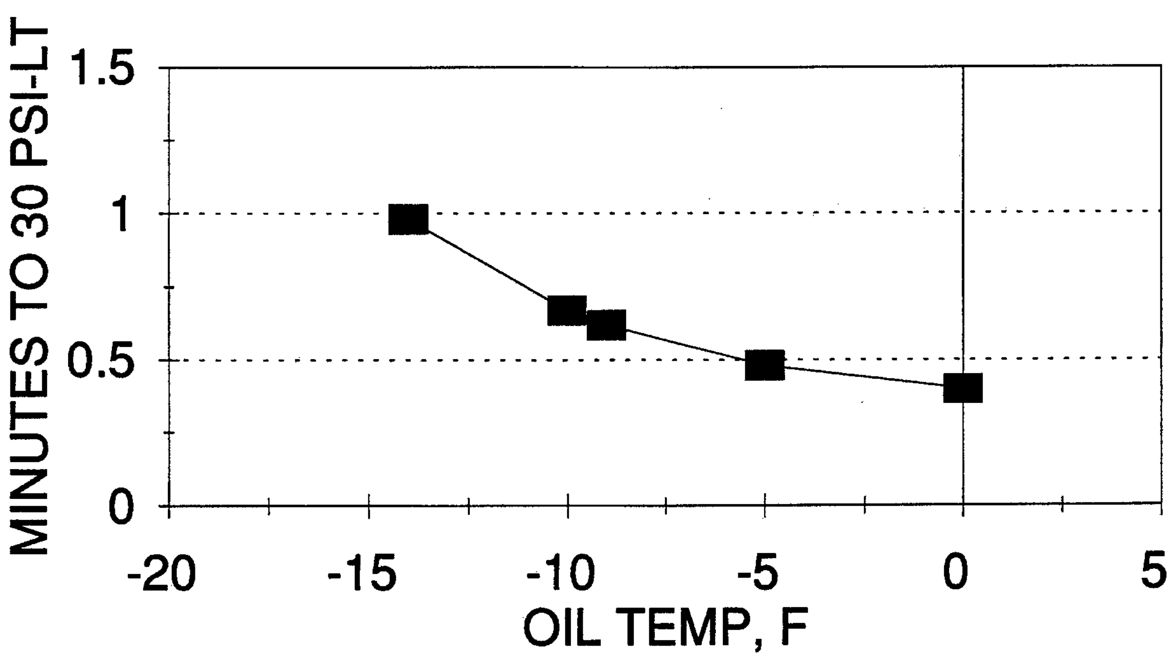

Figure 11. Oil D Pumpability, Left Side

B. New and Used High-Temperature Lubricant (HTL) Candidates

Two HTLs were tested in the GM 6.2L engine to determine their low-temperature oil pumpability characteristics. Oil AL-21095 was developed during a HTL program conducted by Cummins Engine Company. (12,13) This oil was designated oil A-8 in the Cummins program and had a viscosity grade SAE 10W40. Oil pumpability time to 30 psi was measured at various temperatures as shown in Figure 12. BPT for oil A-8 was –30°F. The overall low-temperature pumpability of oil A-8 was excellent.

Low-temperature oil pumpability characterizations were completed for a Cummins SAE 15W40 HTL A-59 (AL-21096) and the end-of-test (EOT) used oil (AL-22081) that was obtained from the 240-hr cyclic endurance test in a high-temperature L10 engine. Figure 13 shows the oil pumpability characteristics of oil A-59, which had a BPT of 0°F. A BPT of 0°F is not quite as low as typical petroleum-based SAE 15W40 oils. The oil pumpability characteristics of the used oil (AL-22081) are presented in Figure 14. The BPT of the EOT used oil was +5°F, an increase of 5°F over the new oil BPT. The EOT used oil had accumulated 120 hours of operation. The effects of used oil on pumpability became increasingly severe at lower temperatures as compared to unused oil.

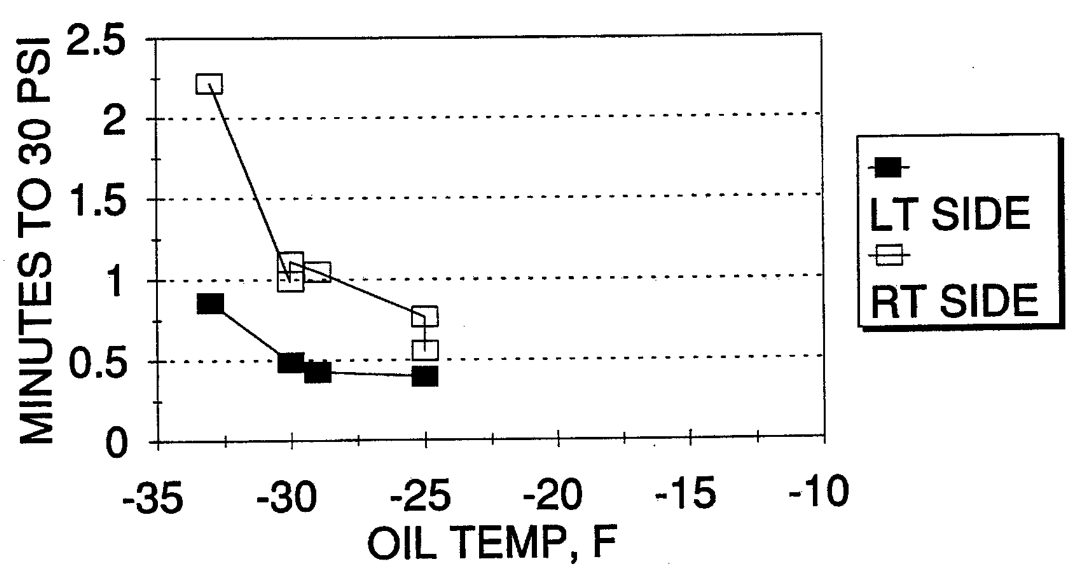

Figure 12. Oil Pumpability for Oil A-8

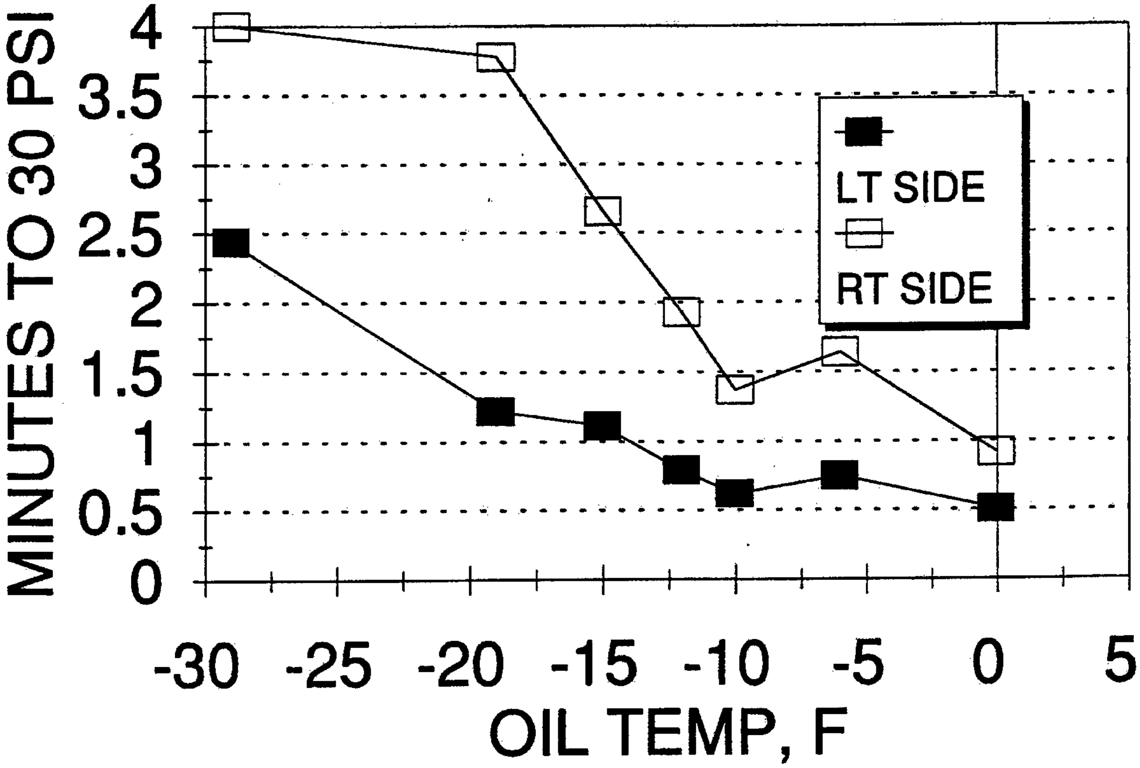

Figure 13. Oil Pumpability for Oil A-59

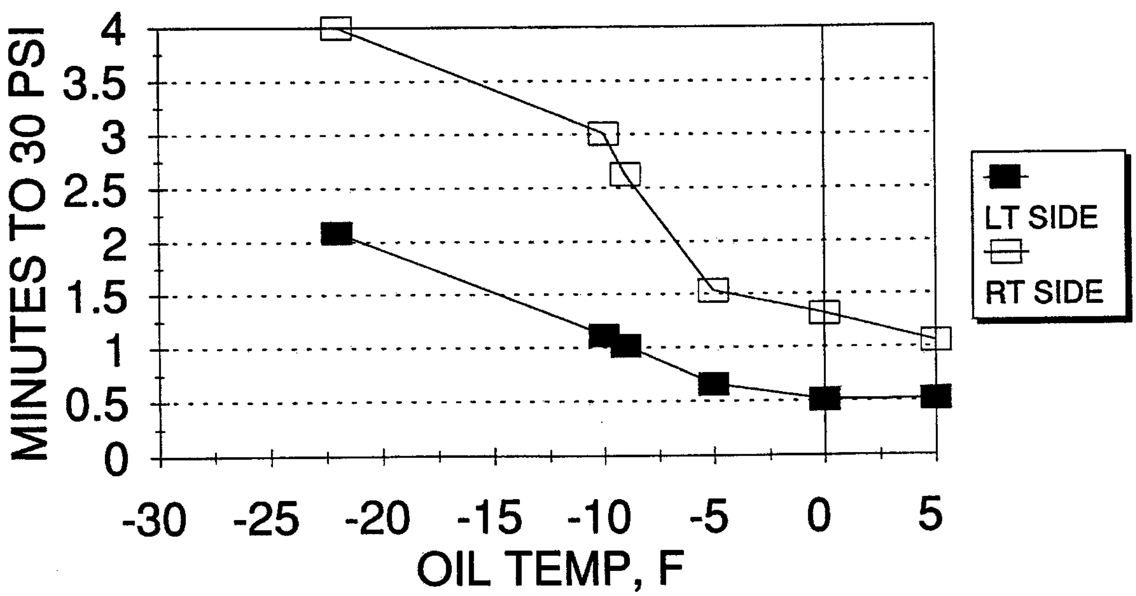

Figure 14. Oil Pumpability for Used Oil A-59

C. Arctic Engine Oils

Low-temperature oil pumpability investigations were conducted using the previous generation Arctic Engine Oil (AL-16678) SAE OW20, and an improved Arctic Engine Oil (AL-22668) that was designated OEA-30. (14) Both oils were tested at a variety of low temperatures; however, the cold box containing the test engine was limited to a minimum of –33°F. Oil pumpability characteristics of oil AL-16678 are presented in Figure 15 (right side of engine) and Figure 16 (left side of engine). The BPT of AL-16678 was below-33°F. Right-side oil pressure of 30psi was reached at 0.65 minute. The OEA-30 oil had improved high-temperature engine performance, but with a slight penalty in low-temperature oil performance. Oil pumpability characteristics of the OEA-30 oil (AL-22668) are presented in Figure 17 (right side of engine) and Figure 18 (left side of engine). Oil AL-22668 had a BPT of –32°F. At –33°F, the OEA-30 oil took approximately twice as long to reach 30 psi on the right side of the engine as the previous-generation Arctic Engine Oil (AL-16678).

D. Effect of Soot on Oil Pumpability

A series of investigations were conducted to determine the effect of used oil soot on low-temperature engine, oil-pumpability characteristics. The used oils were obtained from the GM 6.2L Roller Follower Wear Test. Oil C (AL-22999), the Army SAE/15W40 reference oil, was blended with varying amounts of used AL-22999 from the Roller Follower Wear Test. The following blends were prepared and tested for oil pumpability at –10°F:

- Oil C + 7 %vol used AL-22999 = 0.5 %w soot by TGA
- Oil C + 14 %vol used AL-22999 = 1.0 %w soot by TGA
- Oil C + 29 %vol used AL-22999 = 2.0 %w soot by TGA

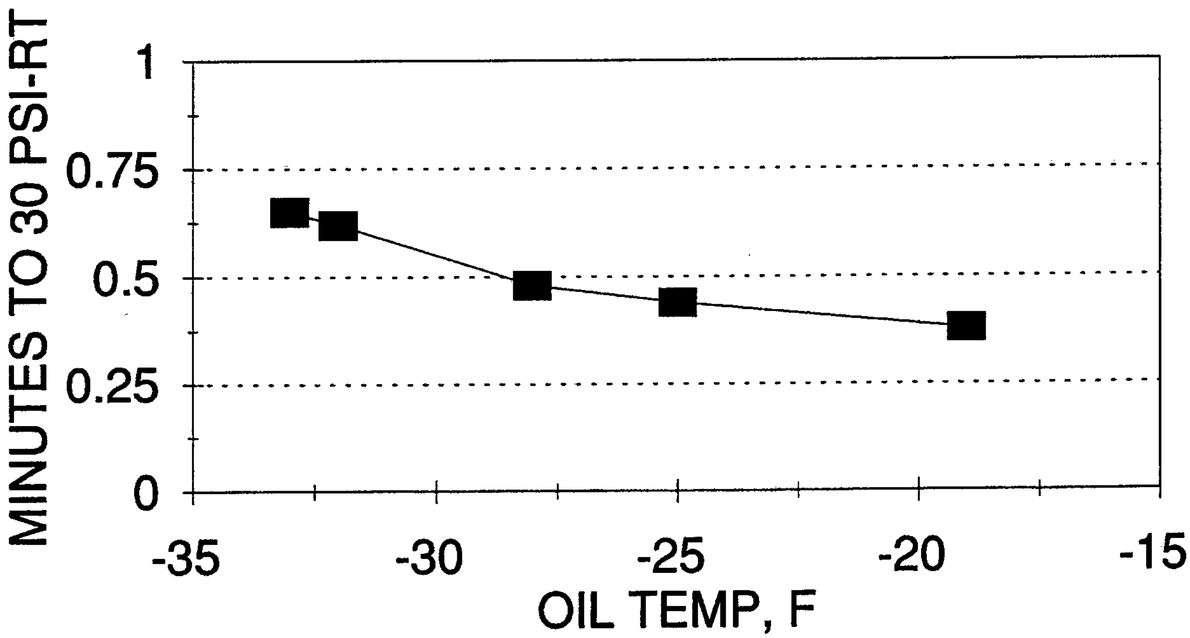

Figure 15. Pumpability of Arctic Engine Oil, Right Side

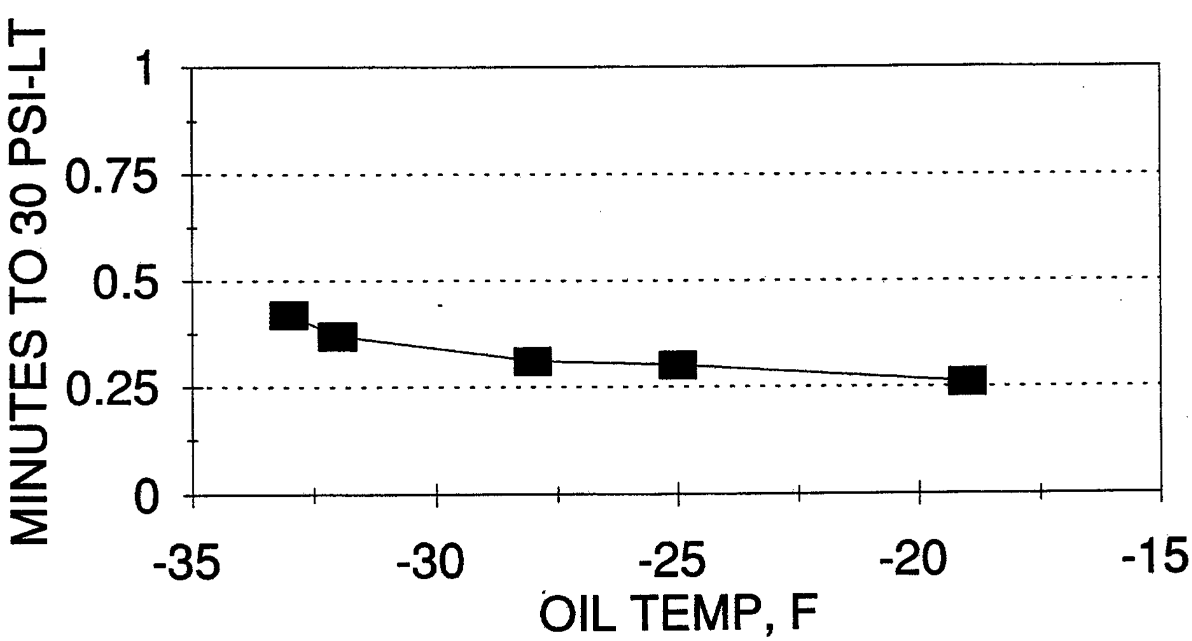

Figure 16. Pumpability of Arctic Engine Oil, Left Side

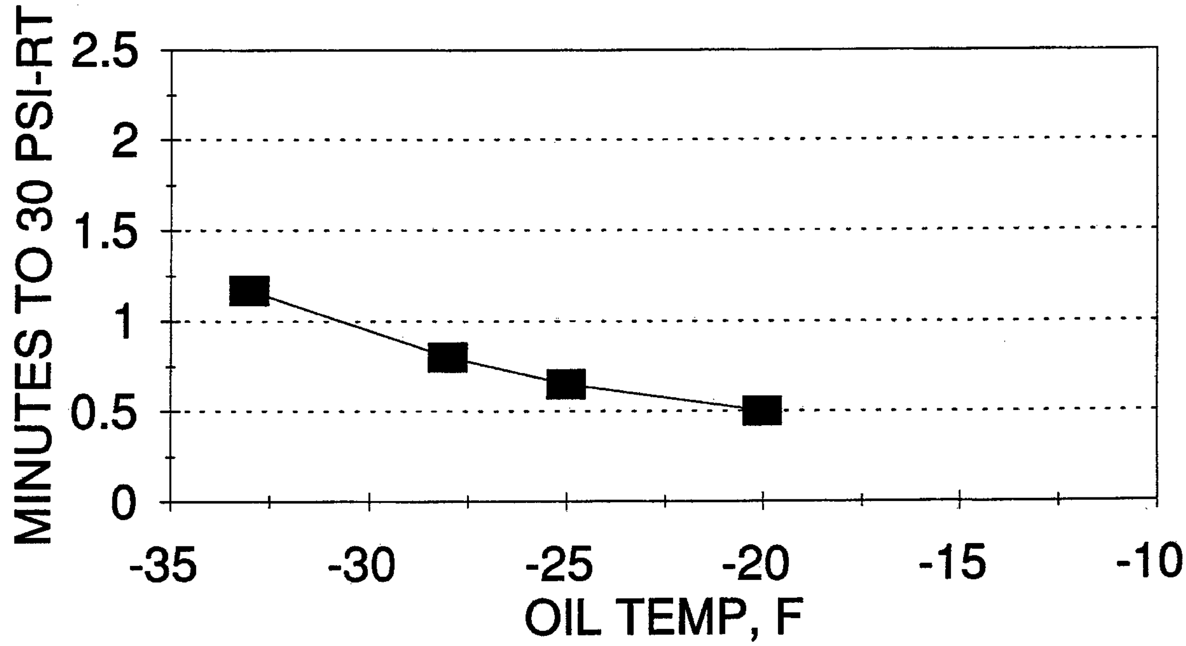

Figure 17. OEA-30 Oil Pumpability, Right Side

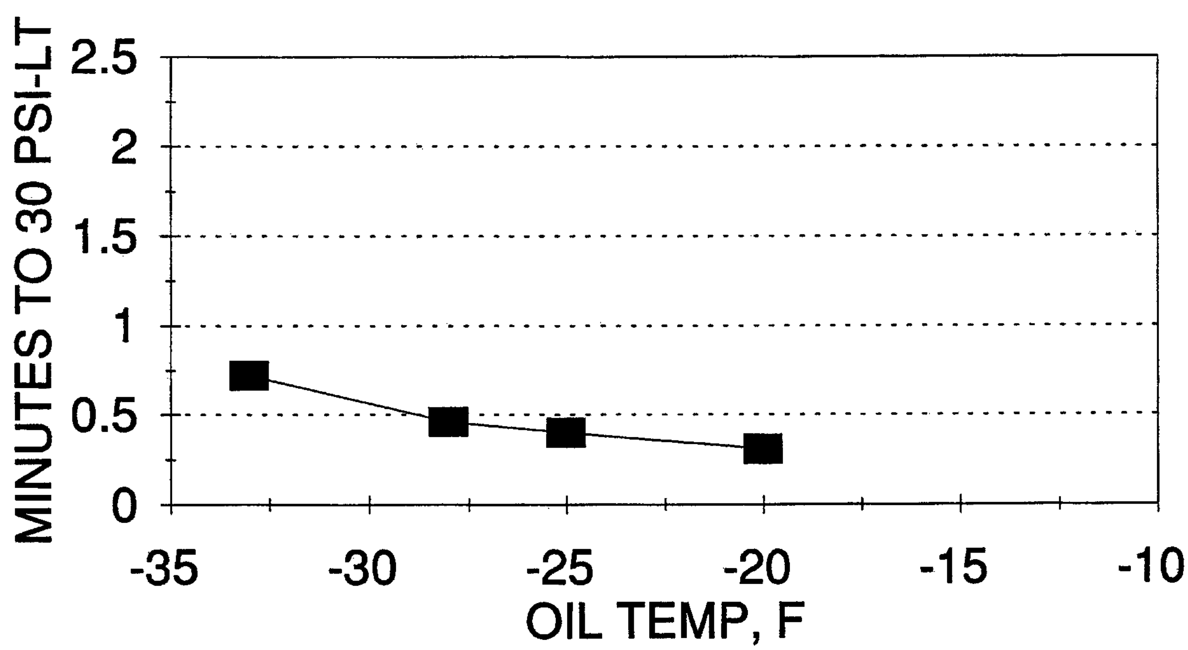

Figure 18. OEA-30 Oil Pumpability, Left Side

Figure 19 shows the minutes to 30 psi (measured at the right side of the engine) for the neat oil C and the blends tested at –10°F. Soot at 0.5 %w had no effect on oil pumpability at this temperature. At 1.0 %w soot pumpability time (at –10°F) to 30 psi increased by 20% compared to the neat oil. At 2.0 %w soot, the time to 30 psi also increased by 20% when tested at –10°F. The oil containing 2.0 %w soot was tested at –5°F and increased 23% in pumping time to 30 psi.

Overall, as little as 2 %w soot in the used oil caused a substantial increase in time to reach 30 psi on the right side of the engine. Figure 20 shows the pumpability results for the left side (oil pressure gauge) of the engine. Up to 2.0 %w soot had no effect on oil pumpability to the left side of the engine at –10°F.

An additional oil blend was made to determine soot effect at a higher soot level. Test oil AL-24360 was blended to contain 57% used oil D from the Roller Follower Wear Test and 43% neat oil D. This produced a test oil (AL-24360) with 5.5 %w soot by TGA. Figure 21 shows oil pumpability to the right side, while Figure 22 shows pumpability to the left side. The results are summarized below in Table 3:

Table 3. Oil D, time to 30 psi, minutes

	Oil D	Oil D with 5.5 %w soot	% increase
Right side @ -5°F	0.7	1.5	114
Right side @ -10°F	1.5	2.5	66
Left side @ -5°F	0.49	0.52	6
Left side @ -10°F	0.7	1.5	114

Overall, the higher soot level produced the expected increase in oil pumpability time compared to the previous tests.

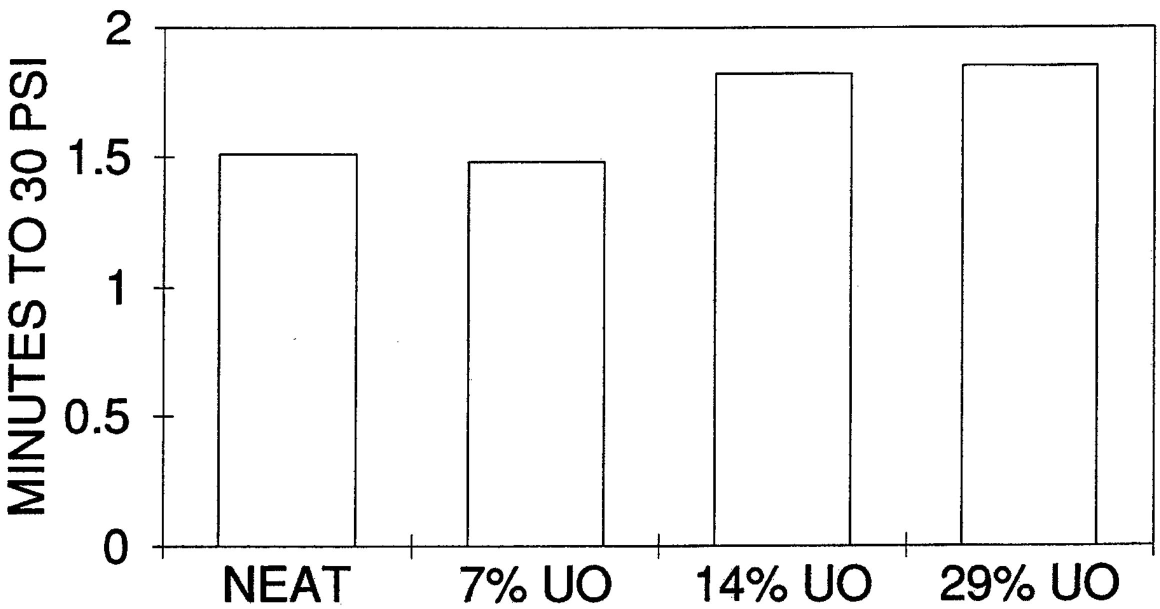

Figure 19. Effect of Soot on Pumpability, Right Side

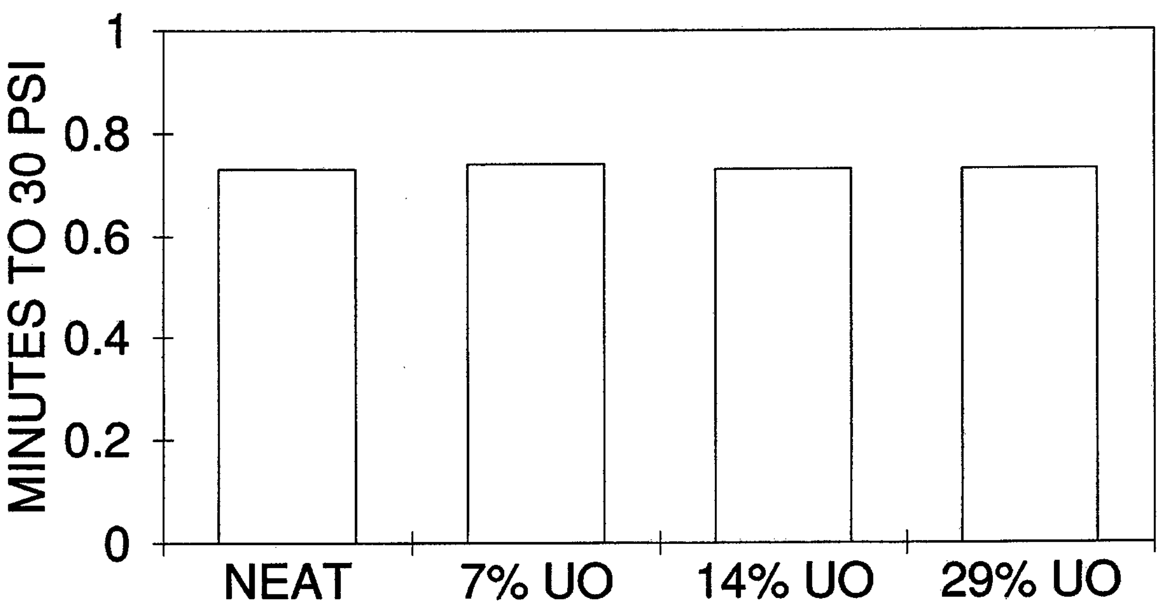

Figure 20. Effect of Soot on Pumpability, Left Side

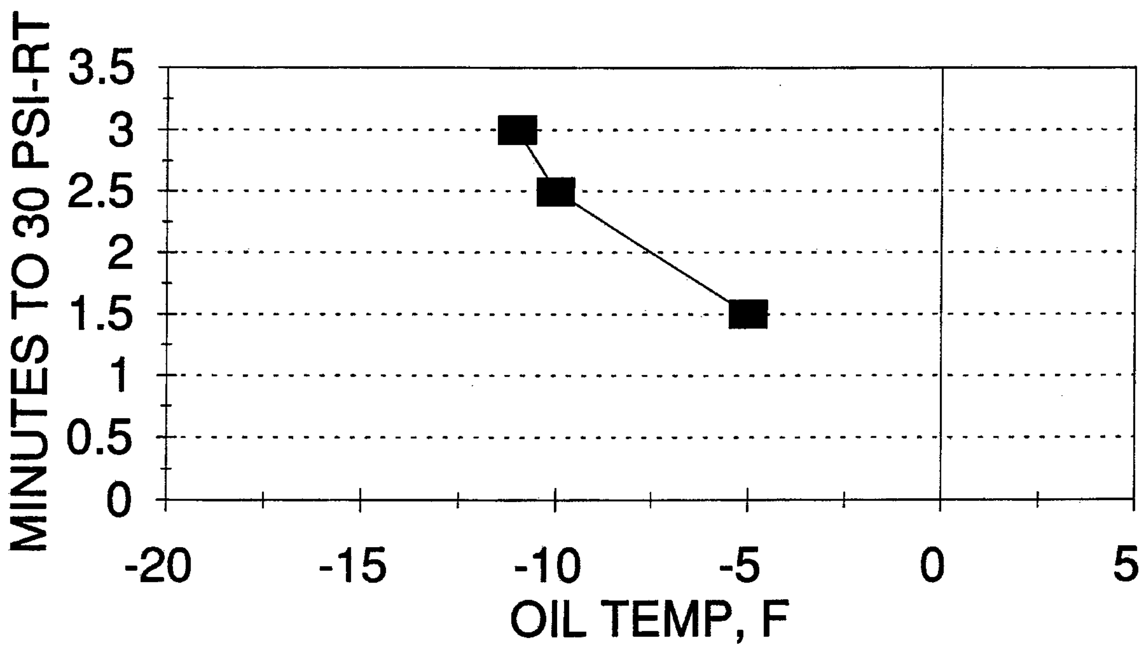

Figure 21. Pumpability of Oil D with 5.5%w Soot, Right Side

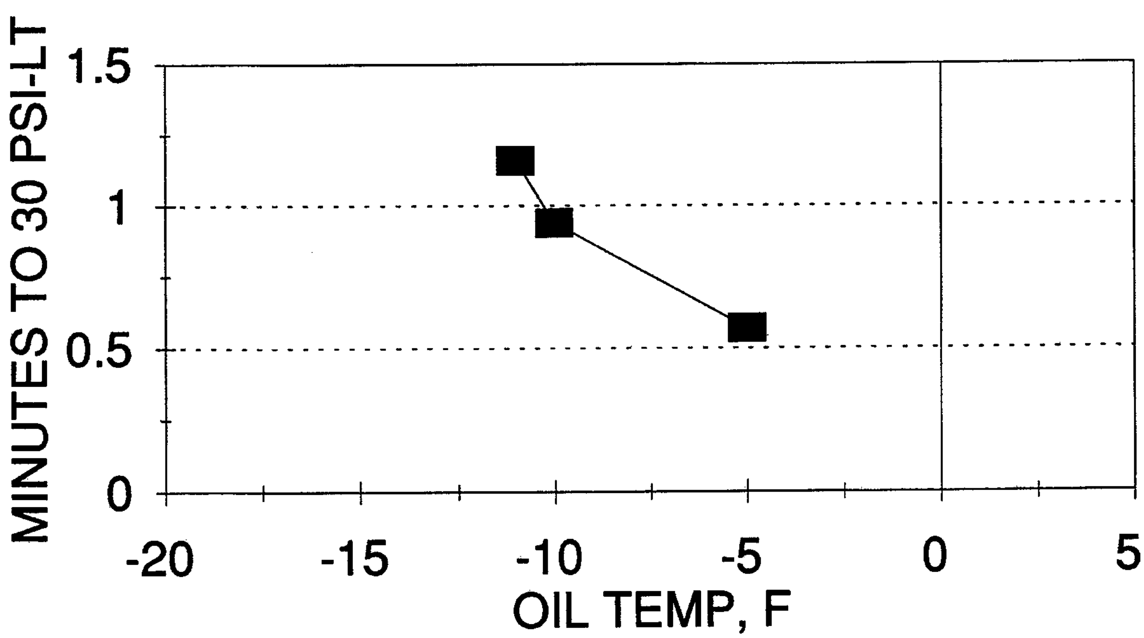

Figure 22. Pumpability of Oil D with 5.5%w Soot, Left Side

V. CONCLUSIONS

The following conclusions are offered based on low-temperature oil pumpability investigations conducted in the 6.2L diesel engine:

A. Petroleum Oil Baseline

- Because of a different (lower) engine cranking speed, the results of this investigation are not directly comparable to the previous work.
- For all oils tested, 30 psi oil pressure was achieved earlier on the left side of the engine at the oil pressure gauge location.
- BPT was defined as the lowest temperature at which right-side oil pressure of 30 psi was achieved within one minute.
- The four SAE 15W40 petroleum-based oils ranged in BPT from -4°F to -9°F.

B. New and Used High-Temperature Oils

- Oil A-8 had excellent low-temperature oil pumpability of BPT = -30°F.
- Oil A-59 had a BPT of 0°F.
- Used oil A-59 (120 hours of operation) had a BPT of +5°F.

C. Arctic Engine Oils

- BPT of Arctic Engine Oil (OEA) was below –33°F.
- BPT of new Arctic Engine Oil (OEA-30) was –32°F.

D. Soot Effects on Oil Pumpability

- At –10°F, up to 0.5 %w soot did not effect oil pumpability.
- At –10°F, 1.0 %w soot increased oil pumpability times (right side of engine) substantially (+20%).
- Higher soot levels (2.0% and 5.5%) produced the expected increases in oil pumpability time (up to +66%).

VI. RECOMMENDATIONS

Low-temperature oil pumpability continues to be an important aspect of diesel engine oil performance. Additional investigations are recommended using new and used oils to determine the effect of low-temperature oil pumpability on the startability of Army equipment at low ambient temperatures.

In the 6.2L engine, the oil pressure gauge shows oil pressure achieved at the left rear of the engine. Unfortunately, this can produce a false sense of oil pressure, because the right front of the engine takes much longer to achieve adequate oil pressure. The Army should consider relocating the oil pressure gauge top to the right front of the engine to display the worst-case oil pressure to the vehicle operator.

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