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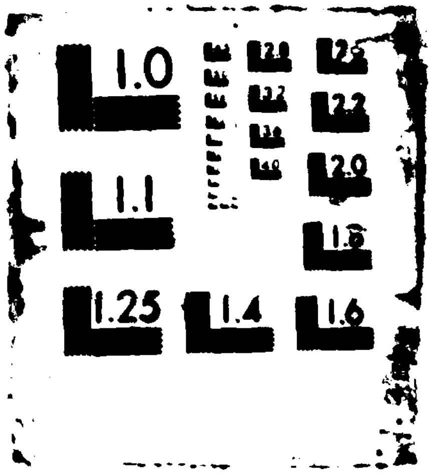
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COLD STARTABILITY OF METHANOL-FUELED CHEVROLET S-10 VEHICLES

INTERIM REPORT
BFLRF No. 221 ✓

By

A.F. Montemayor
B.B. Baber
E.C. Owens
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

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In this program, four Chevrolet S-10 vehicles were tested for cold starting performance. The vehicles consisted of two gasoline-fueled control vehicles and two M85-fueled test vehicles. The M85 vehicles were converted to methanol use with the Bank of America conversion technology. Two engine geometries were tested. The 2.5-liter L-4 throttle body injected engine was used in one M85 and one control vehicle. The 2.8-liter V-6 carbureted engine was used in one M85 and one control vehicle.

All vehicles were tested in a refrigerated trailer capable of maintaining temperatures of ambient to 0°F (-18°C). Both gasoline control vehicles were started successfully at temperatures of 0°F. Minimum starting temperature for the gasoline vehicles is lower than the 0°F temperature that the cold box was able to attain. The methanol vehicles were tested with M85 fuel, M82 fuel, SAE 40 lubricant, 10W-30 lubricant, and, in one case, with a block heater. The V-6 vehicle started much

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easier and at lower temperatures than the L-4 vehicle, believed to be due to the heated grid under the carburetor and the ability of the operator to control the initial mixture by using the accelerator pump.

Useful minimum unaided starting temperatures for the V-6 vehicle was approximately 20°F (-7°C) and 45°F (7°C) for the L-4 using M85 and an SAE 40 lubricant. The use of M82 fuel lowers the starting temperatures by about 10 degrees for both vehicles. The tuning of the fuel injection system on the L-4 throttle body injected engine can vary the minimum starting temperatures widely. The L-4 vehicle was successfully started at temperatures lower than 0°F with the use of a block heater.

FOREWORD

This work was conducted at the Belvoir Fuels and Lubricants Research Facility (SwRI) located at Southwest Research Institute (SwRI), San Antonio, TX under Contract No. DAAK70-85-C-0007 during the period March 1986 through August 1986. The work was funded by the U.S. Army Belvoir Research, Development and Engineering Center, Ft. Belvoir, VA, with Mr. F.W. Schaekel (STRBE-VF) as the Contracting Officer's representative and Mr. M.E. LePera, Chief of Fuels and Lubricants Division (STRBE-VF), as the project technical monitor.

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I. INTRODUCTION AND BACKGROUND

In compliance with Section 202 of Public Law 98-525, the Department of Defense (DOD) is conducting a demonstration program involving the operation of administrative vehicles on methanol fuel. Under the provisions of this legislation, the Department of Army was requested to purchase new methanol-compatible automobiles, establish the durability of these cars in laboratory and fleet tests, test a percentage in cold weather environments, and resolve related support functions relative to methanol fuel utilization.

The US Army has structured and implemented a demonstration program directed to develop the necessary data for compliance with those provisions given in Section 202 of Public Law 98-525. The program was initially structured to consist of three phases, each building upon the previous in terms of experience gained. Phase I was a small conversion fleet involving only five converted 1984 General Motors Chevrolet Citation sedans operating for 4,000 miles to demonstrate the applicability of the Bank of America (BofA) conversion technology and to provide a means for training US Army personnel. Phase II was a medium-fleet conversion involving twenty-five converted 1985 General Motors Chevrolet S-10 pickup trucks. These vehicles were to operate for 12,000 to 15,000 miles as a means to establish the durability aspects of methanol-fueled operation. Phase III was to then follow with a large fleet conversion involving up to one thousand vehicles at several DOD installations.

The BofA engine conversion technology was developed and has been utilized in climatic areas where cold starting and driveability problems do not normally occur. Since the congressional legislation requested that cold starting evaluations be performed, it was necessary to initially define the lower limits of startability for the two engine systems (i.e., the 2.8-liter V-6 and 2.5-liter L-4). The cold starting evaluations were conducted at Belvoir Fuels and Lubricants Research Facility (SwRI), San Antonio, TX and are reported herein.

II. TEST PROGRAM

A. Equipment

For this program, four test vehicles were received from the Phase II fleet test at Fort Ord, CA.(1)* These vehicles consisted of 1985 GM S-10 pickup trucks in the configurations shown in TABLE 1.

TABLE 1. Test Vehicle Configurations

License No.	Sticker No.	Fuel	Engine
CM2892	T102	M85	2.8L V-6
CM2894	T104	M85	2.5L L-4
CM2884	T093	Gasoline	2.8L V-6
CM2890	T099	Gasoline	2.5L L-4

The gasoline vehicles (T093 and T099) were selected as control vehicles with which to compare the M85 vehicles (T102 and T104). Fig. 1 depicts all four test vehicles. All test vehicles had been purchased new by the US Army and broken in for a minimum of 5000 miles. The M85 vehicles were then converted to methanol use using the Bank Of America (BofA) conversion technology.(2,3) To provide the

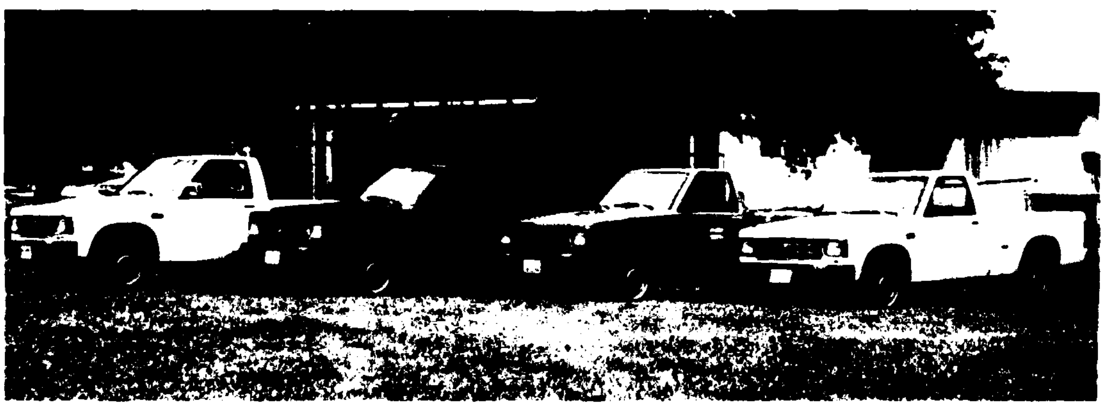

Figure 1. Test Vehicles

* Underscored numbers in parentheses refer to the list of references at the end of this report.

cold-starting environment, a commercial refrigerated trailer was rented. The trailer could hold two test vehicles simultaneously, maintaining temperatures of ambient to 0°F (-18°). The diesel-powered refrigeration system on the trailer required refueling after approximately 48 hours of operation. A 4-inch-diameter hole in the side of the trailer provided a passageway for instrument wiring and the exhaust pipe. Specially fabricated ramps facilitated loading of the test vehicles into the trailer.

The fuel systems in the gasoline vehicles were not modified. The M85 vehicles, however, had the vehicle fuel tank replaced with a 1-gallon fuel container located in the bed of the pickup truck. This replacement permitted easy fuel changes and minimized the amount of test fuel necessary for a given test. The 1-gallon fuel container was sealed and provided the same inputs and outputs as the vehicle-mounted fuel tanks. Methanol-resistant fuel lines connected the fuel container to the truck fuel lines. The exhaust pipes from the test vehicles were routed to flexible stainless steel hoses, teed into a common hose, and routed out of the trailer. Combustion air entered the box through the instrument line hole, as well as through the numerous small leaks in the cold box structure.

B. Instrumentation

Each test vehicle was instrumented to provide fuel temperature, exhaust temperature, oil sump temperature, cranking current, rpm, battery voltage, and throttle position. All temperatures were monitored with type J thermocouples. Cranking current was monitored by using a shunt (300 A on the V-6 and 400 A on the L-4) on the positive battery cable with a millivolt recorder monitoring the output from the shunt. Throttle position was monitored by tapping the stock throttle position potentiometer installed in the fuel-metering device of each vehicle and using a digital voltmeter (DVM) as an indicator. Engine speed was monitored by installing a magnetic speed pickup on the flywheel of each vehicle and monitoring the signal on a digital speed readout adjusted for the number of teeth on the flywheel. In addition, the speed signal was converted to a voltage and recorded on a chart recorder. Throttle position was controlled by installing an air cylinder on the throttle of each vehicle and actuating it with an air regulator.

The control station for the vehicles was located in a building adjacent to the refrigerated trailer to enable the operator to monitor the exhaust of the vehicles through a window from a range of approximately 20 feet. Remote operation was selected rather than direct operator starting in order to minimize danger to the operator from operating a vehicle in a closed, potentially fire hazardous and cold environment. The vehicle ignition and starting systems were operated by relays in order to minimize DC voltage drops in the long control lines. Vehicle batteries were kept fully charged with trickle charge battery chargers throughout the test in order to provide uniform cranking conditions.

C. Materials

The gasoline purchased for use in this program was a summer grade regular unleaded gasoline with a Reid Vapor Pressure (RVP) of approximately 9.8. To simulate a winter grade gasoline, n-butane was added to the purchased gasoline to raise the RVP to 13.6, the approximate RVP which would probably be available during normal cold weather starting periods. The winter grade gasoline was stored in a cold box at approximately 38°F (3.3°C). Gasoline was removed from the cold box as needed for the baseline vehicle tests and for mixing with methanol for the methanol-fueled M85 and M82 vehicle tests. The fuel properties for the M85 and the M82 fuels are presented in TABLE 2.

Two different engine lubricants were used in this series of cold-start tests. The first lubricant was the lubricant recommended by BofA for use in the methanol vehicles converted using BofA technology. This lubricant is a commercially available SAE 40 engine oil with the BofA-added proprietary additive. The second lubricant in the program was a MIL-L-46152 grade 10W-30 lubricant of the same viscosity that would normally be used in administrative vehicle engines during cold weather. TABLE 3 presents lubricant properties for the base SAE 40 oil used by BofA for its recommended lubricant, the formulated BofA lubricant, and the MIL-L-46152 lubricant used in this program.

TABLE 2. Fuel Properties

Property	Method	M85	M82
Reid Vapor Pressure, psig	D 323	10.15	10.00
V/L Ratio = 20, °C	*	60.0	61.1
Distillation, °C			
IBP	D 86	39.4	36.1
5%	D 86	56.7	52.8
10%	D 86	60.0	58.9
20%	D 86	62.8	62.8
30%	D 86	63.9	63.9
40%	D 86	64.4	64.4
50%	D 86	64.4	64.4
60%	D 86	64.4	65.0
70%	D 86	65.0	65.6
80%	D 86	68.9	67.2
90%	D 86	73.3	67.8
95%	D 86	75.0	72.2
EP	D 86	185.6	180.6
Recovered, mL	D 86	99.0	99.0
Residue, mL	D 86	0.5	0.5
Loss, mL	D 86	0.5	0.5
Water, ppm	D 1744	378	383
Gum, unwashed, mg/100 mL	D 381	0.7	1.1
Gum, washed, mg/100 mL	D 381	0.4	0.1
Particulates, mg/L	D 2276	0.2	0.3

* ASTM Appendix X2 (Bomb).

TABLE 3. Lubricant Properties

Property	Method	BofA Base Lubricant	BofA Lubricant	MIL-L-46152
Viscosity at 100°C, cSt	D 445	14.0	14.2	10.6
Viscosity at 40°C, cSt	D 445	136.6	137.8	69.3
Viscosity Index	D 2270	100	100	140
Total Acid Number, mg KOH/g	D 664	2.68	2.86	2.93
Total Base Number, mg KOH/g	D 664	10.50	10.40	6.04

D. Test Procedure

1. Starting Procedure

The starting procedures for all vehicles were taken from the 1985 GM S-10 Owner's Manual (4) and modified slightly to optimize the methanol startability. To provide realistic starting conditions for both vehicles, an 18-hour cold soak was used. This cold soak consisted of beginning cooldown at 1200 hours and performing the start attempt at 0800 hours the following day. If a vehicle failed to start, the temperature in the trailer was raised by opening the doors. The vehicle was then started and idled for 10 minutes to purge the unburned fuel from the combustion chamber. Otherwise, the unburned fuel could adversely affect the next start attempt. The starting procedures for the carbureted V-6 vehicles were:

- Turn ignition key on and wait 30 seconds.
- Push the accelerator to the floor and slowly release. Repeat this procedure two more times.
- Crank the engine with no throttle for a maximum of 15 seconds. If the engine fails to start, wait a minimum of 30 seconds and try again.
- Perform three start attempts. Continue to perform start attempts using the throttle at 1/4 to 1/2 open until the cranking rpm decrease.
- If the engine fails to start, it must be started later to purge any fuel remaining in the combustion chamber.

The ignition on the V-6 vehicle was turned on 30 seconds early in order to preheat the fuel grid heater under the carburetor prior to pumping the accelerator, thus optimizing fuel vaporization. The three pumps provided a very rich starting mixture, which is in keeping with the cold starting procedure from the S-10 owner's manual.

For the 2.5L L-4 engine, the starting procedure was:

> With no throttle, crank the engine for a maximum of 15 seconds. If the engine fails to start, wait a minimum of 30 seconds and try again. If the engine still fails to start, depress the accelerator and hold while cranking for

a maximum of 15 seconds. Continue to attempt starts until the cranking rpm decreases. If the engine fails to start, it must be started later to purge any fuel remaining in the combustion chamber.

2. Gasoline-Fueled Vehicles

The gasoline control vehicles were tested first to establish baseline data against which to compare the methanol vehicles. Test temperatures for the gasoline vehicles were begun at 0°F (-18°C) since these vehicles were designed to start under sub-zero conditions. Each start attempt began by recording before-test conditions. These data consisted of oil sump, fuel, exhaust pipe, and inlet air temperatures; and engine, fuel, date, operator, lubricant, and initial battery voltage. The start attempt was timed with a stop watch for the desired 15 seconds of cranking time. During the start attempt, cranking speed and cranking amps were recorded on a strip-chart recorder to provide a permanent record of the starting conditions and to allow judgments of the validity of a start attempt. After the start attempt, the aforementioned temperatures were recorded again. The number of stopwatch seconds to start was also recorded. The gasoline vehicles were tested with an SAE 40 lubricant with a BofA additive and with a winter grade unleaded fuel.

3. Methanol-Fueled Vehicles

The same starting procedures used for the gasoline vehicles were also used for the M85 vehicles. Beginning test temperature for the M85 vehicles was ambient temperature (83°F) (28°C) in order to assure good warm weather startability. Test temperatures were lowered until both vehicles failed to start. The limit of cranking time was the limit of the battery. Start attempts were continued until a noticeable drop in cranking rpm was evident, which generally required 4 to 10 attempts, depending upon temperature and battery condition.

Early in the testing, the methanol-fueled L-4 vehicle demonstrated very poor startability. Even at ambient temperatures, the vehicle was difficult to start. Conversations with BofA personnel indicated that there was a probable maladjustment of the fuel injection system. The fuel injection system was adjusted by cold tuning the vehicle using a carbon monoxide meter and the BofA procedure to provide the richest starting mixture that the specification would allow. This adjustment was intended to optimize cold startability and it improved cold startability markedly.

Several different configurations of the M85 vehicles were tested. Minimum starting temperature was first obtained for both vehicles using M85 fuel and an SAE 40 lubricant with BofA additive. Then the vehicles were tested with M85 fuel and a 10W-30 lubricant. The fuel was then changed to M82 (82 percent methanol + 18 percent winter grade unleaded gasoline), and the same 10W-30 lubricant was used.

In addition to the fuel and lubricant changes, an electric block heater was used on the L-4 vehicle. Since the L-4 vehicle had demonstrated poorer startability than the V-6, the reasoning was that if the L-4 would start with the block heater, then the V-6 would also. The 110-volt, 1000-watt block heater was connected to the heater hoses of the engine. A variable transformer (variac) varied the voltage to the heater and provided 700 watts of heat to the engine. In practice, the heater was turned on 20 hours before each start attempt. The full 1000 watts of power was not used since the heater was sized for larger vehicles than the L-4.

4. Test Problems

During the tests, several problems arose. The refrigerated trailer was replaced due to a cooling system failure. Since the refrigeration system required fueling every 48 hours, it was difficult to run a start attempt on Monday mornings. In order to run five tests per week, it was necessary to start the cooldown cycle on Sundays. An attempt was made to measure relative humidity in the cold box in order to account for its effects in the analysis of the cold start data. This was difficult since it required a person to enter the cold box to perform the measurement. A person entering the cold box before the test allowed entry of ambient air and disturbed the initial test temperatures. In addition, many of the test temperatures were below the operating range of the humidity meter [32°F (0°C) to ambient]. After several humidity measurements, the portable humidity instrument failed, and further measurements were abandoned.

During the tests with the block heater, the oil sump temperature increased along with the water temperature. In all other tests, the oil sump temperature was used as the test temperature since it represents a thermal mass and is more representative of average temperature. For the block heater tests, the fuel temperature (in the small fuel container) was recorded as the test temperature.

III. DISCUSSION OF RESULTS

A. Gasoline-Fueled Vehicles

The gasoline control vehicles were successfully started at 0°F (18°C). Refrigeration equipment limitations did not permit testing at temperatures much lower than 0°F. The cold starting of the gasoline vehicles was very dependent on the purging of unburned fuel from previous start attempts. Therefore, each vehicle was run for 10 to 15 minutes after starting to assure uniform starting conditions for the next test. This is a realistic condition, since the vehicle will be cold soaked after running for extended periods of time in the field. Part of this effect may be due to the interaction of the computer-controlled fuel mixture on each engine. The objective of the baseline runs was met since both gasoline-fueled vehicles demonstrated good startability at the limits of the refrigeration equipment.

B. Methanol-Fueled Vehicles

Cold starting data for the V-6 and L-4 methanol vehicles are tabulated in Appendices A and B, respectively. Several runs were invalidated by failure to crank until the battery voltage declined, improper use of the block heater, nonadherence to the starting procedure, or a short cold-soak period. These runs are noted in the appendices.

Starting time versus temperature for the V-6 methanol vehicle is plotted in Fig. 2. Start attempts in which the engine failed to start are not shown on the graph but are indicated as no start (NS) in Appendix A. Curves associated with the data points are least squares curve fits. Equations for the lines and R^2 statistics are shown in TABLE 4. Starting time (Y) is in seconds and temperature (X) is in °F. In Fig. 2, a line is drawn indicating the 45-second cranking limit. The limit of 45

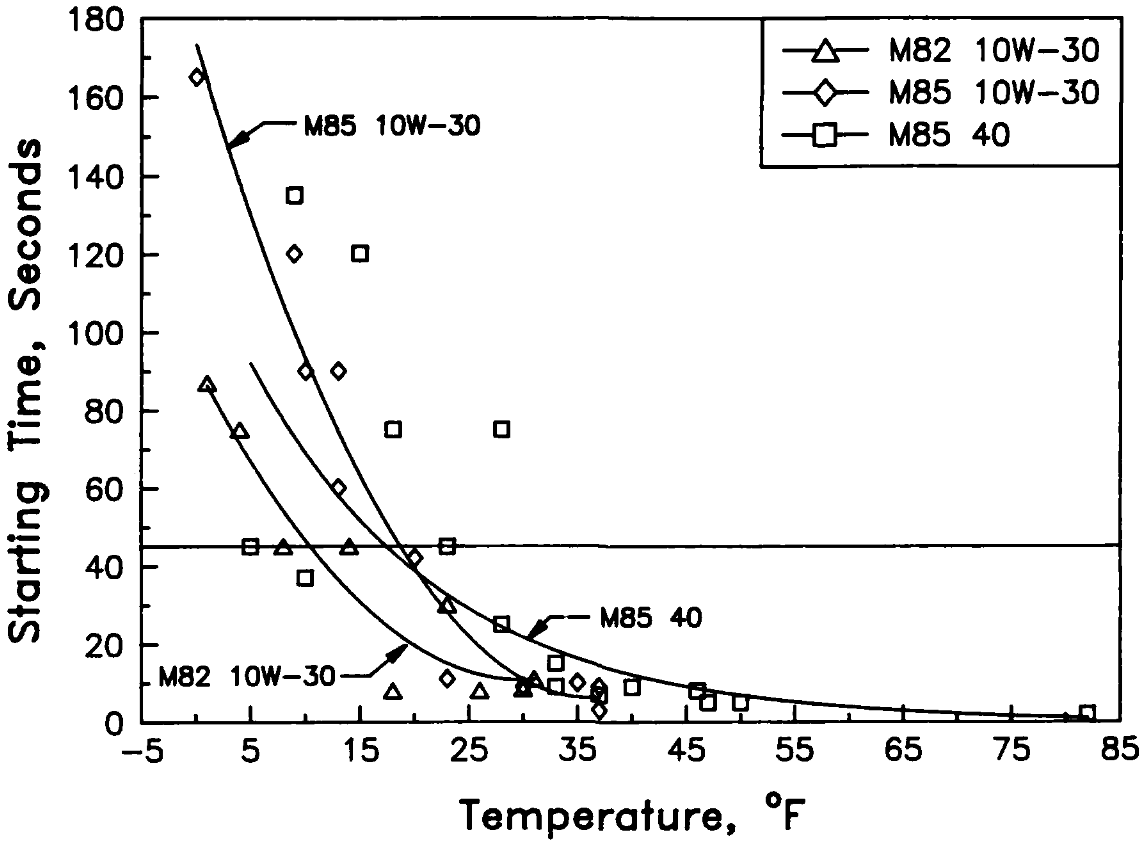

Figure 2. V-6 Methanol Vehicle Cold Startability

TABLE 4. Starting Time Prediction Equations for V-6 Methanol Vehicle

For M85 fuel/SAE 40 lubricant, $Y = 122.89E^{(-0.0578X)}$
$R^2 = 0.774$

For M85 fuel/10W-30 lubricant, $Y = 0.128X^2 - 9.262X + 1731.13$
$R^2 = 0.960$

For M82 fuel/10W-30 lubricant, $Y = 0.091X^2 - 5.418X + 91.622$
$R^2 = 0.902$

seconds was chosen as the limit of startability since it represents three start attempts of 15 seconds each.

This is, in reality, a very long cranking time and is close to the practical limit that a cold battery will sustain. The fully charged batteries of the test vehicles represent a best case in terms of cranking duration. Warm batteries were not used since this would be considered an additional modification (starting aid). Data above the 45-second line should be considered applicable only to fully charged starting systems in good repair, and in which the operator attempts starting until the battery is exhausted. A great deal of scatter is evident in the data. This scatter is virtually unavoidable in cold starts due to the complexity of the starting process. To obtain more accurate curves would require extensive testing and a large number of data points to average. Obtaining this data would be costly in terms of money and time since each start attempt requires a cold soak of 20 hours to be realistic.

Referring again to Fig. 2, the use of the 10W-30 lubricant had little effect at the warmer temperatures, but did lower the low temperature starting by approximately 5 degrees. This lower starting temperature was probably the result of increased cranking time made possible by the decreased viscosity of the multiviscosity lubricant. This benefit begins to take effect in the 5° (-15°C) to 10°F (-12°C) range.

Use of the M82 fuel with the 10W-30 lubricant significantly improved cold startability of the V-6 engine. Use of this combination decreased the minimum starting temperature by approximately 10°F (-12°C) when compared to the M85/SAE 40 configuration. This is probably a vapor pressure and volatility effect coupled with the increased cranking times made possible by the multiviscosity lubricant.

Fig. 3 depicts the starting data from the L-4 engine. Note that more engine configurations were tested since this engine received a coolant-heater starting aid. The M85/SAE 40 RECAL curve is similar to the M85/SAE 40 curve except allowable fuel injection system was recalibrated to provide the richest starting mixture that by BofA conversion procedure. This optimization produced an improvement in startability of approximately 17°F (-8°C). Again, all curves are least-squares curve fits. A reference line is drawn at the 45-second cranking time. The M85/10W-30 curve is very short, although not from lack of colder start attempts but from the fact that all start attempts lower than 37°F (3°C) failed. The M82/10W-30 curve

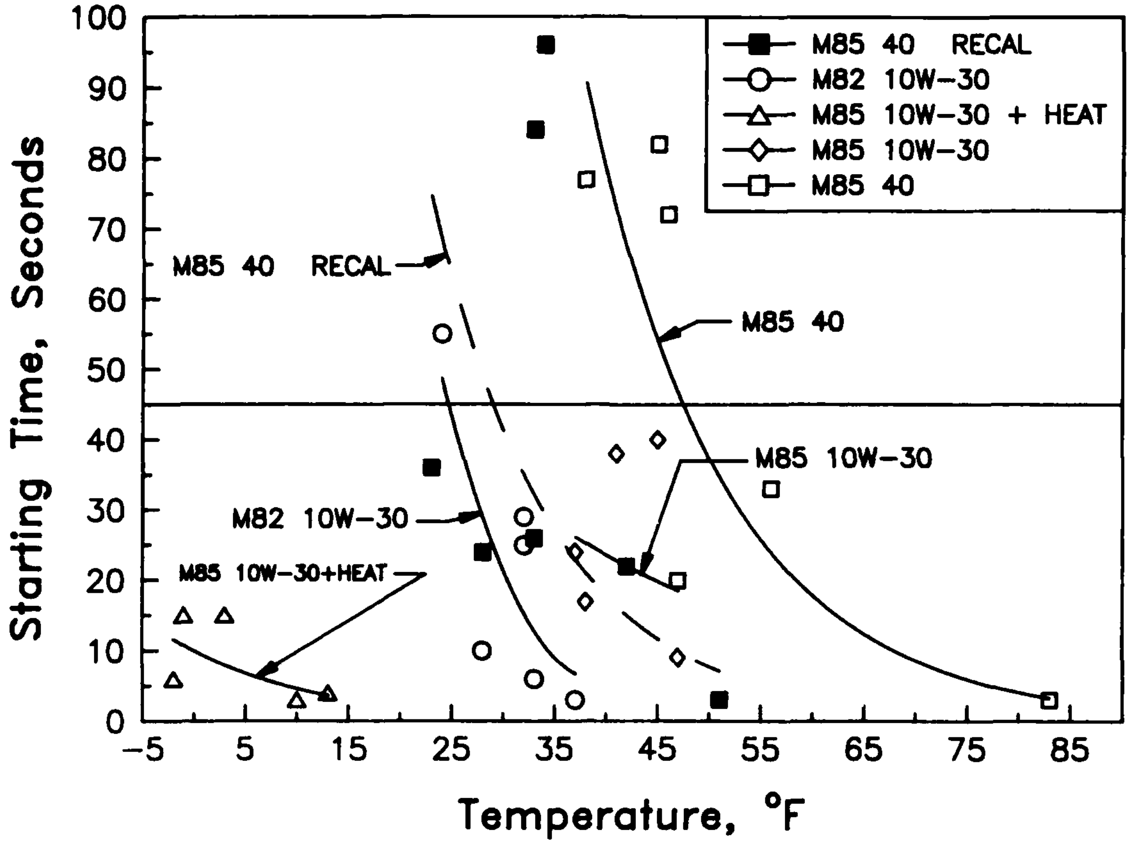

Figure 3. L-4 Methanol Vehicle Cold Startability

is 5 to 10 degrees shifted from the M85/SAE 40 curve, indicating that the combination of M82 volatility characteristics and 10W-30 viscosity characteristics is beneficial to the startability of the L-4 engine.

The M85/10W-30+HEAT curve indicates that the use of the block heater can enable easy starts, even at sub-zero temperatures. This improvement is significant, since the retrofit of block heaters is an easy procedure that should extend the usable temperature range of these vehicles. This, of course, assumes that 120-volt electric power is available in those areas at which the vehicles will park for extended periods of time, and that personnel will plug them in. As noted earlier, temperatures for this curve were obtained from the fuel containers rather than the oil sumps since the oil sump receives some heat from the block heater. TABLE 5 lists the starting time prediction equations for the L-4 vehicle.

TABLE 5. Starting Time Prediction Equations for L-4 Methanol Vehicle

For M85 fuel/SAE 40 lubricant, $Y = 1495.83E^{(-0.0738X)}$
$R^2 = 0.858$

For M85 fuel/10W-30 lubricant, $Y = 93.874E^{(-0.0345X)}$
$R^2 = 0.059$

For M85 fuel/10W-30 lubricant, and heat, $Y = 9.928E^{(-0.0776X)}$
$R^2 = 0.481$

For M82 fuel/10W-30 lubricant, $Y = 0.188X^2 - 14.685X + 292.94$
$R^2 = 0.611$

For M85 fuel/SAE 40 lubricant, recalibrated, $Y = 517.368E^{(-0.0842X)}$
$R^2 = 0.457$

Fig. 4 depicts minimum starting temperatures for each of the configurations tested. For purposes of this illustration, minimum starting temperature is taken

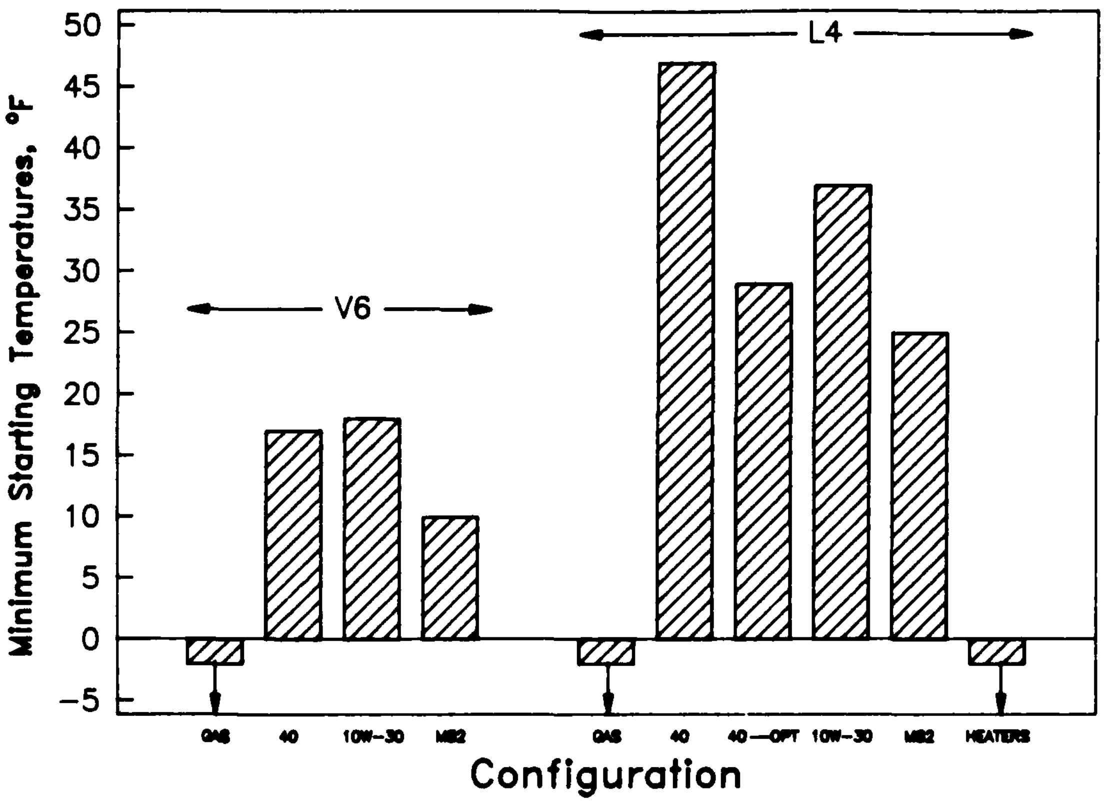

Figure 4. Methanol Vehicle Minimum Starting Temperatures

as the point where each curve from Fig. 2 and 3 crosses the 45-second line. In real terms, the minimum starting temperature shown in Fig. 4 approximates the minimum temperature at which a persistent operator, following the extreme cold start procedure from the owner's manual, could start his vehicle. As in any real-life situation, uncertainties exist that could skew the minimum starting temperatures. Humidity, battery conditions, starting procedure, and fuel system maintenance are but a few of the factors that can affect cold startability. The results obtained herein are from only two vehicles and do not represent the composite average of an entire fleet. Nevertheless, valid trends and approximate starting temperatures were obtained.

IV. CONCLUSIONS

- Gasoline control vehicles demonstrated good cold startability at sub-zero temperatures with a winter grade gasoline and an SAE 40 lubricant.

- The carbureted V-6 methanol vehicle demonstrated significantly better cold startability than the throttle-body injected L-4 engine. This better startability is thought to be due to the heated grid beneath the carburetor, as well as to the better initial mixture control afforded the operator by this configuration. In a fleet of vehicles, the L-4 vehicle would be the limiting case in terms of cold startability.

- Below temperatures of 47°F (8°C), the L-4 vehicle with M85 fuel/SAE 40 lubricant will experience starting problems. This temperature limit can be reduced to approximately 25°F (-4°C) by optimizing (enriching) the fuel mixture, and using M82 fuel (higher volatility) with a multiviscosity lubricant. Sub-zero starts are possible using a block heater, M85 fuel, and a 10W-30 lubricant.

- Below temperatures of 20°F (-7°C), the V-6 vehicle with M85 fuel/SAE 40 lubricant will experience starting problems. This temperature limit can be reduced to approximately 10°F (-12°C) by using M82 fuel and a 10W-30 lubricant. Use of a block heater on this vehicle should enable sub-zero starts even using M85 and an SAE 40 lubricant.

V. RECOMMENDATIONS

- Starting aids should be used for these vehicles when temperatures are expected to drop below 47°F (8°C). Block heaters should be considered since good sub-zero startability was obtained in this test program.

- A multiviscosity lubricant should be used in these vehicles for extreme cold weather (<15°F) (<-9°C) starting. This would require cooperation with BofA in order to formulate in the correct anti-wear additive.

- The use of a higher volatility fuel (M82) should be considered for cold weather starting in lieu of starting aids. BofA should be consulted before doing this, however, since deposit or emission problems may result.

- Additional cold start testing of these vehicle configurations, while desirable to obtain more representative cold starting limits, would probably not be economically justifiable.

VI. REFERENCES

1. U.S. Army Methanol-Fueled Administrative Vehicle Demonstration Program, Southwest Research Institute, 1986.
2. Bank Of America internal publication, "Bank Of America 82-84 GM 4-Cylinder (Injected) Methanol Conversion."
3. Bank Of America internal publication, "Bank Of America 81-84 Citation and S-10 Methanol Conversion."
4. 1985 GM S-10 Owner's Manual.

APPENDIX A
COLD-STARTING DATA FOR V-6 METHANOL VEHICLE

COLD-STARTING DATA FOR V-6 METHANOL VEHICLE

Inlet Air Temperature, °F (°C)	Oil Sump Temperature, °F (°C)	Exhaust Temperature, °F (°C)	Fuel Temperature, °F (°C)	Cranking Time, Seconds
		SAE 40 Lubricant/M85 Fuel		
80 (-0.5)	82 (28)	78 (25)	80 (27)	2
46 (8)	46 (8)	46 (8)	46 (8)	8
46 (8)	46 (8)	47 (8)	46 (8)	8
45 (7)	47 (8)	45 (7)	47 (8)	5
48 (9)	50 (10)	50 (10)	50 (10)	5
35 (2)	40 (4)	43 (-6)	44 (7)	9
36 (2)	37 (3)	39 (4)	37 (3)	7
26 (-3)	28 (-2)	28 (-2)	26 (-3)	NS
26 (-3)	28 (-2)	28 (-2)	27 (-3)	25
27 (-3)	28 (-2)	28 (-2)	28 (-2)	75
32 (0)	33 (0.5)	34 (1)	33 (0.5)	15
32 (0)	33 (0.5)	34 (1)	32 (0)	9
22 (-6)	23 (-5)	23 (-5)	22 (-6)	45
17 (-8)	18 (-8)	18 (-8)	17 (-8)	75
12 (-11)	15 (-9)	13 (-11)	12 (-11)	120
6 (-14)	9 (-13)	7 (-14)	9 (-13)	135
-1 (-18)	2 (-17)	1 (-17)	-1 (-18)	NS
8 (-13)	10 (-12)	9 (-13)	9 (-13)	37
3 (-16)	5 (-15)	5 (-15)	4 (-16)	45
		10W-30 Lubricant/M85 Fuel		
17 (-8)	20 (-7)	19 (-7)	19 (-7)	42
6 (-14)	10 (-12)	10 (-12)	10 (-12)	90
1 (-17)	6 (-14)	14 (-10)	9 (-13)	NS
3 (-16)	5 (-15)	4 (-16)	3 (-16)	NS
8 (-13)	9 (-13)	10 (-12)	8 (-13)	120
12 (-11)	13 (-11)	14 (-10)	12 (-11)	60
-2 (-19)	0 (-18)	2 (-17)	-3 (-19)	165
-3 (-19)	-1 (-18)	1 (-17)	-2 (-19)	NS
28 (-2)	30 (-1)	30 (-1)	30 (-1)	9
38 (3)	37 (3)	38 (3)	36 (2)	3
23 (-5)	23 (-5)	24 (-4)	23 (-5)	11
12 (11)	13 (-11)	13 (-11)	12 (-11)	90
32 (0)	35 (2)	32 (0)	31 (-0.5)	10
34 (1)	35 (2)	35 (2)	34 (1)	10
36 (2)	37 (3)	37 (3)	35 (2)	9

NS = No Start.

COLD-STARTING DATA FOR V-6 METHANOL VEHICLE (CONT'D)

Inlet Air Temperature, °F (°C)	Oil Sump Temperature, °F (°C)	Exhaust Temperature, °F (°C)	Fuel Temperature, °F (°C)	Cranking Time, Seconds
		10W-30 Lubricant/M82 Fuel		
25 (-4)	29 (-2)	29 (-2)	29 (-2)	54*
27 (-3)	30 (-1)	30 (-1)	29 (-2)	8.5
17 (-8)	18 (-8)	18 (-8)	16 (-9)	8
6 (-14)	8 (-13)	7 (-14)	5 (-15)	45
-4 (-20)	-1 (-18)	-3 (-19)	-4 (-20)	NS
11 (-12)	14 (-10)	10 (-12)	9 (-13)	45
2 (-17)	4 (-16)	2 (-17)	2 (-17)	75
0 (-18)	1 (-17)	ND	-1 (-18)	87
22 (-6)	23 (-5)	ND	21 (-6)	30
24 (-4)	26 (-3)	ND	24 (-4)	8
30 (-1)	31 (-0.5)	ND	30 (-1)	11
31 (-0.5)	32 (0)	ND	31 (-0.5)	40*

* = Dropped from analysis due to experimental error.
NS = No Start.
ND = No Data.

APPENDIX B
COLD-STARTING DATA FOR L-4 METHANOL VEHICLE

COLD-STARTING DATA FOR L-4 METHANOL VEHICLE

Inlet Air Temperature, °F (°C)	Oil Sump Temperature, °F (°C)	Exhaust Temperature, °F (°C)	Fuel Temperature, °F (°C)	Cranking Time, Seconds
SAE 40 Lubricant/M85 Fuel				
82 (28)	83 (34)	140 (60)	80 (27)	3
48 (9)	48 (9)	51 (10)	46 (8)	NS*
47 (8)	46 (8)	132 (55)	47 (8)	72
48 (9)	47 (8)	50 (10)	47 (8)	20
53 (12)	56 (13)	136 (58)	50 (10)	33
44 (7)	45 (7)	47 (8)	40 (4)	82
38 (3)	38 (3)	37 (3)	38 (3)	77
28 (-2)	28 (-2)	26 (-3)	29 (-2)	NS
28 (-2)	28 (-2)	127 (53)	27 (-3)	NS
29 (-2)	29 (-2)	28 (-2)	27 (-3)	NS
33 (0.5)	33 (0.5)	32 (0)	32 (0)	84
34 (1)	34 (1)	32 (0)	32 (0)	96
23 (-5)	24 (-4)	163 (73)	24 (-4)	NS*
10W-30 Lubricant/M85 Fuel, Block Heater				
43 (-6)	25 (-4)	19 (-7)	18 (-8)	45*
38 (3)	13 (-11)	10 (-12)	8 (-13)	NS*
38 (3)	13 (-11)	7 (-14)	1 (-17)	NS*
43 (-6)	20 (-7)	2 (-17)	3 (-19)	15
52 (11)	30 (-1)	10 (-12)	10 (-12)	3
53 (12)	32 (0)	11 (-12)	13 (-11)	4
45 (7)	17 (-8)	-4 (-20)	-2 (-19)	6
38 (3)	21 (-6)	-3 (-19)	-1 (-18)	15
10W-30 Lubricant/M85 Fuel				
31 (-0.5)	33 (0.5)	30 (-1)	29 (-2)	NS
39 (4)	38 (3)	100 (38)	38 (3)	17
23 (-5)	24 (-4)	21 (-6)	22 (-6)	NS
13 (-11)	13 (-11)	13 (-11)	13 (-11)	NS
34 (1)	35 (2)	32 (0)	32 (0)	NS
35 (2)	36 (2)	33 (0.5)	34 (1)	NS
37 (3)	37 (3)	36 (2)	36 (2)	NS
44 (7)	45 (7)	41 (5)	42 (6)	40
40 (4)	41 (5)	40 (4)	38 (3)	38

NS = No Start.
* = Dropped from analysis due to experimental error.

COLD-STARTING DATA FOR L-4 METHANOL VEHICLE (CONT'D)

Inlet Air Temperature, °F (°C)	Oil Sump Temperature, °F (°C)	Exhaust Temperature, °F (°C)	Fuel Temperature, °F (°C)	Cranking Time, Seconds
		10W-30 Lubricant/M85 Fuel		
47 (8)	47 (8)	44 (7)	45 (7)	9
33 (0.5)	33 (0.5)	31 (0.5)	31 (0.5)	NS
37 (3)	37 (3)	36 (2)	35 (2)	24
30 (-1)	31 (0.5)	28 (-2)	28 (-2)	NS
		10W-30 Lubricant/M82 Fuel		
31 (-0.5)	32 (0)	30 (-1)	29 (-2)	29
31 (-0.5)	34 (1)	114 (46)	30 (-1)	92*
23 (-5)	23 (-5)	117 (47)	18 (-8)	NS
5 (-15)	5 (-15)	ND	5 (-15)	NS
38 (3)	37 (3)	36 (2)	35 (2)	3
24 (-4)	24 (-4)	100 (38)	22 (-6)	55
27 (-3)	28 (-2)	26 (3)	24 (-4)	10
32 (0)	32 (0)	31 (0.5)	29 (-2)	25
33 (0.5)	33 (0.5)	33 (0.5)	31 (-0.5)	6
		SAE 40 Lubricant/M85 Fuel, Re-runs		
42 (6)	42 (6)	42 (6)	41 (5)	22
51 (10)	51 (11)	50 (10)	50 (10)	3
33 (0.5)	33 (0.5)	30 (-1)	30 (-1)	26
28 (-2)	28 (-2)	27 (-3)	26 (-3)	24
24 (-4)	23 (-5)	21 (-6)	21 (-6)	36
19 (-7)	19 (-7)	16 (-9)	16 (-9)	NS

NS = No Start.
* = Dropped from analysis due to experimental error.
ND = No Data.

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