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AIRCRAFT CARBURETTOR ICING STUDIES

by

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SUMMARY

A study has been made of the effect of gasoline icing inhibitors on aircraft carburettor icing. An engine test was developed and used to evaluate various types of inhibitor. The results obtained showed that aircraft carburettor icing can be prevented by the inclusion of additives in the gasoline.

The use of a teflon-coated throttle plate to prevent ice adhesion was studied and found to virtually eliminate any ice formation on the plate. The use of ethylene glycol monomethyl ether at 0.10 - 0.15% by volume in the gasoline and the teflon-coated plate was shown to prevent both carburettor and fuel system icing.

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AIRCRAFT CARBURETTOR ICING STUDIES

1.0 INTRODUCTION

The problem of induction system icing in piston engine aircraft has long been recognized, and as early as 1921 a United States National Advisory Committee on Aeronautics Technical Note was published[1] suggesting that icing was a cause of otherwise inexplicable engine failures. A well publicised and documented accident attributed to carburettor icing was the loss of the British flying boat "Cavalier" in 1939[2]. During the period 1930-1946, 1094 cases out of 4833 reports of accidents and failures were attributed to carburettor icing[3].

Although the advent of turbine-powered aircraft has caused a marked reduction in the number of larger piston engine aircraft flying, the light aircraft population has increased. The problems associated with aircraft carburettor icing have therefore not diminished over the years. In a sample review of 1960 Canadian aircraft incidents 29.1% of engine problems were attributed to icing[4], and 44 accidents attributed to carburettor icing were reported in 1966-1967[5].

2.0 TECHNICAL BACKGROUND

Coles et al.[3] classify three types of induction system icing.

(a) Impact icing:	freezing of supercooled water droplets from the atmosphere on sub-freezing surfaces.
(b) Throttling icing:	freezing of water droplets or water vapour produced by the expansion of charge air as it passes through restrictions in the induction system.
(c) Fuel evaporation icing:	freezing of water droplets or vapour in charge air by the cooling produced by fuel evaporation.

In addition to induction system icing as classified above, undissolved water in fuel can freeze as it passes through lines, valves, or filters. This icing is generally termed fuel system icing.

Of the three types of induction system icing defined by Coles, fuel-evaporation or carburettor icing is considered the most significant and difficult to control, because of the wide range of climatic conditions over which it occurs and the difficulty in recognizing its inception.

To prevent carburettor icing, alcohol injection and carburettor heat have been used with success for larger aircraft. With light aircraft, however, the problem is still severe as evidenced by the number of incidents reported annually. The provision of heat theoretically should prevent carburettor icing; however, since the application of such heat can entail a 15% power loss[6], it is only used on a demand basis. Considerable pilot experience is required to detect carburettor icing because of the similarity of its symptoms to those of other engine problems. Application of heat can therefore often be delayed too long to prevent power failure. Induction system icing is not necessarily a cold weather phenomenon and while icing probability curves, of the type produced by the Department of Transport (see Fig. 1), can be used to predict its occurrence, they are not infallible.

Carburettor icing is not limited to aircraft and its occurrence in automotive applications has, until the past few years, received considerable attention and study. The published work in this field is too extensive to reference. Prior to the installation of anti-pollution devices, which provide sufficient carburettor heat to prevent icing, the automotive problem was solved mainly by the use of gasoline additives. The use of anti-icing additives in aviation gasoline has not been very extensive owing to the difficulties in obtaining government approval. Approval for the use of any aviation fuel additive is given only after extensive testing to show that its use does not adversely affect the performance of engine and airframe components. The use of an ethylene glycol monomethyl ether and glycerol mixture in aviation gasoline has been recommended[7)] as a means of preventing carburettor icing. This mixture, and more recently the ethylene glycol monomethyl ether (EGME) alone, have been used with success as jet fuel system icing inhibitors. The effectiveness of EGME or other materials as aircraft carburettor icing inhibitors has not been proven.

The National Research Council of Canada, at the request of the Department of Transport, has undertaken an investigation into the prevention of carburettor icing in aircraft by the use of gasoline-soluble inhibitors. The results of the investigation are presented in this Report.

In addition to, or instead of, using gasoline additives, the possibility of treating interior components of the carburettor on which ice is formed, to prevent ice adhesion, has been investigated. The results of this investigation are also presented.

3.0 EXPERIMENTAL DISCUSSION

3.1 General

The main purpose of the investigation was to determine whether or not aircraft carburettor icing could be inhibited by gasoline additives or by treatment of internal carburettor surfaces. The test procedure used would have to be quantitative in order to compare the relative effectiveness of the measures used.

An engine test procedure had therefore to be developed that:

(a) could produce sufficient carburettor ice to affect engine performance, and

(b) allowed engine performance to be monitored in such a way that the relative effectiveness of icing inhibitors, or other remedial measures, could be determined.

The investigation was not concerned with determining the effect of climatic and engine conditions on carburettor icing and it was possible only to select temperature, humidity, and throttle plate settings to give the most severe icing conditions.

The ability of any candidate carburettor icing inhibitors to provide protection against fuel system icing would be a useful adjunct. A test procedure was therefore developed to evaluate this property also (see Para. 5.0).

3.2 Carburettor Icing Test Equipment and Procedures

3.2.1 Engine Test Rig

The Fuels and Lubricants Laboratory is not equipped to do performance runs on aircraft engines; however an automotive engine, which is part of a hypoid gear lubricant test rig, was available. This engine is a V-8 of 283 cubic inch capacity that is coupled to two 800 hp dynamometers. The use of an automotive engine for aviation studies was considered acceptable, since the main use of the engine as far as our program was concerned was to draw charge air through the carburettor and volatilise gasoline. The automotive carburettor normally used on this engine was replaced by an updraft aircraft carburettor. The use of an updraft carburettor necessitated a special induction system to allow for reversal of the air/fuel flow direction (Fig. 2).

The 90° bend immediately above the carburettor and the flange attaching the bend to the carburettor were made from plexiglass to allow for visual observation of ice formation. This bend was attached at each end by couplings that allowed rapid disassembly for ice inspection and photography. The carburettor throttle shaft was fitted with a pointer leading to an arbitrary scale marked in degrees that allowed accurate re-setting of the throttle plate for consecutive runs.

Humidity and temperature control of charge air was obtained by installing an ice tower, of the type used in octane rating measurement (Ref. 8), upstream of the carburettor. With this control the inlet air was maintained at 37-40°F and 95-98% relative humidity. A trap was placed between the ice tower and the carburettor to prevent carry-over of water droplets.

3.2.2 Test Materials

3.2.2.1 Test Fuel

The test fuel used was aviation gasoline, grade 100/130 (conforming to CGSB Specification 3-GP-25e), typical inspection data of which is presented in Table A-1, Appendix A. Initially this fuel was used at room temperature, but it was found that harder and more durable ice was produced in the carburettor with cold fuel, allowing a longer time for inspection and photography after the completion of a test. The fuel was therefore cooled to about 37°F in an ice box, giving a fuel temperature of approximately 45°F at the carburettor.

3.2.2.2 Gasoline Additives

For automotive applications two types of carburettor icing inhibitor have been used:

(i) freeze point depressants, e.g. alcohols, glycols, and glycol-ethers

(ii) surface active materials, e.g. amine salts of phosphate esters, and pentaethylene oxide adduct of nonyl phenol.

The mechanism by which the type (i) materials function is by freeze point depression, while (ii) supposedly function by coating carburettor internals and reducing adhesion of the ice crystals. Reduction of ice particle size is also probably achieved by using surface active materials.

Materials evaluated are presented in Table B-1, Appendix B.

3.2.3 Carburettor Modifications, Teflon Coating

Although initially the program was designed to evaluate the use of gasoline additives, preliminary tests showed that ice formation occurred preferentially on the edges of the throttle plate and spread progressively across the plate face. Intermediate situations showed the formation of ice nuclei from which the spreading occurred. Consideration was given to attempting to reduce ice adhesion by coating the throttle plate and shaft with a low surface energy material. Since the coating would have to be permanent, gasoline or water-soluble materials were not suitable. Teflon coating appeared to offer the best solution and a spare throttle plate and shaft were coated with 0.00125" ± 0.00025" of teflon. The coated plate and shaft were inserted in the carburettor and subjected to the standard engine test identical with that used for screening gasoline additives.

3.2.4 Engine Test Program

As stated previously, throttle plate setting and temperature and humidity of the charge air were selected to give severe icing. The atmospheric conditions were controlled by the ASTM ice tower and maintained a charge air temperature and relative humidity of 37-40°F and 95-98%. Tests were made to determine the throttle plate setting that, without causing the engine to operate at too high rpm, produced detectable icing. It was found that the optimum plate setting was 40° on the arbitrary scale used, which approximated 70% of the maximum opening.

Initially the engine was operated under constant load and the rpm allowed to drop as ice formed. However it was difficult to obtain repeatable results by this method and an improvement was obtained by maintaining the engine rpm constant and monitoring engine operation by manifold vacuum readings to give an indication of power loss. The following test procedure was devised.

(a) Start engine on aviation gasoline maintained at room temperature, using air at room temperature and humidity.

(b) Bring engine to operating temperature and place in gear.

(c) Set the following conditions:

  (i) dynamometer rpm 900
  (ii) dynamometer load 100 lb
  (iii) throttle plate at 40° on arbitrary scale.

(d) Record manifold vacuum.

(e) Connect air inlet to ice tower to provide conditioned charge air and switch to cooled gasoline (5 gallons).

(f) Record manifold vacuum.

(g) Record at minute intervals

  (i) dynamometer rpm
  (ii) load

(iii) manifold vacuum
(iv) charge air temperature (wet and dry bulb)
(v) fuel temperature (tank and carburettor).

(h) Continue operation until engine labours or runs out of gasoline.

(i) Dismantle plexiglass inlet tube, visually observe ice conditions in the tube and inside the carburettor. Photograph if required.

4.0 RESULTS AND COMMENTS - CARBURETTOR ICING

The results obtained are presented in Appendix C. Ice formation occurred essentially on the throttle plate, building up at the edges to give the restriction in flow detected by changes in manifold vacuum. Initially the downstream (upper) face of the plate became iced and, depending on the conditions, ice then formed on the upstream (lower) face. Typical examples of icing are illustrated in Figures 3a, b, c, and d.

Although the manifold vacuum readings were used as the primary method of assessing ice formation, observation of visible ice was useful as a secondary measure. The ice rating system used in the Tables of Results is as follows:

Heavy: ice formation both faces of plate with a build-up of 1/8" - 1/4" on edges and at least 1/16" over centre of plate

Medium: ice formation mainly on upper face with a build-up of 1/16" - 1/8" on edges. Lower face only partially or lightly covered

Light: ice formation mainly on edges with build-up of up to 1/16". Centre of plate normally bare

Trace: few spots, usually on edges of screw heads.

The inside of the plexiglass tube immediately downstream of the carburettor normally also became coated with ice, although some additives had some effect on its formation. A description of this ice is given in the Tables of Results.

4.1 Baseline Carburettor Icing

Tests made with aviation gasoline not containing any icing inhibitor were used to establish a baseline performance. These tests were repeated at intervals during the program to ensure that baseline conditions were not varying. The tests were found to be repeatable and the results presented in Table C-1, Appendix C, are typical of all the baseline results. These three tests are also shown in Figure 4, and were obtained with a 21-day spread between the first and third tests.

The curves illustrate that the ice formation was immediate and continuous during a test. The rate of ice formation decreased towards the end of a test as the charge air became restricted because of freezing. The ice formed was white in appearance and quite hard.

4.2 Effect of Inhibitors on Carburettor Icing

4.2.1 Alcohols

The effect of alcohols on icing is illustrated in the results presented in Table C-2, Appendix C, and a comparison of baseline performance with three alcohols is shown in Figure 5. Some improvement in performance was obtained with the alcohols, although in no case was 100% icing inhibition approached. In all cases the ice that formed on the plate and in the inlet tube was very wet and melted easily. It is therefore possible that the application of only a limited amount of heat would keep the throttle plate clear. The relative effectiveness of the alcohols in preventing ice formation based on manifold vacuum change and visual appearance was found to be:

1-Propanol $>$ 2-Propanol $\simeq$ Methanol $\simeq$ 1-Butanol $>$ 1-Pentanol

4.2.2 Glycols

The two materials evaluated were hexylene glycol and ethylene glycol monomethyl ether (EGME), a glycol-ether. The former is commonly used in automotive gasoline as an anti-stall agent, while the latter is used as a jet fuel system icing inhibitor.

The effect of hexylene glycol on carburettor icing is presented in Table C-3 and Figure 6. At a concentration of 0.15% by volume, hexylene glycol limited ice deposition on the plate to a minimum and kept the plexiglass inlet tube clear. A marked fall-off in performance was noted if the hexylene glycol concentration was reduced to 0.10%.

The results presented in Table C-3 and Figure 6 show that ethylene glycol monomethyl ether was not quite as effective as hexylene glycol in preventing carburettor icing; it did however give better inhibition than any of the alcohols. There was no reduction in performance when the concentration was lowered to 0.10%, and in this respect ethylene glycol monomethyl ether is superior to hexylene glycol. This can be of importance since both additives can be extracted from fuel by water, and storage and transportation may cause a decrease below the effective concentration. As with the alcohols, any ice formed was very wet and melted easily.

4.2.3 Detergents

The effect of four proprietary surface active materials on carburettor icing is presented in Table C-4 and Figure 7. Three of these were found to give good inhibition. One, Additive C, completely prevented ice formation. The manufacturer's recommended dosage level of 200 ppm (or 70#/1000 bbl) for this additive is higher than the other additives.

As indicated previously, one mechanism by which these additives function is by coating the carburettor plate with a film to which ice is less adherent. With these additives (particularly Additive C) it was found that this film persisted for a while after removing the additive fuel. Consequently the barrel and plate of the carburettor had to be scrubbed with alcohol and iso-octane after each test to prevent interference with the next test.

Any ice formed with these additives was quite dry and hard.

4.2.4 Glycols/Detergents

A combination of three of the proprietary detergents and the glycols on carburettor icing was studied. Combinations of these additives at several concentrations were evaluated, some of the results of which are presented in Tables C-5 and C-6 and Figure 8. The concentration of detergent shown is the minimum found to give reasonable inhibition. The following combinations of additives were effective in preventing ice formation on the throttle plate.

0.15% hexylene glycol + 10# 1,000 bbl Additive A

" " " + 10# " " B

" " " + 35# " " C

0.15% ethylene glycol monomethyl ether + 20# 1,000 bbl Additive B

" " " " " + 70# " " C

The reduction in hexylene glycol concentrations to 0.10% was again shown to markedly decrease the performance obtained from the 0.15% concentration.

4.3 Effect of Teflon Coating on Carburettor Icing

Replacing the standard throttle plate and shaft with teflon-coated components produced a marked reduction in ice formation. The throttle plate was virtually clear and ice formed only where the uncoated part of the throttle shaft contacted the barrel wall. The addition of 0.15% by volume ethylene glycol monomethyl ether completely eliminated any ice in the carburettor and produced the smallest decrease in manifold vacuum of any of the tests. These results are presented in Table C-7 and Figure 9.

5.0 FUEL SYSTEM ICING STUDIES

As discussed in Section 2.0, lines, valves, screens, or filters in a fuel system can become blocked if undissolved water in the fuel freezes. The water may have been inadvertently carried over into the aircraft fuel system or it may have come out of solution in the fuel owing to cooling. This type of icing is called fuel system icing. Materials that are effective as carburettor icing inhibitors are not necessarily good fuel system icing inhibitors; this is particularly true of the detergent type materials. The ability of a material to inhibit both types of icing would be considered very beneficial. To assess the fuel system icing inhibiting properties of certain candidate carburettor de-icers, a small experimental program was established.

5.1 Fuel System Icing Test Rig and Procedure

To assess the fuel system icing inhibiting properties of certain candidate carburettor icing inhibitors, a small laboratory test rig, illustrated in Figure 10, was assembled. The rig consists of:

(a) an insulated gasoline reservoir containing a cooling coil capable of maintaining a fuel temperature of approximately 20°F

(b) a syringe pump, capable of quantitatively injecting water into the system over a wide range of concentrations

(c) a gasoline filter fitted with manometers up and downstream

(d) a gasoline suction pump

(e) a control valve to maintain flow rate

(f) a flowrator.

The gasoline was cooled in the reservoir to 20°F and then pumped through the filter system at a flow rate of 480 ml/minute. When the temperature of the fuel in the line stabilized at 26°F, water was added at a constant rate upstream of the filter. The pressure differential across the filter was recorded at periodic intervals and the flow rate maintained constant by the control valve. Filter blocking because of freezing was evidenced by a rapid increase in pressure differential. The time, at a particular water addition rate, to block the filter was recorded. If the pressure did not increase, the test was terminated after 18 minutes. Tests on a particular gasoline/additive mixture were repeated at higher water addition rates until filter blockage occurred in less than 18 minutes.

5.2 Results and Comments - Fuel System Icing

The results presented in Table D-1, Appendix D show that the order of fuel system icing inhibiting ability of the materials at the concentrations evaluated is:

Methanol > Ethylene glycol monomethyl ether > hexylene glycol.

The difference in inhibiting ability is quite marked at the concentrations used. These concentrations are controlled by solubility factors, and at equal concentrations ethylene glycol monomethyl ether would be expected to be superior to methanol.

6.0 CONCLUSIONS

The results obtained from the test procedure used in the investigation show that:

(a) Carburettor icing in aircraft can be prevented by the use of gasoline additives.

(b) Alcohols are not very effective carburettor icing inhibitors, although the ice produced when they are present in the fuel is easily removed. Methanol has been shown to be a good fuel system icing inhibitor.

(c) Hexylene glycol and ethylene glycol monomethyl ether were shown to be capable of eliminating most ice deposition.

(d) A combination of a proprietary detergent carburettor additive and 0.15% by volume of hexylene glycol or ethylene glycol monomethyl ether was shown to eliminate ice deposition.

(e) The 0.15% by volume concentration of hexylene glycol, either alone, or in combination with a detergent, is quite critical, and a marked deterioration in performance was noted with a lower concentration.

(f) Ethylene glycol monomethyl ether has fuel system icing inhibiting properties superior to hexylene glycol.

(g) Coating the throttle plate and shaft with teflon virtually eliminates ice deposition on the plate. Coating of the shaft at the point where it enters the barrel wall may be required to eliminate all ice depositions.

(h) The use of ethylene glycol monomethyl ether with the teflon-coated plate and shaft eliminated all ice deposition.

7.0 RECOMMENDATIONS

If it is considered preferable to avoid using anti-icing additives in aviation gasoline, the use of a teflon-coated throttle plate and shaft is recommended for the inhibition of carburettor icing. Extension of the coating may be required to prevent ice deposits where the throttle plate shaft enters the barrel wall.

The use of ethylene glycol monomethyl ether at a concentration of 0.10 to 0.15% by volume, in conjunction with the teflon-coated plate and shaft, would be recommended if the inclusion of this additive in aviation gasolines can be approved. This combination would inhibit both induction and fuel system icing.

The use of 0.10 to 0.15% ethylene glycol monomethyl ether or hexylene glycol plus 10 to 20#/1000 bbl. Additive B would be required for complete elimination of carburettor icing if teflon coating is not adopted.

This combination of additives would require extensive type and flight testing to ensure that there was no harmful effect on engine or airframe performance. If teflon coating is not used it may be considered preferable to limit the inhibitor to a single additive, and in this case the recommendation would be for ethylene glycol monomethyl ether at a dosage of 0.10 - 0.15% by volume. This recommendation is made on the basis of:

(i) The ability of EGME to reduce carburettor icing to a minimum, which, together with some heat from the aircraft, could cause complete elimination of icing. In the test procedure used very little or no heat soak-back was present.

(ii) The demonstrated efficiency of EGME as a fuel system icing inhibitor.

(iii) The extensive experience obtained with EGME in aviation turbine fuels.

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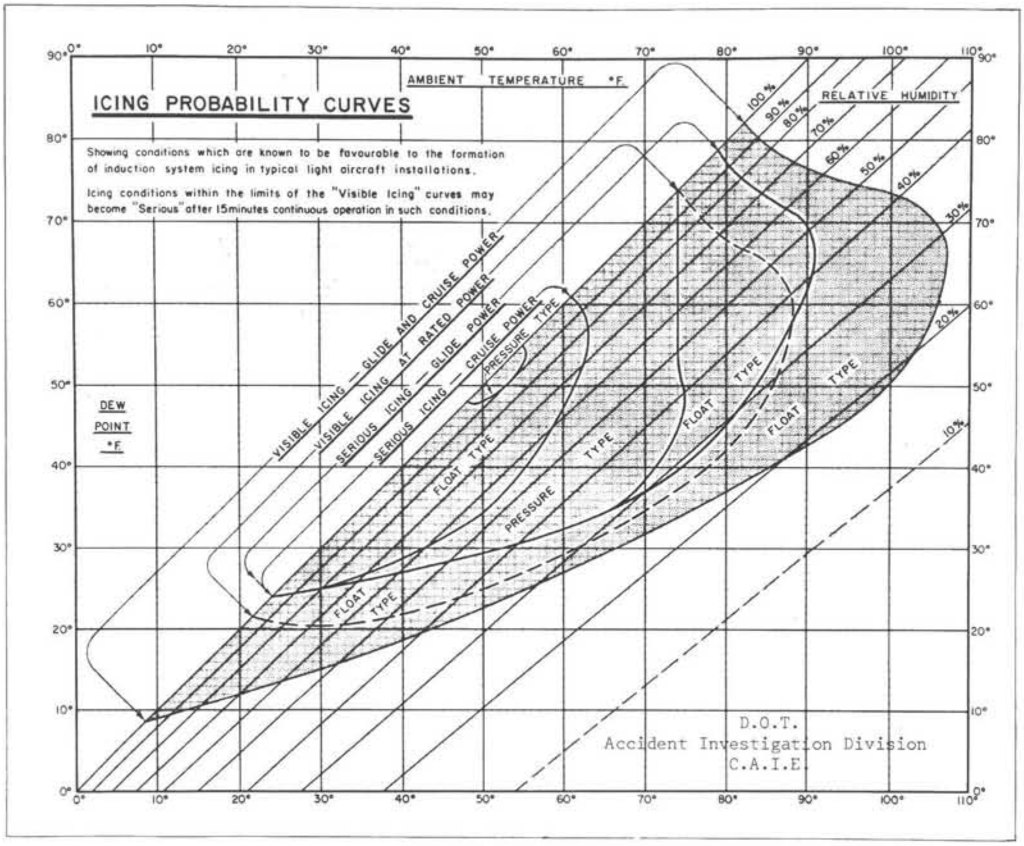


FIG. 1 : D O T ICING PROBABILITY CURVES

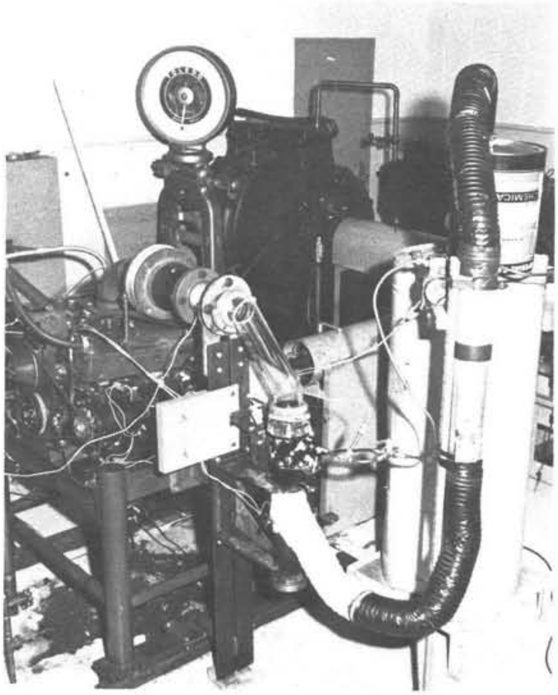
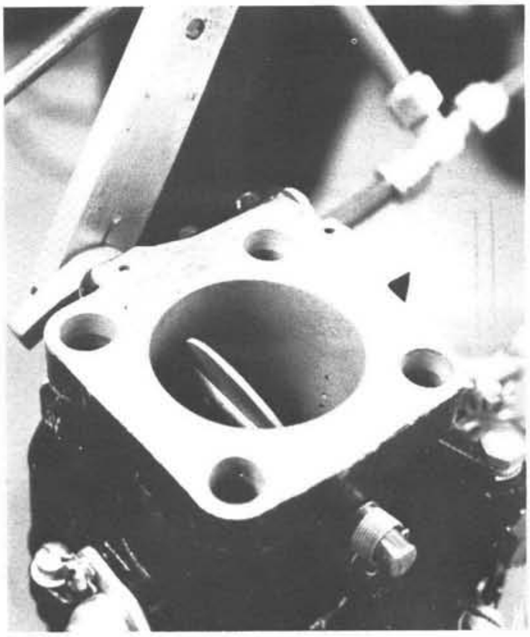
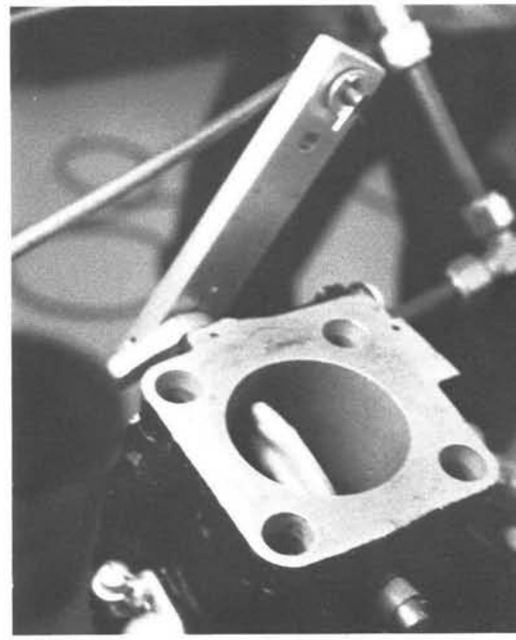


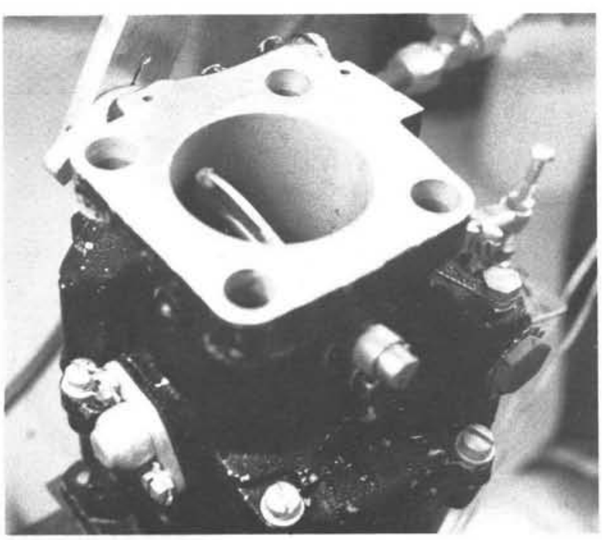
FIG. 2: ENGINE TEST RIG



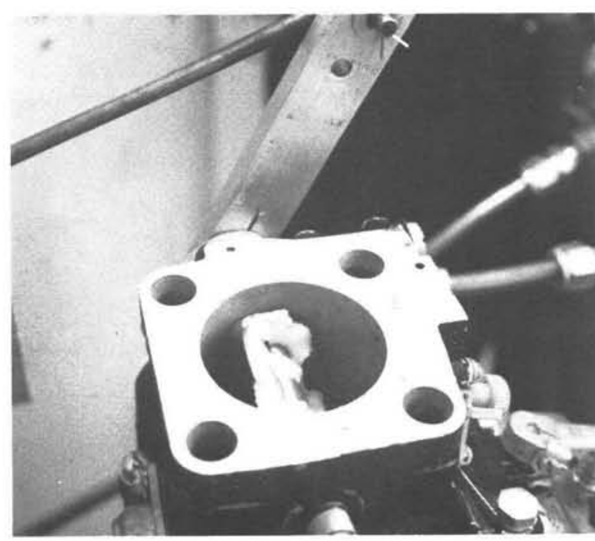
3a NO ICING



3c MEDIUM ICING



3b LIGHT ICING



3d HEAVY ICING

FIG. 3 : CARBURETTOR ICE FORMATION

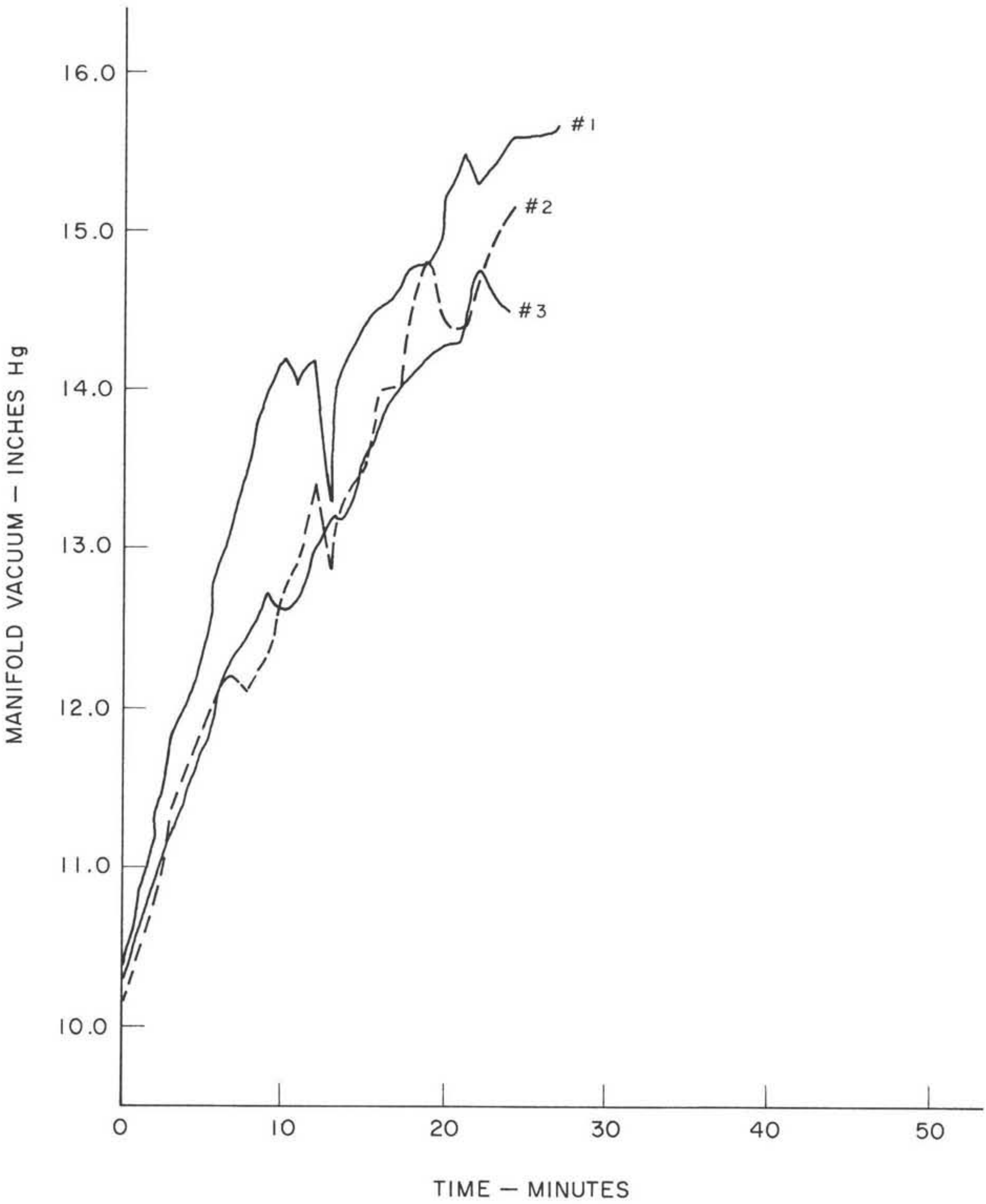


FIG. 4: BASELINE CARBURETTOR ICING

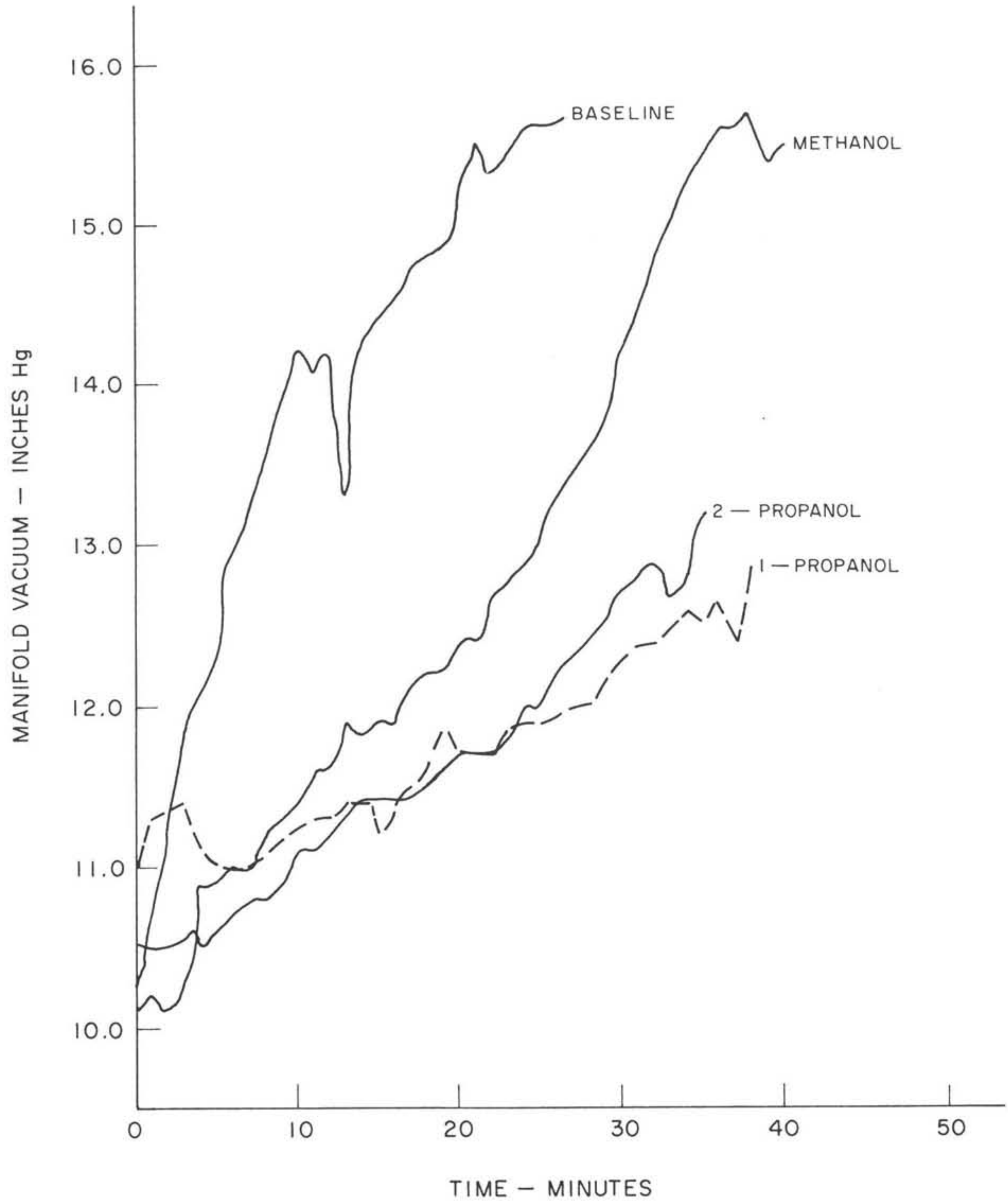


FIG. 5 : EFFECT OF ALCOHOLS ON CARBURETTOR ICING

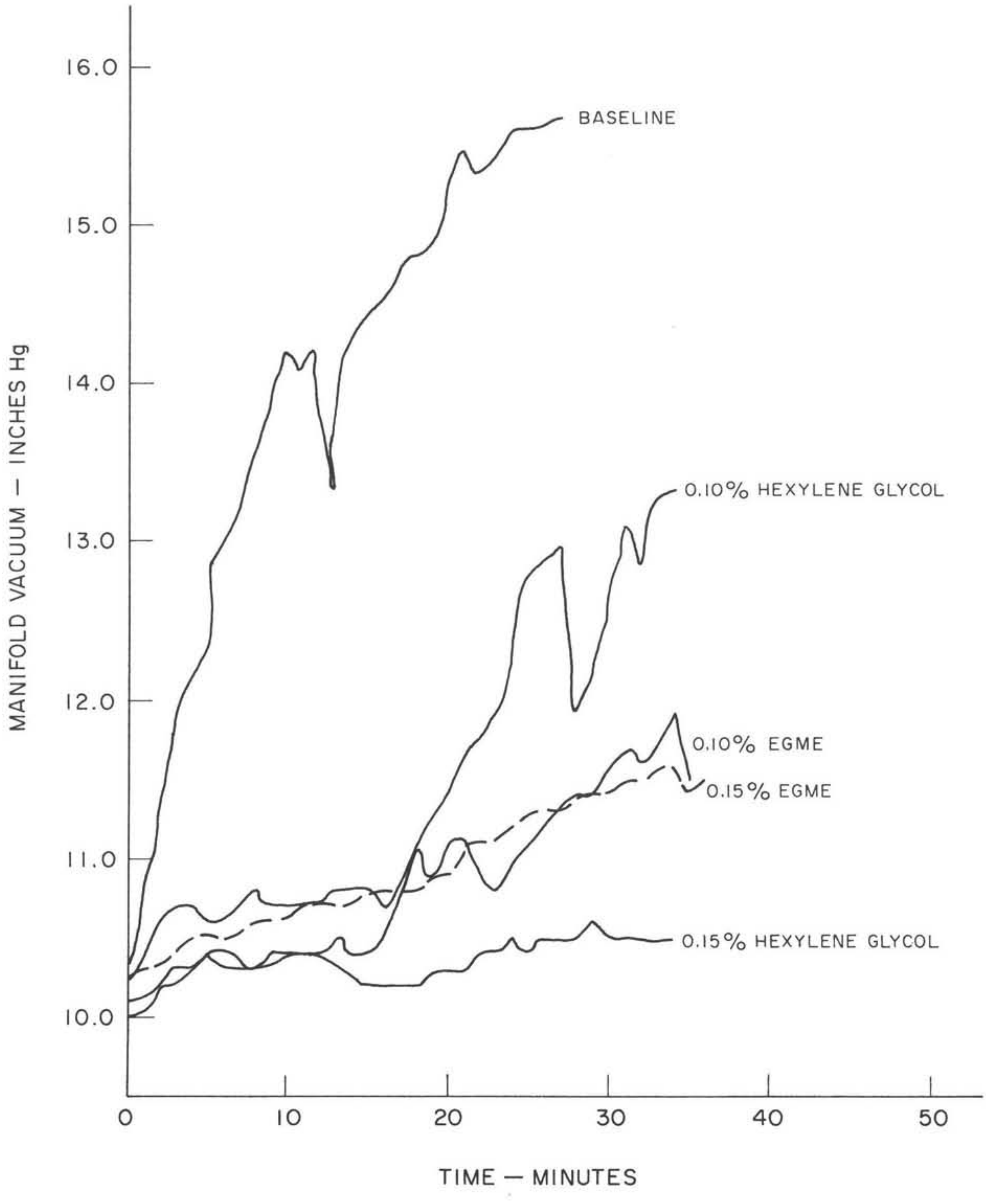


FIG.6 : EFFECT OF GLYCOLS ON CARBURETTOR ICING

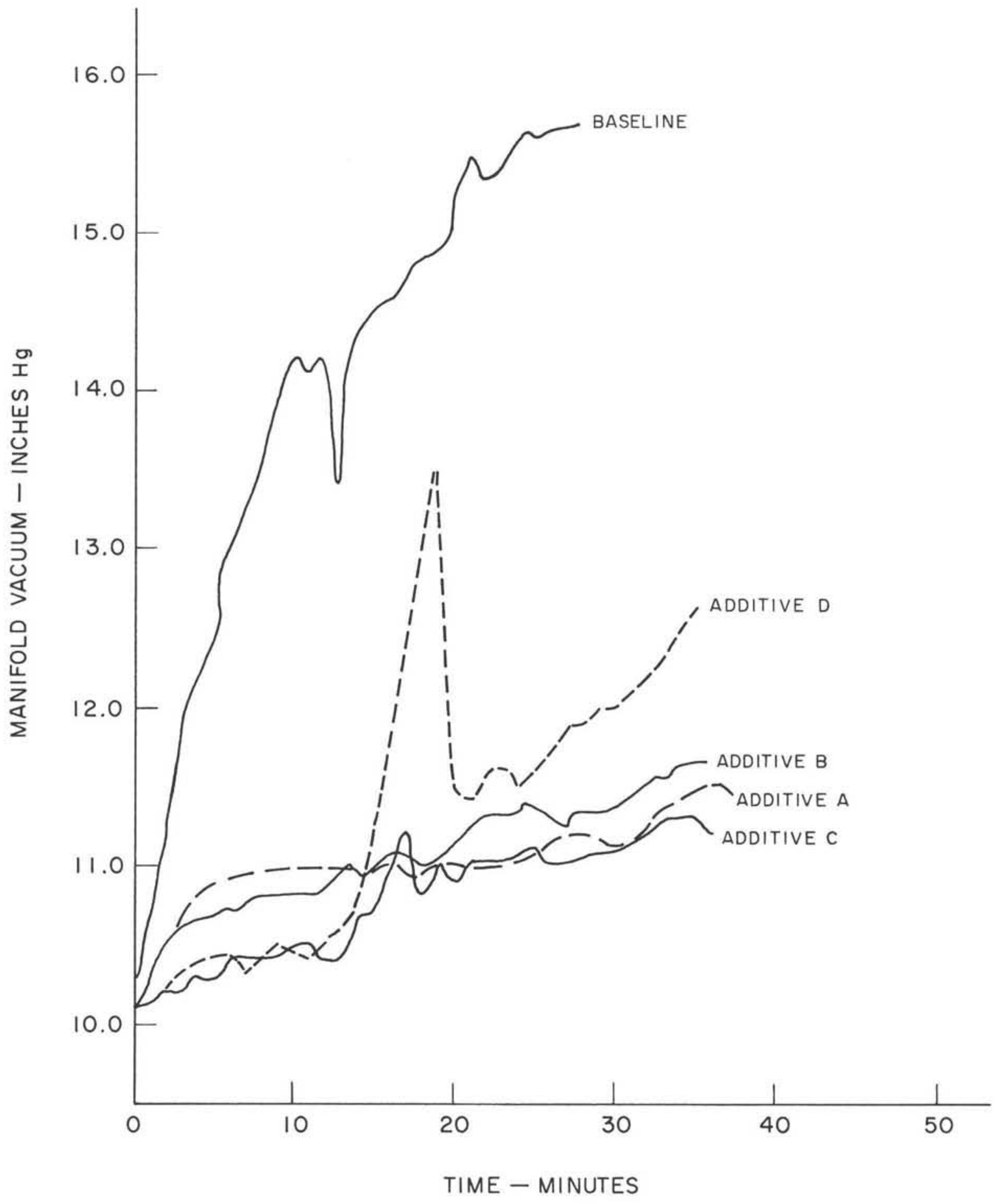


FIG. 7: EFFECT OF DETERGENTS ON CARBURETTOR ICING

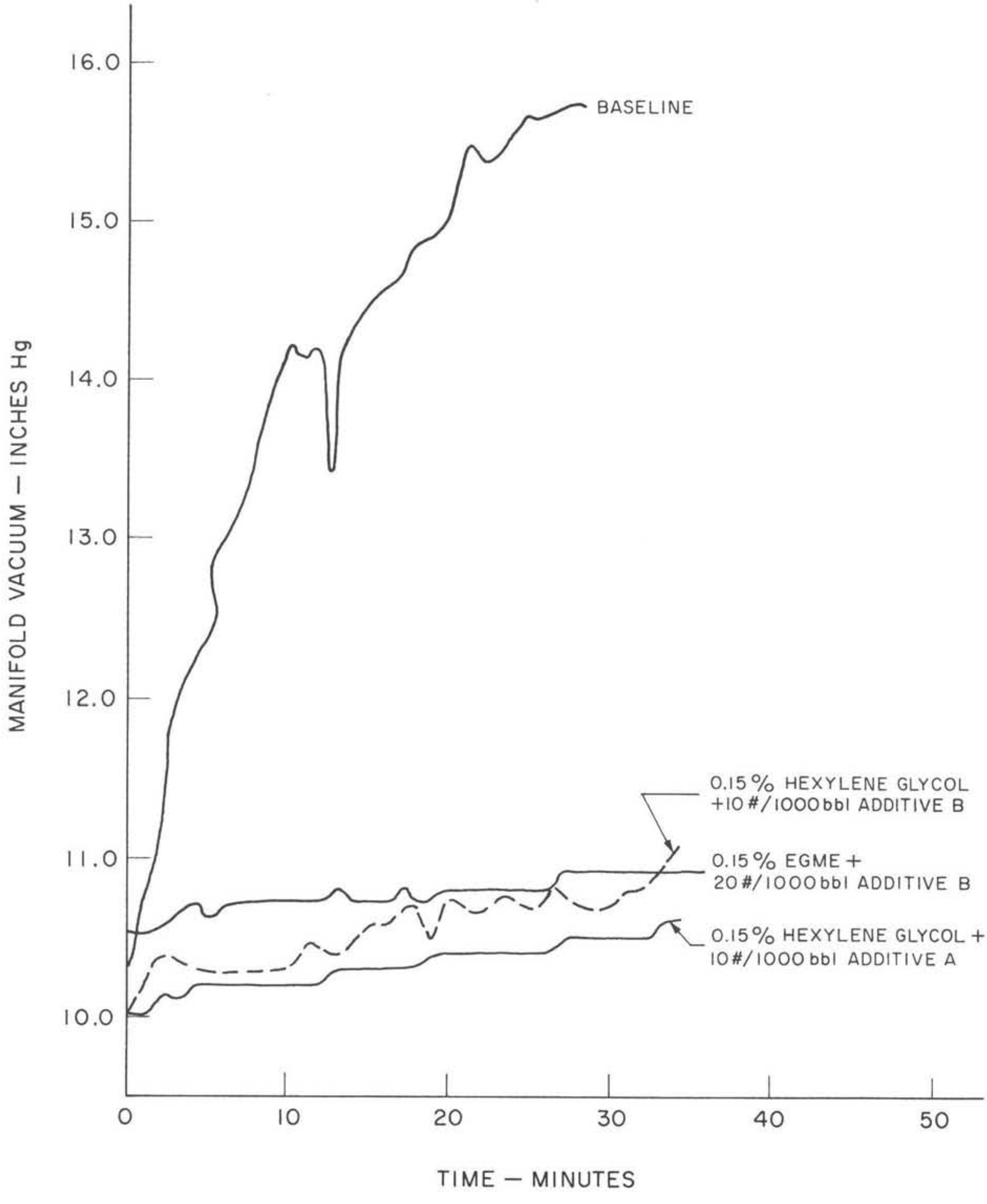


FIG. 8 : EFFECT OF GLYCOLS / DETERGENTS ON CARBURETTOR ICING

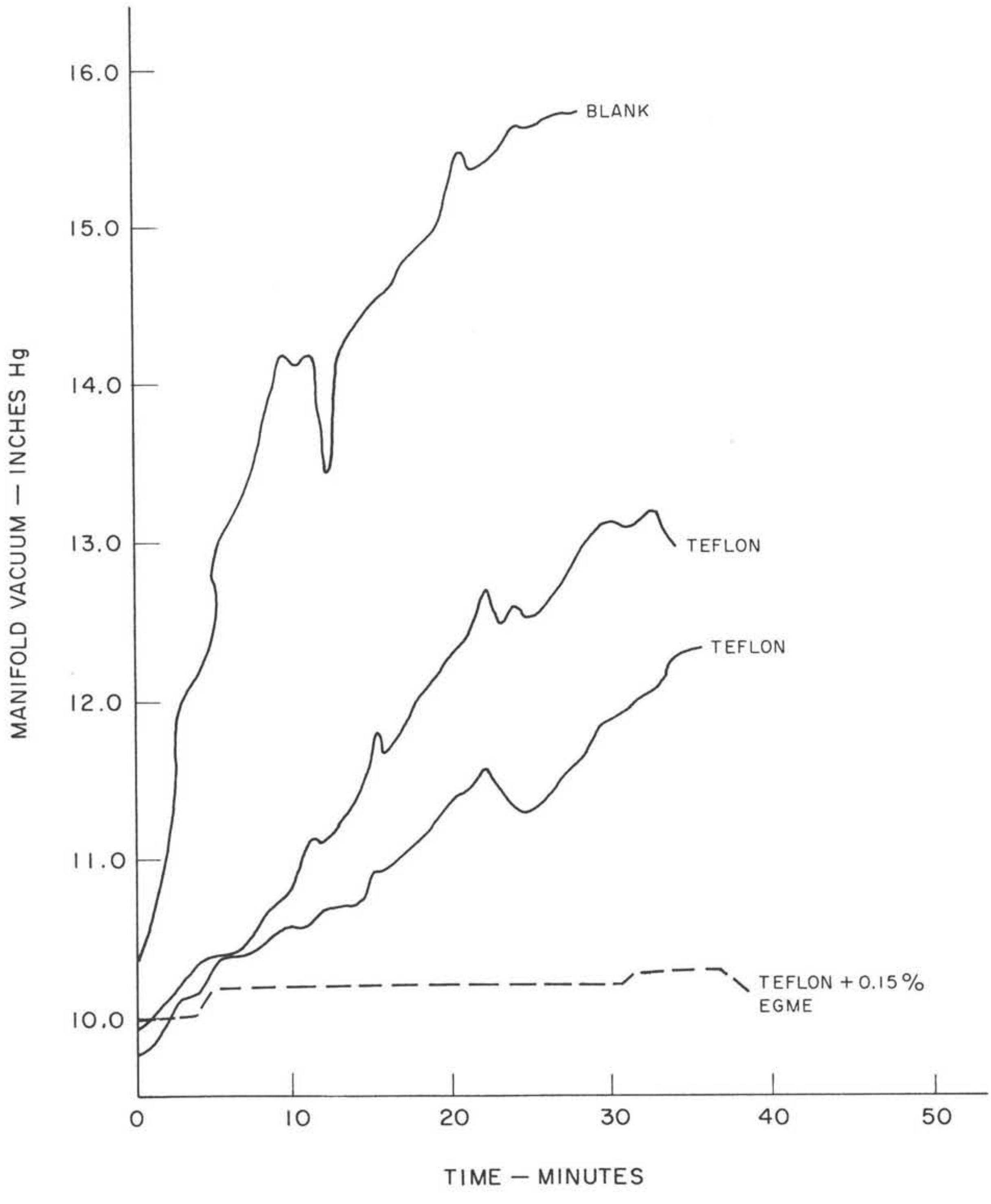


FIG.9: EFFECT OF TEFLON-COATED PLATE ON CARBURETTOR ICING

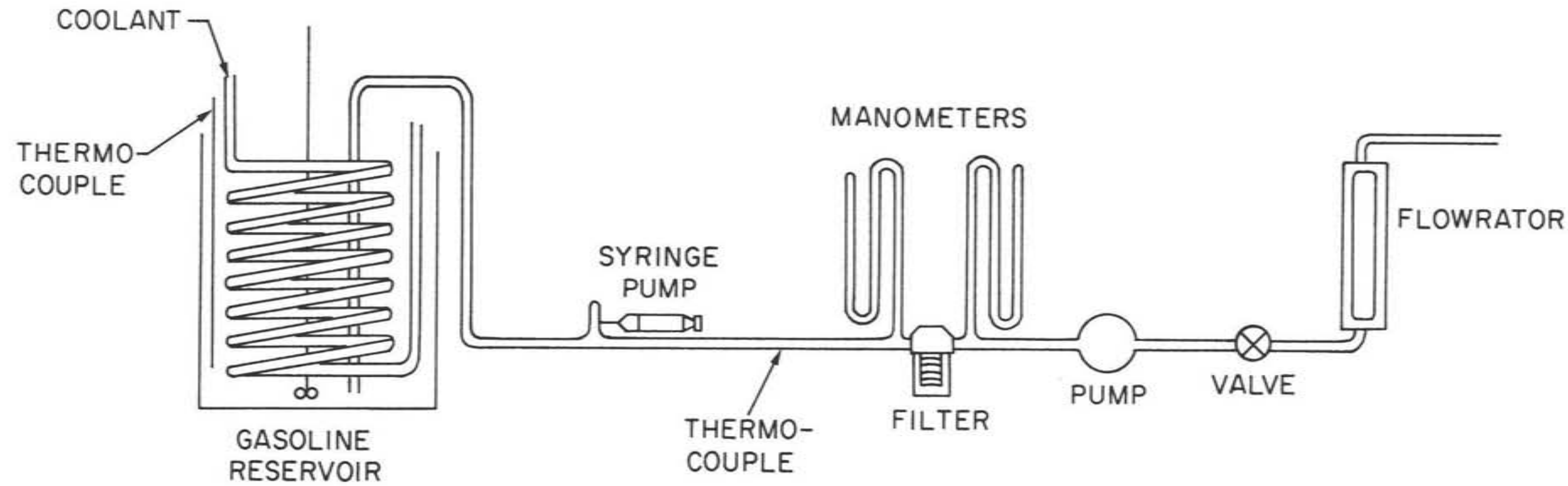


FIG. 10: FUEL SYSTEM ICING TEST RIG

APPENDIX A

TEST GASOLINE

The gasoline used in the program was Aviation Gasoline, 3-GP-25e, Grade 100/130. Typical properties are presented in Table A-1.

TABLE A-1

TEST GASOLINE PROPERTIES

Property	3-GP-25e Requirements		Test Fuel Properties	
	Minimum	Maximum		
(1) Distillation				
% Evaporated at 167°F (75°C)	10	40	14.0	16.0
" " " 221°F (105°C)	50	-	65.0	68.0
" " " 275°F (135°C)	90	-	97.0	96.0
End Point, °F, (°C)	-	338 (170)	322	311
Sum of 10% and 50% evaporated temperatures, °F	307	-	363	368
Residue, % volume	-	1.5	0.3	1.1
Distillation loss, % volume	-	1.5	0.6	0.4
(2) Reid Vapor Pressure, psi	5.5	7.0	6.4	5.8

APPENDIX B

ICING INHIBITORS

A list of icing inhibitors used in the program is presented in Table B-1.

TABLE B-1

ICING INHIBITORS

Additive	Type	Description
Methanol	Freeze Point Depressant	Monohydric primary alcohol b.p. 65°C
1-Propanol	"	Monohydric primary alcohol b.p. 97°C
2-Propanol	"	Monohydric secondary alcohol b.p. 82°C
1-Butanol	"	Monohydric primary alcohol b.p. 118°C
1-Pentanol	"	Monohydric primary alcohol b.p. 137°C
Hexylene glycol	"	Diol, b.p. 196°C
Ethylene glycol mono-methyl ether	"	Glycol-ether b.p. 200°C
A	Detergent	Proprietary multi-functional motor gasoline additive containing 5.1% by wt. phosphorus.
B	"	Proprietary ashless corrosion inhibitor-anti-stalling additive
C	"	Proprietary gasoline additive active ingredient amino propyl ether of tetra-ethoxylated nonyl phenol
D	"	Proprietary anti-stall additive active ingredient isononyl phenoxy tetraethoxy ethanol

APPENDIX C

TEST RESULTS - CARBURETTOR ICING*

TABLE C-1

BASELINE CARBURETTOR ICING

Fuel	Duration	Manifold Vacuum, "Hg			Temperature, °F		Ice Formation	
	(min)	P_1	P_2	ΔP	Fuel	Air	Plate	Tube
Avgas 100/130	23	10.1	15.1	5.0	38/46	38/39	heavy	covered
" " "	27	10.3	15.7	5.4	38/49	38/39	"	"
" " "	23	10.3	14.8	4.5	39/43	36/38	"	"

*Explanation of Table Headings

(1) Manifold Vacuum: P_1 initial vacuum

P_2 final

ΔP vacuum change

(2) Temperature °F

Fuel	Air
tank/carburettor	wet bulb/dry bulb

TABLE C-2

EFFECT OF ALCOHOLS ON CARBURETTOR ICING

Fuel	Duration	Manifold Vacuum, "Hg			Temperature °F		Ice Formation	
AVGAS 100/130 +	(min)	P_1	P_2	ΔP	Fuel	Air	Plate	Tube
Methanol (1% by vol)	40	10.1	15.5	5.4	40/52	38/39	heavy	covered
1-Propanol (1% by vol)	38	11.0	12.9	1.9	37/50	37/38	medium	covered
2-Propanol (1% by vol)	36	10.5	13.1	2.6	40/51	38/39	medium/ heavy	covered
1-Butanol (1% by vol)	32	10.8	14.6	3.8	43/49	38/39	heavy	covered
1-Pentanol (1% by vol)	27	10.4	14.4	4.0	39/50	38/39	heavy	clear

TABLE C-3

EFFECT OF GLYCOLS ON CARBURETTOR ICING

Fuel	Duration	Manifold Vacuum, "Hg			Temperature, °F		Ice Formation	
AVGAS 100/130 +	(min)	P_1	P_2	ΔP	Fuel	Air	Plate	Tube
Hexylene glycol								
(0.15% by vol)	35	10.0	11.1	1.1	37/51	39/40	light	partial
(0.15% by vol)	38	10.4	11.8	1.4	39/45	38/38	very light	partial
(0.10% by vol)	33	10.2	13.3	2.1	39/47	38/37	light/ medium	covered
Ethylene glycol monomethyl Ether								
(0.15% by vol)	36	10.2	11.5	1.3	40/45	37/38	light	covered
(0.15% by vol)	35	9.9	11.6	1.7	40/46	37/38	light	covered
(0.10% by vol)		10.0	11.4	1.4	40/46	37/38	light	covered

TABLE C-4

EFFECT OF DETERGENTS ON CARBURETTOR ICING

Fuel	Duration	Manifold Vacuum, "Hg			Temperature, °F		Ice Formation	
AVGAS 100/130 +	(min)	P_1	P_2	ΔP	Fuel	Air	Plate	Tube
Additive A (40#/1000 bbl)	38	10.1	11.4	1.3	44/47	37/38	trace	
Additive B (20#/1000 bbl)	36	10.1	11.6	1.5	36/49	37/38	trace	faint trace
Additive C (70#/1000 bbl)	36	10.1	11.2	1.1	40/49	37/38	nil	clear
Additive D (35#/1000 bbl)	35	10.0	12.6	2.6	38/44	37/38	medium	clear

TABLE C-5

EFFECT OF HEXYLENE GLYCOL/DETERGENT
ON CARBURETTOR ICING

Hexylene Glycol % vol	Detergent	Conc #1000 bbl	Duration (min)	Manifold Vacuum, "Hg			Ice Formation	
				P_1	P_2	ΔP	Plate	Tube
0.15	A	10	39	10.0	10.6	0.6	clear	partially covered
0.15	B	10	33	10.1	11.0	0.9	clear	covered
0.15	C	17.5	35	10.0	10.9	0.9	very faint trace	covered
0.15	C	35	32	10.1	10.7	0.6	clear	covered
0.10	A	10	33	9.9	11.1	1.2	trace	covered
0.10	B	10	34	9.8	11.8	2.0	trace	covered

TABLE C-6

EFFECT OF EGME/DETERGENT ON CARBURETTOR ICING

Ethylene Glycol Monomethyl ether % vol	Detergent	Conc #1000 bbl	Duration (min)	Manifold Vacuum, "Hg			Ice Formation	
				P_1	P_2	ΔP	Plate	Tube
0.15	A	40	39	10.5	12.6	2.1	trace	covered
0.15	B	20	36	10.5	10.9	0.4	clear	trace
0.15	C	70	34	10.3	10.7	0.4	very light trace on screw head	partial

TABLE C-7

EFFECT OF TEFLON COATING ON CARBURETTOR ICING

Fuel	Plate	Duration (min)	Manifold Vacuum, "Hg P_1	P_2	ΔP	Ice Formation
AVGAS 100/130	Standard	28	9.6	15.6	6.0	Very heavy ice formation on both sides of plate
" " "	Teflon-coated	34	9.8	13.0	3.2	Plate clear except for one or two spots. Some ice formation where uncoated part of shaft contacts barrel walls
" " "	"	36	10.0	12.3	2.3	As above
AVGAS +0.15% EGME	"	38	10.0	10.2	0.2	No ice on plate or barrel walls

APPENDIX D

TEST RESULTS - FUEL SYSTEM ICING

TABLE D-1

COMPARISON OF FUEL SYSTEM ICING PROPERTIES

Inlet Water Concentration	Time To Freeze Filter (Min)			
mg/liter	No Additive	EGME (0.15%)	Hexylene Glycol (0.15%)	Methanol (1.0%)
208	8	>18	>18	>18
350		>18	16	>18
500		>18	14	>18
1030		>18	7	>18
1940		>18		>18
3420		7		>18
8830				6