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EFFICIENCIES OF PETROLEUM DISTILLATES AS COOLING MEDIA FOR INTERNAL COMBUSTION ENGINES

by

Richard S. Apple

A Thesis Submitted to the Graduate Faculty
for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject Inorganic Chemistry

Approved:

Signature was redacted for privacy.

In charge of Major work

Signature was redacted for privacy.

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Signature was redacted for privacy.

Dean of Graduate College

Iowa State College
1936

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INDEX

INTRODUCTION

The internal combustion engine is today highly developed and widely used in the production of power. Probably its greatest use is found in furnishing the motive power for automobiles and trucks. Since the majority of such engines are not air-cooled, it becomes a problem of vital interest to the automobile and truck owners to know cheap and dependable cooling media, especially in cold weather.

Since various individuals have used petroleum distillates as cooling media for their automobile engines at various times and under various conditions, without knowing the effects of such cooling, it was considered logical, since the subject appears not to be recorded in the literature, to investigate the effects of petroleum distillates, such as kerosene or distillate, upon the motor and the cooling system.

This object is to be attained by a study of the actual cooling conditions in an automobile engine, the corrosive effect upon the cooling system, the effect upon the rubber hose connections, the fire hazard, and other minor points.

HISTORICAL

A. General Considerations

The desirable properties of an ideal cooling medium for internal combustion engines have been cited by Keyes (12) and Cummings (5). These properties may be grouped into two classes, major and minor. The major requirements are:

(1) The prevention of freezing of the cooling medium at the lowest temperature encountered.
(2) The absence of injury by corrosion to any metal parts of the engine or radiator.
(3) The failure to soften or deterioriate the rubber connections.
(4) The stability of the medium over the operating temperature range.
(5) The adequacy of the supply at a reasonable cost.

Of less importance are the following requirements:

(6) It should have a low viscosity at all working temperatures, permitting free circulation under the most adverse conditions.
(7) It should have a high heat capacity per unit volume.
(8) It should boil near the boiling point of water without decomposition.
(9) It should be non-inflammable.
(10) It should have no unpleasant odor.

(11) It should have a low coefficient of expansion.

(12) It should keep its properties for a long period of time.

(13) It should not attack the automobile finishes.

Various substances have been used as cooling media, and these will be briefly discussed. The foremost substance, of course, is water. Because of its abundance, its high heat capacity and low viscosity, it has been accepted as the standard cooling medium and engine design has taken this into account. But water does not meet all the qualifications outlined above. The most serious defect is the inability to use it at temperatures below 32°F. Water is also found to have a swelling effect on rubber (13), sometimes to the extent of 500 per cent (2) and this continuing even after 10,000 hours (20). In addition, it has a more or less severe corrosive action on metal, depending upon the characteristics of the water.

Because the chief disadvantage in the use of water is its high freezing point, the problem has been attacked from the angle of adding substances to the water to lower its freezing point and thereby increase its usable temperature range. Various salt solutions were tried and patented, but abandoned because of the severe corrosion encountered (24). Alcohol, both methyl and ethyl, find quite common use, but both have the objections of low boiling point, with subsequent loss, and a corrosive action. Radiator glycerine, a by-product from the soap industry, has had poor reception due largely to its insufficient refining. After a comparatively short time the material tends to gum up, clogging the cooling system. Ethylene glycol formulations are being used with much success, the chief disadvantage being the cost.

The use of petroleum distillates has been sporadic, and performance data are very limited. "Kerosene has been used with some success in cooling systems that were designed for water, although its heat capacity per unit volume is less than one-half that of water. It is safe as regards freezing, circulates with comparative freedom at low temperatures, and permits normal engine-temperature in very cold weather without the use of radiator covers or shutters. However, in less severe weather the high boiling point of kerosene may lead to serious over-heating of the engine. The odor and inflammability of its vapors and its action upon rubber are objections to the use of kerosene." (5). Shapiro and Valkov (19) have prepared an anti-freeze for automobile radiators remaining fluid at -60° to -70° C. from kerosene and the neutral oils obtained in wood distillation. Greenstreet (7) has patented a mixture of kerosene and oil of mirbane for use as a cooling medium at low temperatures.

B. Thermal Properties of Petroleum Distillates.

Kaye (11) has investigated the thermal conductivity of light petroleum oils and Bridgman (3) has studied the thermal conductivity of petroleum distillates under pressure. Tikhomirov and Zhuze (23) found the specific heat of kerosene distillate over the range 26°- 144° C. to vary between 0.4418 and 0.5936. Zhuze (26) investigated the thermal conductivity of Baku kerosene ($d_{15} = 0.8112$) and his results are tabulated in Table I.

Table I

Thermal Conductivity of Baku Kerosene

Temp. °C	Conductivity (cal/cm/sec/deg. C.)
20	0.400
30	0.474
50	0.574
110	0.725

Lang (13, 14) has given the following summary of kerosene from crude oil from British Borneo and Persia.

Table II

Properties of Kerosene from British Borneo Crude

Fraction	Boiling Range C°	Sp. Gr. 60/60F.	Mean Mol. Wt.	Sp. heat Cal/gm C	Coeff. Vol. Exp. Vol/C°
1	75-100	0.7583	88	0.4635	0.00118
2	100-125	0.7680	97	0.4615	0.00109
3	125-150	0.7862	108.5	0.4605	0.00104
4	150-175	0.8070	125	0.4582	0.00098
5	175-200	0.8295	140	0.4517	0.00092

Table III

Properties of Kerosene from Persian Crude

Fraction	Boiling Range C°	Sp. Gr. 60/60F.	Mean Mol. Wt.	Coeff. Vol. Exp. Vol/C°
1	75-100	0.7238	85	0.00126
2	100-125	0.7446	100	0.00117
3	125-150	0.7640	114	0.00110
4	150-175	0.7807	126	0.00102
5	175-200	0.7940	135	0.00097

Cragoe (4) has investigated various petroleum fractions and found that many of the thermal properties appear to vary systematically with temperature and with the density of the oils. Cragoe also presents the following equations, based on over 100 measurements within the temperature interval 32° to 400°F. on 30 petroleum distillates ranging in specific gravity at 60/60°F. from 0.75 to 0.96, with a difference between calculated and experimental values of less than 5 per cent.

$$c = \frac{1}{\sqrt{d}} (0.388 + 0.00045\ t) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

$$L = \frac{1}{d} (110.9 - 0.09\ t) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

$$H = \sqrt{d} (3.235\ t + 0.0001875\ t^2 - 105.5) \quad . \ . \ . \ . \ . \quad (3)$$

in which

d = specific gravity at 60/60°F.

t = temperature in °F.

c = specific heat in B.T.U. per pound per °F. or calories per gram per °C.

L = latent heat of vaporization in B.T.U. per lb.

H = heat content in B.T.U. per gal. at 60/60°F.

Upon the arbitrary assumption that kerosene might be represented by a distillate of 40 A.P.I. (sp. gr.=0.825) and fuel oil by a distillate of 30 A.P.I. (sp. gr.=0.876), the pertinent thermal properties presented by Cragoe are presented in Table IV.

Table IV

Thermal Properties of Distillates

Oil	Sp. Gr. 60/60°F.	Temp. °F.	K	C	L	H
Kerosene	0.825	0	1.00			
		100		0.477	123	215
		160		0.502	117	418
		200	0.94	0.526	113	560
		240		0.546	108	707
Fuel oil	0.876	0	0.94			
		100		0.463		222
		160		0.491		431
		200	0.88	0.511	106	577
		240		0.530	102	729

K = thermal conductivity in B.T.U. per hr., sq. ft. and °F. per in.

c = specific heat in B.T.U. per pound per °F.

L = latent heat of vaporization in B.T.U. per lb.

H = heat content in B.T.U. per gal. at 60/60°F.

C. Effect of Petroleum Distillates Upon Rubber

Dubose (6) has investigated the swelling of rubber in petroleum solvents and found that with a "white spirit" of specific gravity of 0.767 and an initial boiling point of 88°C., the major portion of which distilled at 140°C., the maximum swelling was attained in about 100 hours. Examination of the solvent at the end of the experiment showed approximately 9.7% of the rubber sample had gone into solution while the weight of the rubber had increased 72.5%. In all of the experiments quoted, the swelling occurred almost entirely in the first 24 hours. The phenomenon of rubber swelling in various organic liquids has also been investigated by Stamberger (21), Tanaka, Kambara and Noto (22) and Scott (16), who finds the swelling to be the resultant of two simultaneous processes: (1) Saturation of the rubber with liquid, which reaches a maximum and stops, and (2) a slow uniform increase in swelling.

Hayden and Krismann (8) have shown that rubber discs immersed in kerosene increase about 80% in volume at 82°F. in seven days and are completely disintegrated at 212°F. in eight days, whereas under the same conditions Duprene compounds swelled 22% and 37% respectively. In addition, they found that rubber compounds become very tender in warm kerosene and go to pieces in hot kerosene, whereas the Duprene compounds retain a large portion of their original strength and tear resistance.

Although vulcanizates highly resistent to oils can be prepared by proper formulation (25), there is yet to be seen a true oil-proof rubber (10). Ishiguro (9) states that the absorption of oil by vulcanized rubber diminishes with increase in hardness, whereas oil-resistant hose is made from the highest quality rubber, cured to its fullest tensile properties and often containing a flexible metal lining (1).

EXPERIMENTAL

A. Distillation Range

The distillation range of the materials used in this investigation,—six commercial kerosenes obtained on the market, sp. gr. at 60/60=0.81 to 0.82, a denatured alcohol, a commercial radiator glycerine and a commercial radiator glycol,—was determined by the A. S. T. M. method for kerosene, using A. S. T. M. specified equipment (17). The data are presented in Table V and shown graphically in Figures 1 to 7. Figures 1 to 6 also show the differential distillation curves for the kerosene samples.

Table V

Distillation Range (°F.) of Anti-freeze Solutions

	Kerosenes							Radiator	
	A	B	C	D	E	F	Alcohol	Glycerine	Glycol
Initial	330	352	348	346	350	369	168	219	325
10%	392	410	382	391	382	401	170	219	368
20%	404	422	393	404	392	414	170	219	374
30%	414	432	404	414	400	420	170	219	374
40%	422	439	412	422	408	426	170	219	374
50%	429	446	420	432	416	432	170	288	374

Table V (Continued)

	Kerosenes						Radiator		
	A	B	C	D	E	F	Alcohol	Glycerine	Glycol
60%	436	453	430	441	424	438	170	492	375
70%	443	461	441	450	434	444	171	522	376
80%	453	470	454	460	444	454	171	538	376
90%	468	485	470	476	469	468	172	620	378
End	495	514	494	485	504	499	368	Decomp.	410
Recovery	98.0	98.5	98.6	98.9	98.0	98.0	98.0	98.0	96.5
Residue	1.5	1.5	1.4	0.2	1.6	1.2	0.9	----	1.3
Loss	0.5	0.0	0.0	0.9	0.4	0.8	1.1	----	2.2

Distillation tests were also run on some of the kerosenes after they had been subjected to various tests. These data are presented in Table V-a.

B. Viscosity Measurements

The viscosities of the different substances were determined at both 0°C. and -32°C. using the Saybolt Universal Viscosimeter. The lower temperature was obtained by using solid crude bromobenzene as the "ice" in the bath. Solid CO_2 added to the system --- liquid C_6H_5Br:solid C_6H_5Br --- kept the temperature of the liquid in the inner cup at -32 ± 0.2°C. The results are given in Table VI.

Table V-a

Distillation Range (°F.) of Kerosenes after Various Treatments

	Kerosenes					
	1	2*	3*	4	5*	6*
Initial	384	381	380	363	368	379
10%	409	402	430	415	414	414
20%	417	---	---	428		
30%	421	420	445	436	430	432
40%	428			442		
50%	434	429	450	449	442	445
60%	440			456		
70%	447	447	466	464	459	461
80%	456			472		
90%	473	497	488	481	488	493
End	492	519	505	505	522	530
Recovery	97.8	95.6	95.5	98.0	98.4	96.9
Residue	1.7	3.2	3.0	1.6	0.6	2.1
Loss	0.5	1.2	1.5	0.4	1.0	1.0

Identification:

1- Kerosene F after 264-hour corrosion test
2- Kerosene F after test in black radiator hose
3- Kerosene B after test in red radiator hose
4- Kerosene B after 264-hour corrosion test
5- Kerosene B after rate of heating test in automobile
6- Kerosene B after road test to Salt Lake City, Utah.

* Results obtained by Chemistry Technology seniors, winter quarter, 1936, Iowa State College.

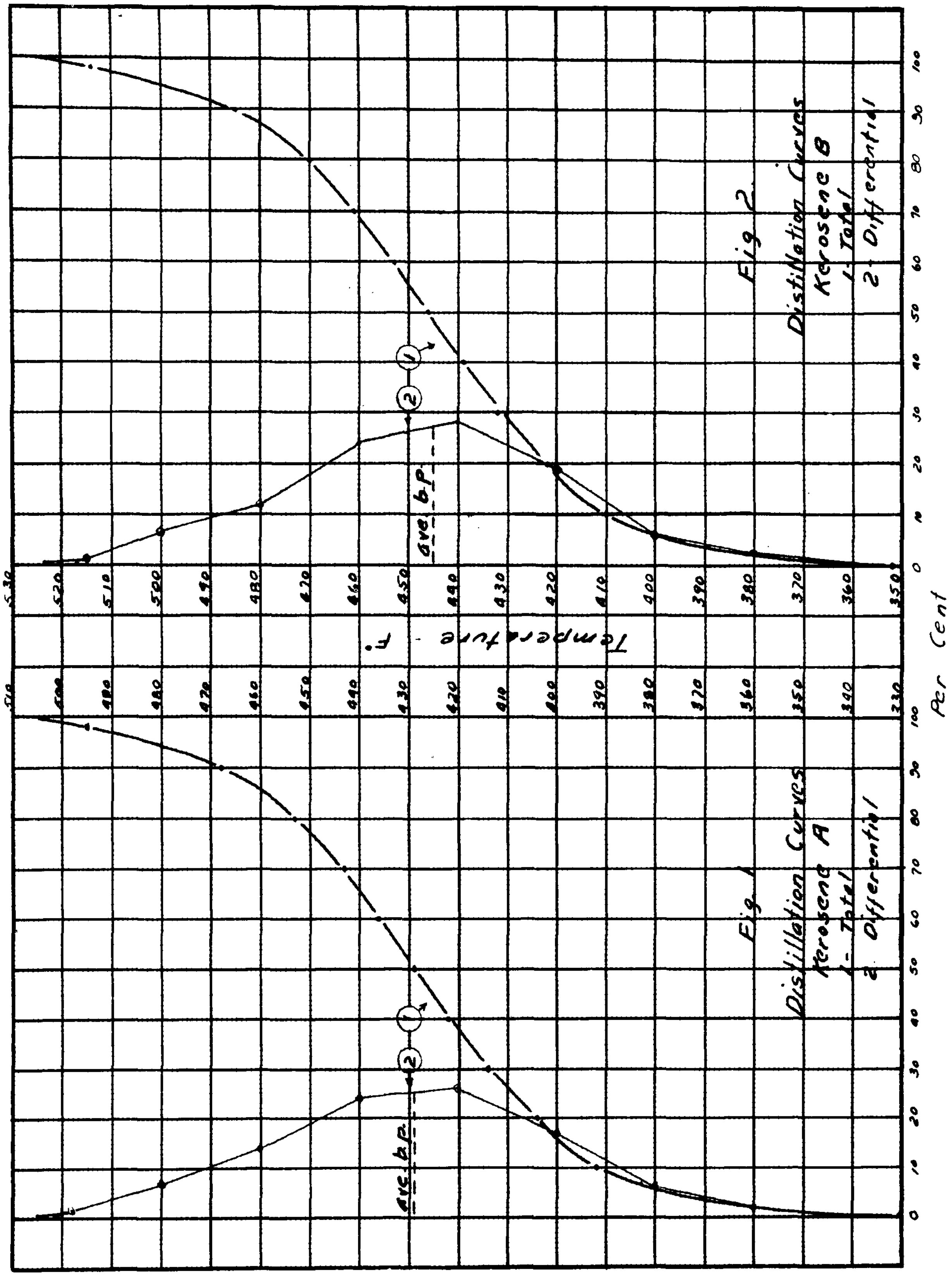


Fig 2
Distillation Curves
Kerosene B
1. Total
2. Differential
Fig 1
Distillation Curves
Kerosene A
1- Total
2 Differential
Temperature - F°
Per Cent
ave b.p.
ave b.p.
1
2
1
2
530
520
510
500
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
510
500
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
0
10
20
30
40
50
60
70
80
90
100

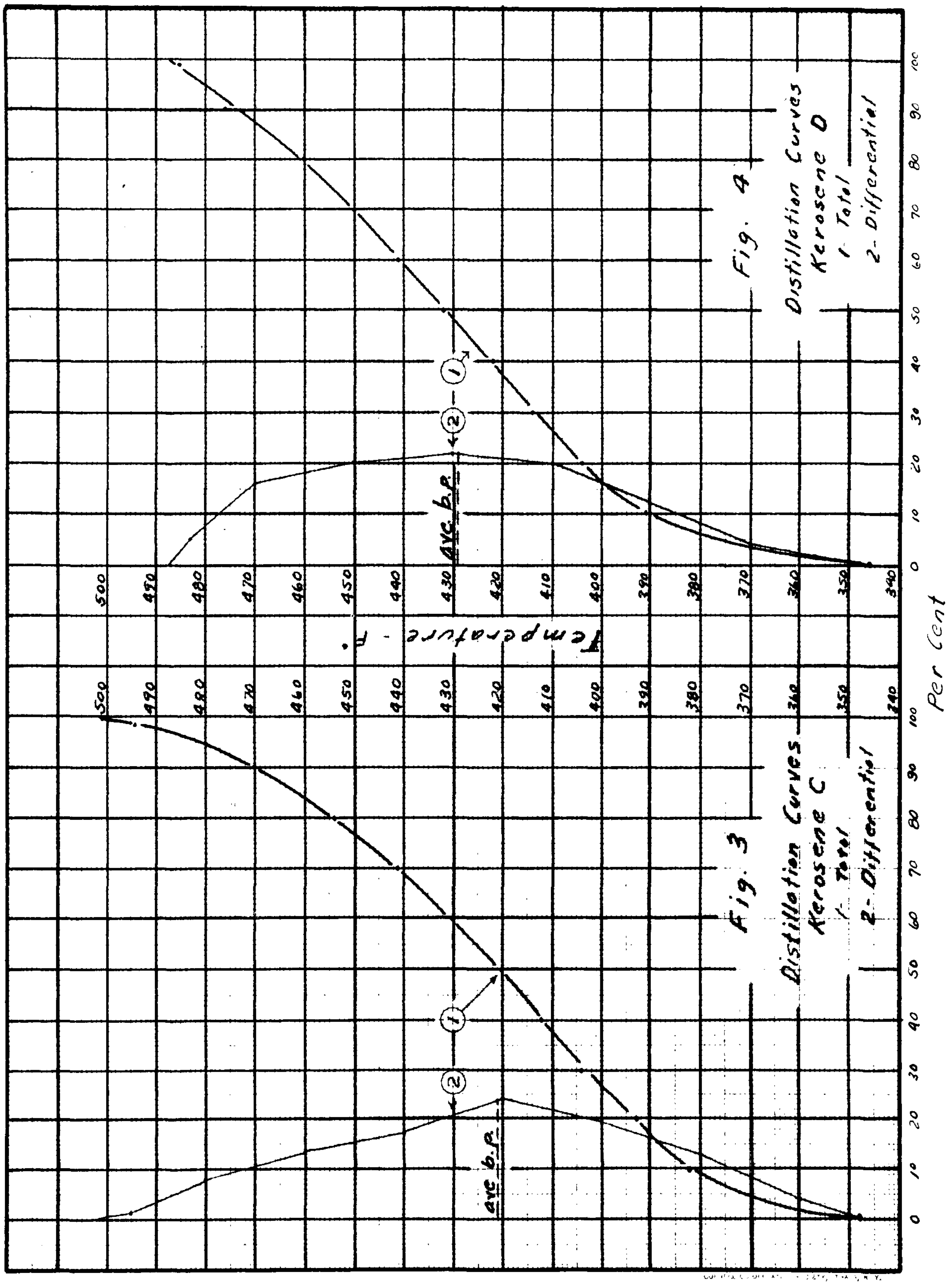


Fig. 4
Distillation Curves
Kerosene D
1- Total
2- Differential

Fig. 3
Distillation Curves
Kerosene C
1- Total
2- Differential

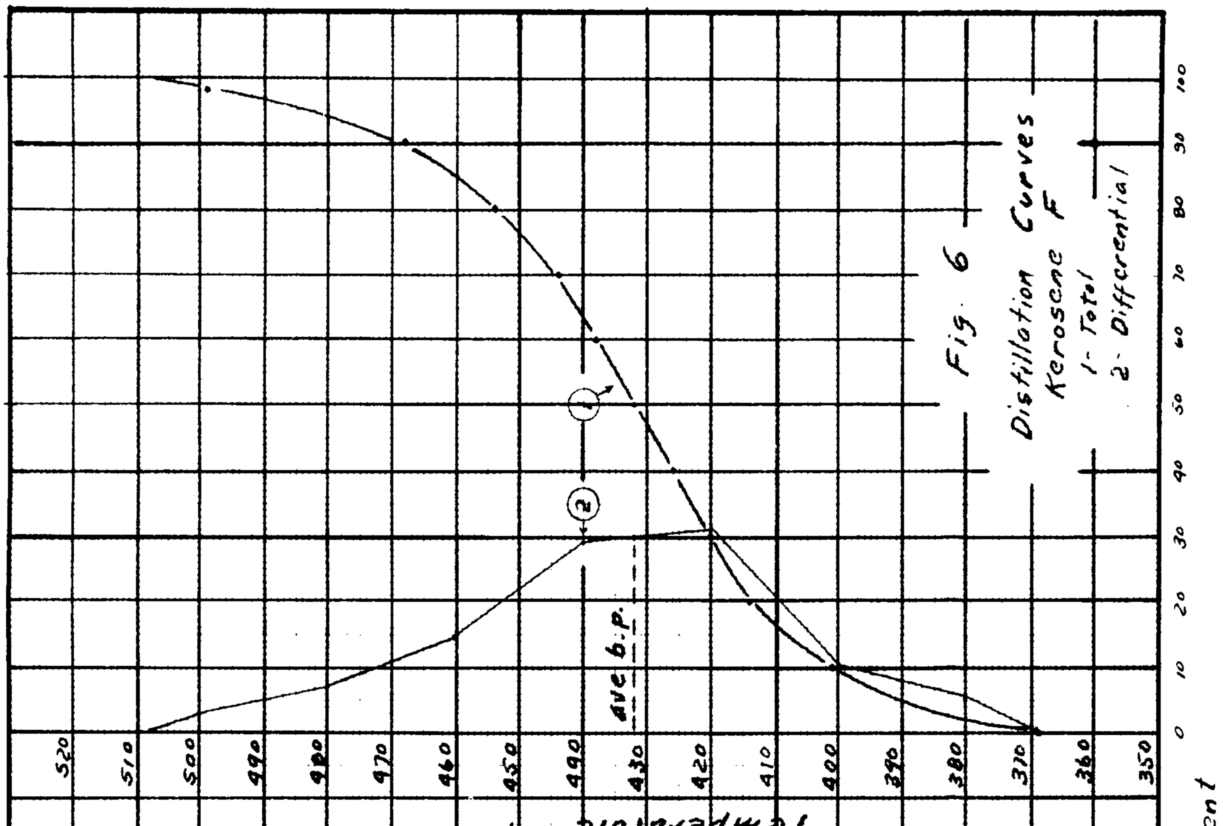


Fig 6

Distillation Curves
Kerosene F
1- Total
2- Differential

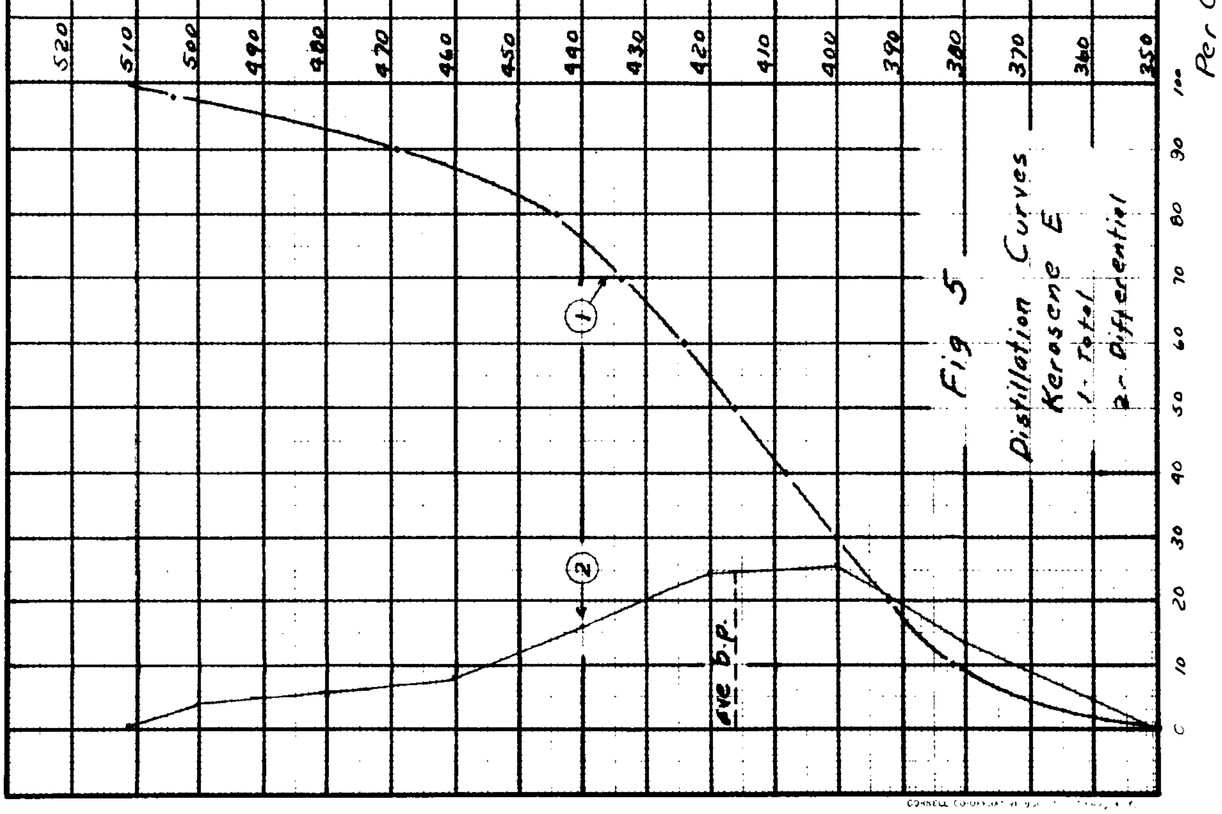


Fig 5

Distillation Curves
Kerosene E
1- Total
2- Differential

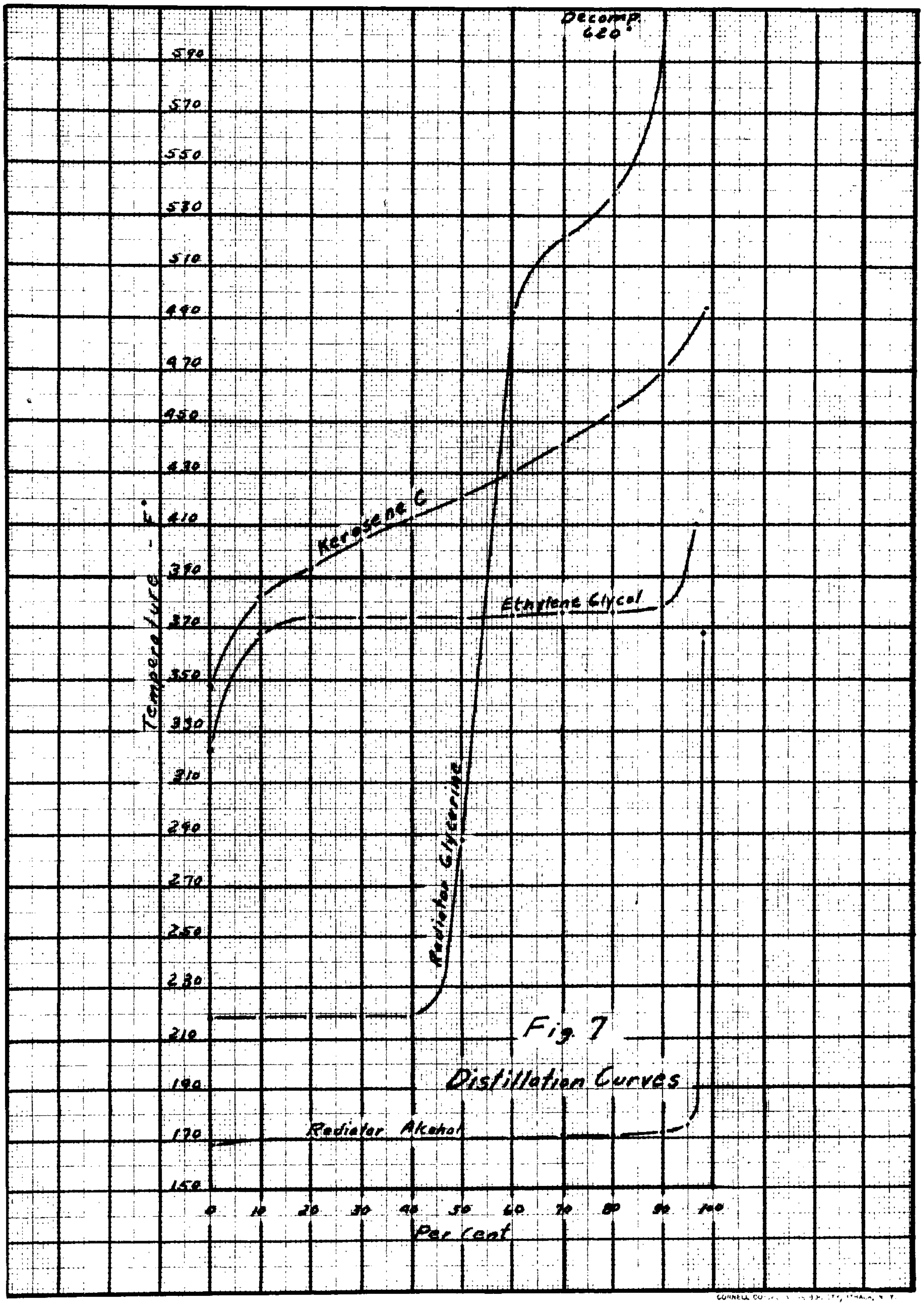


Fig. 7

Distillation Curves

Table VI

Viscosity of different liquids in Saybolt Seconds

Liquid	Temperature			
	0° C		-32° C	
Kerosene A	38.0	38.0	59.1	59.2
" B	39.6	39.7	65.2	66.5
" C	38.0	37.8	56.7	57.2
" D	38.9	38.7	58.7	59.1
" E	37.9	37.6	53.5	53.6
" F	39.3	39.3	61.0	61.7
Conductivity water	33.7	33.5	----	----
50% (vol.) Et OH	50.6	50.5	234.5	237.0
50% (vol.) rad. alcohol	51.7	51.2	362.8	
50% (vol.) rad. glycerine	75.0	74.5	Froze-27.5	
49% (vol.) rad. glycol	55.7	56.0	168.1	

C. Flash and Fire Points

The flash points of the kerosenes and a 50% alcohol solution were determined in both the Cleveland open cup and the Pensky-Martens closed tester. The fire points were determined in the open cup. The results are presented in Table VII. These solutions were also tested after 264 hours of refluxing at 85 C. (corrosion test) and the results are given in Table VIII.

Table VII

Flash and Fire Points of Different Liquids

Solution	Flash Point (°F.)		Fire Point (°F.)
	open cup	closed cup	open cup
Kerosene A	131	114	166
B	154	138	188
C	146	130	164
D	146	132	170
E	144	130	164
F	158	146	186
50% (vol) alcohol	66	66	78

Table VIII

Flash and Fire Points of Different Liquids After 264 Hours Refluxing at 85°C.

Solution	Flash Point (°F.)		Fire Point (°F.)
	open cup	closed cup	open cup
Kerosene A	144	132	166
B	158	148	188
C	148	140	166
D	158	146	186
E	146	130	166
F	168	160	192
50% (vol) alcohol	74	74	88

D. Corrosion Tests

The corrosive action of the various solutions was tested by suspending the metallic strips to be tested so that half of the strip was immersed in the liquid. Eight three-neck one-liter flasks were set on a constant level water bath and fitted with reflux condensers (Fig. 8). Each was filled half full with the liquid to be tested, and the strips (two) hung from glass hooks in the stoppers of the side necks.

Table IX shows the results of a continuous 264-hour test using tinned copper strips in kerosenes A, B, C, D, E and F and a 50% (vol.) solution of radiator alcohol. The strips were prepared from sheet copper soldered on one side, soaked in 2% NH_3 for 8 hours, rinsed, soaked in distilled water for one week, dried, marked-off, numbered, drilled, burnished on a wire wheel, cut into strips 5/8" x 5", dried in the oven at 110°C. for one hour, cooled in the desiccator and weighed.

Fig. 8 Apparatus for Testing Corrosion Strips

Table IX

264 Hour Corrosion Test

Solution	Change in wt. mg/kg/hr.	Evap. loss	Remarks
Kerosene A	+ 0.9	3.0	Tarnish developed on Cu side on liquid surface first.
B	+ 0.8	3.0	Tarnish developed on Cu side on both liquid and vapor surface.
C	+ 0.9	3.6	Tarnish developed first in vapor phase on Cu.
D	+ 0.7	5.4	Least stain and slowest to develop.
E	+ 0.7	3.4	Tarnish nil below liquid surface.
F	+ 1.2	5.2	Definite corrosion on Cu side by completion of test.
50% (vol) Radiator alcohol	+17.6	4.8	Cu side tarnished rapidly, starting below surface; strips badly scaled at completion of test.

Table X and Figure 9 (a,b,c, etc.) show the same type of strips suspended in kerosenes D and F, 50% (vol.) solutions of ethyl alcohol, radiator alcohol, radiator glycerine, 49% (vol.) radiator glycol, tap water and conductivity water for 480 hours. In Figure 9, the copper and tinned sides are both shown in contrast with sections of the original strips.

Table X
480 Hour Corrosion Test

Solution	Change in wt. mg/kg/hr.	Evap. loss %	Remarks
Kerosene D	+0.5	4.6	Tarnish appeared on Cu side during first 24 hours.
" F	+1.4	4.2	Submerged Cu side entirely black during first 24 hours.
50% (vol.) Radiator alcohol	+3.2+	0.4	Corrosion very pronounced first hour, scale flaking at end of test.
49% (vol.) Radiator glycol	-3.3	0.4	No tarnish below liquid, slight tarnish on Cu vapor surface.
50% (vol.) Radiator glycerine	+1.2	1.6	No effect on liquid surfaces, Cu side definitely effected in vapor during first 24 hours.
50%(vol.) Radiator ethyl alcohol	---	3.4	Corrosion very pronounced first hour. Severe flaking before test completed.
Tap water	+2.1	1.0	Cu side stained on liquid surface during first 24 hours.
Conductivity water	+1.4	0.4	Corrosion started on all sides during first 24 hours.

Strips of sheet aluminum were also used, in place of the tinned copper strips, but after 120 hours' corrosion, the kerosene had no apparent effect, either in the appearance or in the weight of the strips.

Differential corrosion tests were also run, progressively replacing the corroded strips with new ones. The results are presented in Table XI and the strips shown in Figure 10 (a,b,c, etc.).

Key to Figure 9

480-hour Corrosion Test

a- Kerosene D

b- Kerosene F

c- 50% radiator alcohol

d- 49% radiator glycol

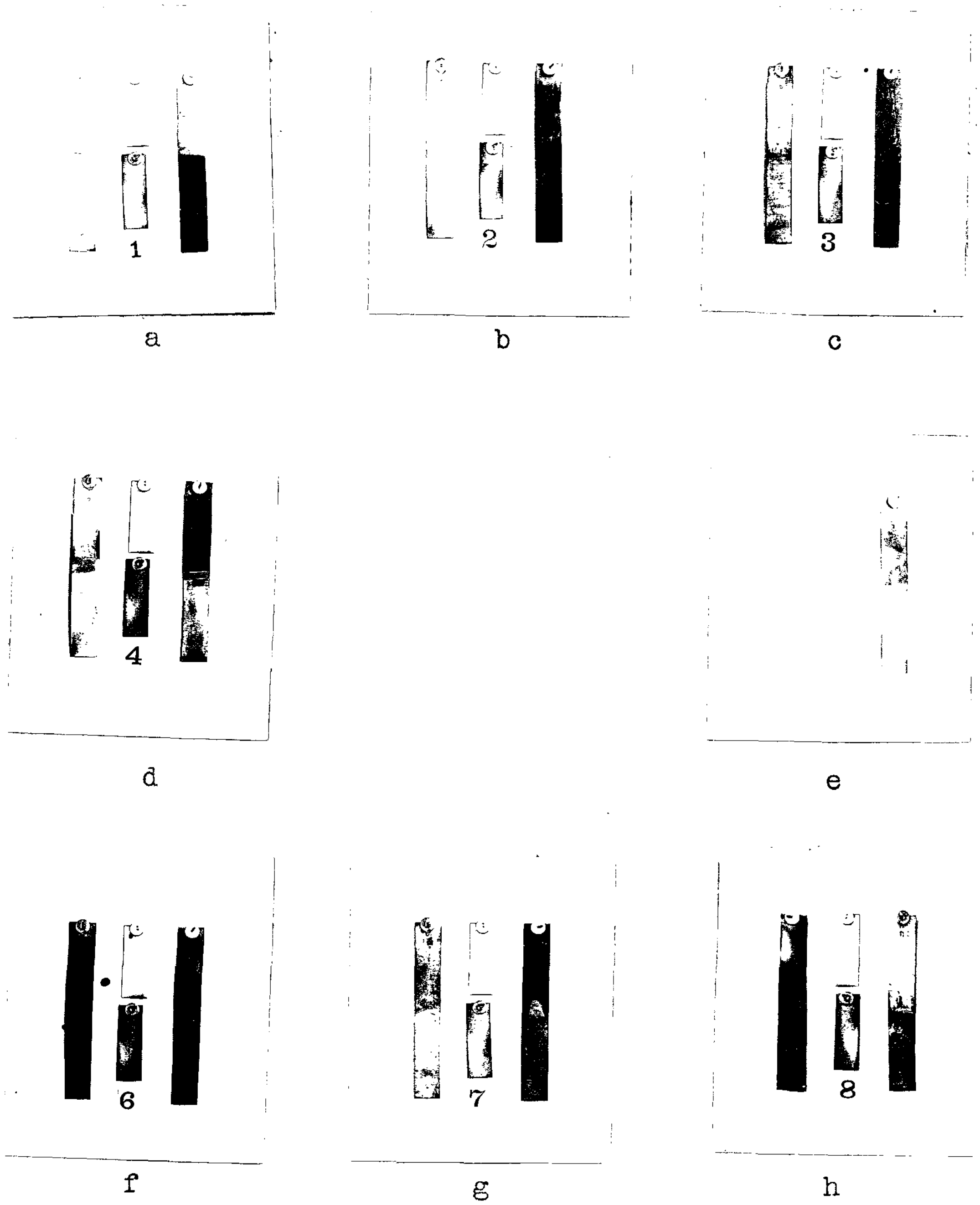
e- 50% radiator glycerine

f- 50% ethyl alcohol

g- tap water

h- conductivity water

Both tinned and copper sides of corroded strips shown in comparison with original strips.



a b c

d e

f g h

Fig. 9. 480-hour Corrosion Test

Table XI

Differential Corrosion Test

	Change in Weight -- mg/kg/hr.							
Solution Time interval	1	2	3	4	5	6	7	8
1-1 hr.	- 9.7	- 9.7	+77.0	-14.3	-14.6	+27.8	+77.0	- 4.8
2-1 hr.	-29.0	-19.2	+24.6	-19.4	0.0	+34.8	+ 4.8	-24.8
3-1 hr.	-65.3	-23.8	+24.2	0.0	+14.5	+ 9.6	+14.9	- 9.4
4-1 hr.	-34.6	-28.6	+14.5	-43.7	-38.5	- 4.7	-29.4	-38.4
5-2 hr.	-12.4	-12.6	+53.0	+ 2.4	0.0	+ 2.4	+ 9.5	- 7.5
6-2 hr.	- 4.5	- 6.9	+34.8	- 4.6	- 2.3	+14.4	+ 7.2	+ 2.4
7-4 hr.	- 6.2	+ 2.3	+38.2	- 4.8	+ 1.2	-16.7	+ 9.6	0.0
8-8 hr.	+ 3.0	+ 7.8	+52.5	- 2.3	- 3.0	-21.8	+ 1.2	+ 3.7
9-16 hr.	+ 7.0	+ 4.1	+51.9	- 2.1	0.0	-12.5	+ 6.7	+ 4.1
10-24 hr.	+ 4.5	+ 2.3	+40.0	- 3.3	- 0.2	-36.8	+ 8.2	+ 4.3
11-57 hr.	+10.1	+ 4.2	+18.8	- 4.0	+ 2.2	-19.1	+ 9.2	+ 3.1

Solutions:

1- Kerosene D
2- Kerosene F
3- 50% (vol.) radiator alcohol
4- 49% (vol.) radiator glycol
5- 50% (vol.) radiator glycerine
6- 50% (vol.) ethyl alcohol
7- tap water
8- conductivity water

Key to Figure 10

Differential Corrosion Test

a- first 1 hour

b- next 1 hour

c- next 1 hour

d- next 1 hour

e- next 2 hours

f- next 2 hours

g- next 4 hours

h- next 8 hours

i- next 16 hours

j- next 24 hours

k- next 57 hours

Top row in each picture is tinned surface; bottom row of each picture is copper surface.

In each picture, from left to right:

kerosene D

kerosene F

50% radiator alcohol

49% radiator glycol

50% radiator glycerine

50% ethyl alcohol

tap water

conductivity water

original strip

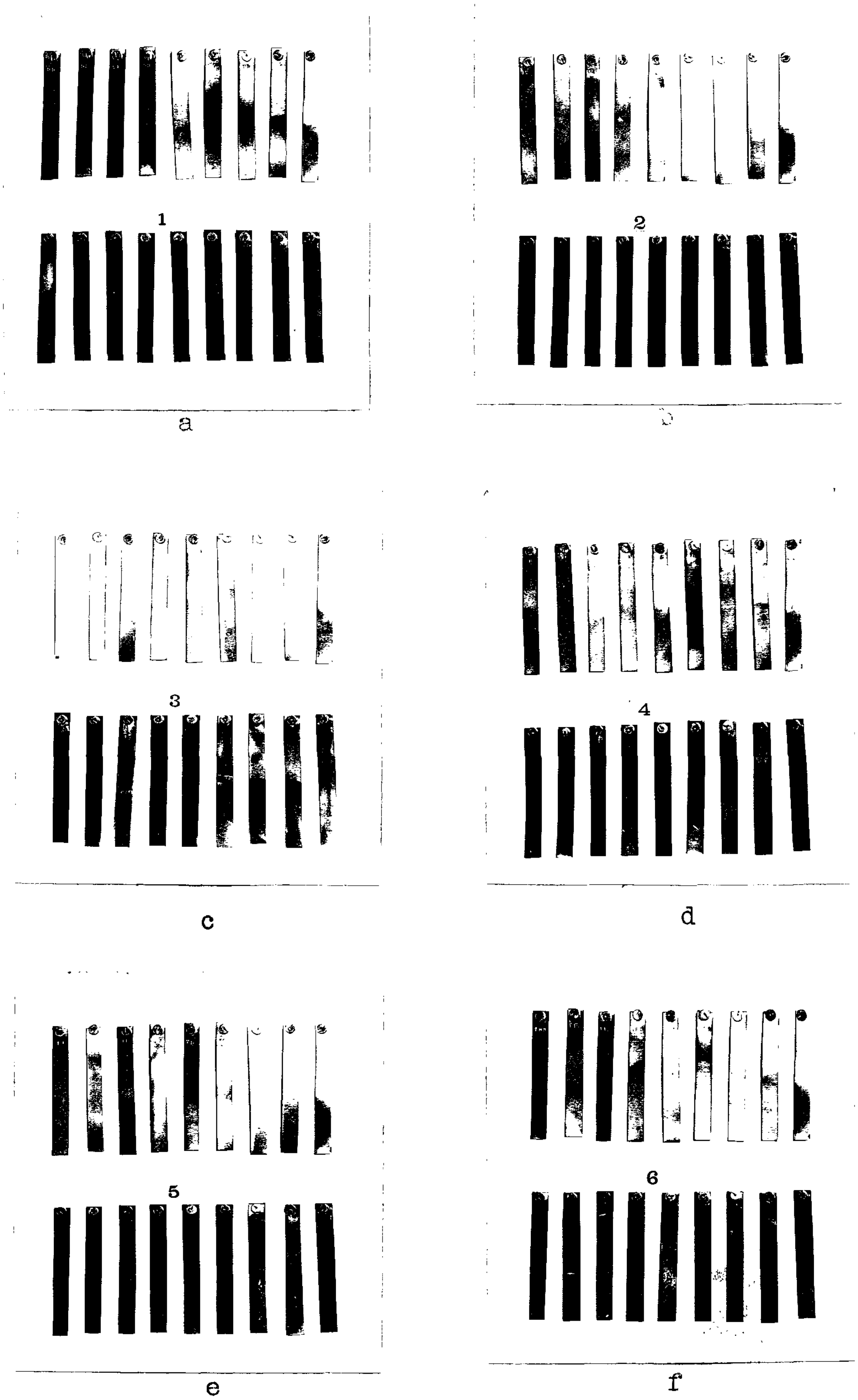
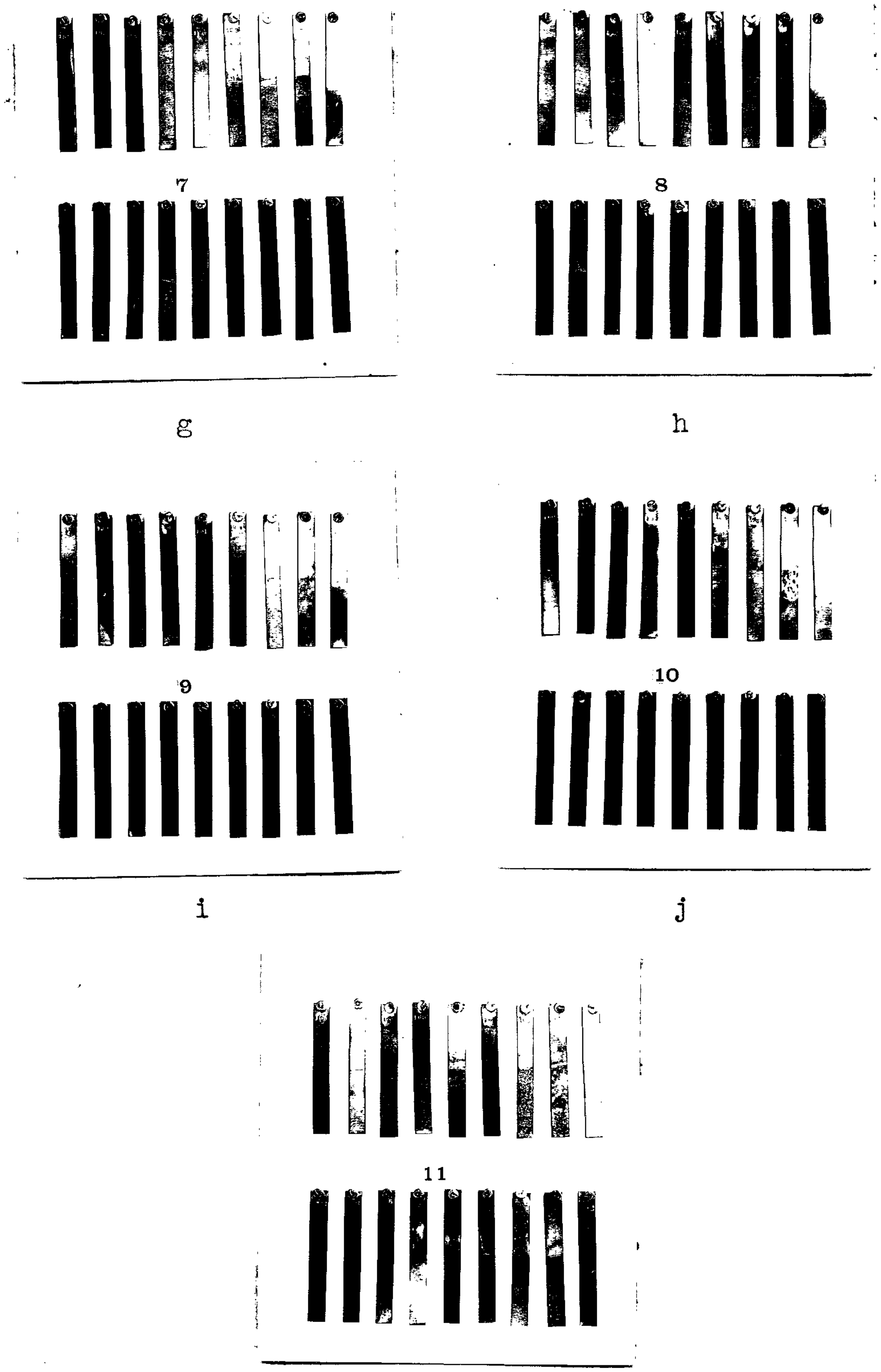


Fig. 10. Differential Corrosion Test



g

h

i

j

k

Fig. 10. (Continued)

In connection with the corrosion by the kerosenes, sulphur determinations were made on the original material, as well as on kerosenes that had been used in corrosion tests and in motor tests. The apparatus and method used were those of the A.S.T.M. (18). The results are presented in Table XII.

Table XII

Sulphur Content of Various Kerosenes

Kerosene	% Sulphur					
	Original	After 264 hrs. Corrosion	After black rad. hose test	After red rad. hose test	After rate of heat test	After Salt Lake trip
A	0.039	0.040				
B	0.036	0.049		0.080	0.018	0.031
C	0.022	0.042				
D	0.033	0.056				
E	0.069	0.092				
F	0.056	0.060	0.215			

E. Rate of Heating of Motor

A Ford (Model A, 1929) car was used in making these tests. The motor was a factory re-built motor and had run about 5,000 miles. A new radiator core had been installed about 10,000 miles previously (one year). Thermocouple wells were inserted in the hot water pipe to the radiator, in the cold water pipe from the radiator, the inside surface of the head of #3 cylinder and in the oil in the crankcase. Thermocouples were also placed in front of the radiator and in the air stream behind the fan to measure the air temperatures.

The rate of heating tests were made in the armory in the absence of all drafts. Water, kerosene, denatured alcohol and radiator glycol were used with both a free radiator and with the lower half of the radiator covered to prevent any air cooling. The throttle was set so that the same motor speed was attained in all cases.

These data are presented in Tables XIII - XX and Figures 11 - 18.

Table XIII

Rate of Heating of Motor Using Water with a Free Radiator

	Temperatures °F.					
Location Time (min.)	1	2	3	4	5	6
0	120	90	110	66	142	70
1	106	81	176	58	144	98
5	126	88	207	56	149	126
10	130	92	220	58	160	133
15	140	95	222	57	173	136
20	142	96	222	58	181	140
25	142	95	222	58	186	139
30	144	96	222	58	188	140
35	144	95	222	58	191	140

Table XIII (Continued)

Rate of Heating of Motor Using Water with a Free Radiator

Location Time (min.)	Temperatures ° F. 1	2	3	4	5	6
40	144	96	222	57	192	140
45	144	96	221	58	193	140

Locations: 1- top of radiator

2- hot air

3- head

4- cool air

5- oil

6- bottom of radiator

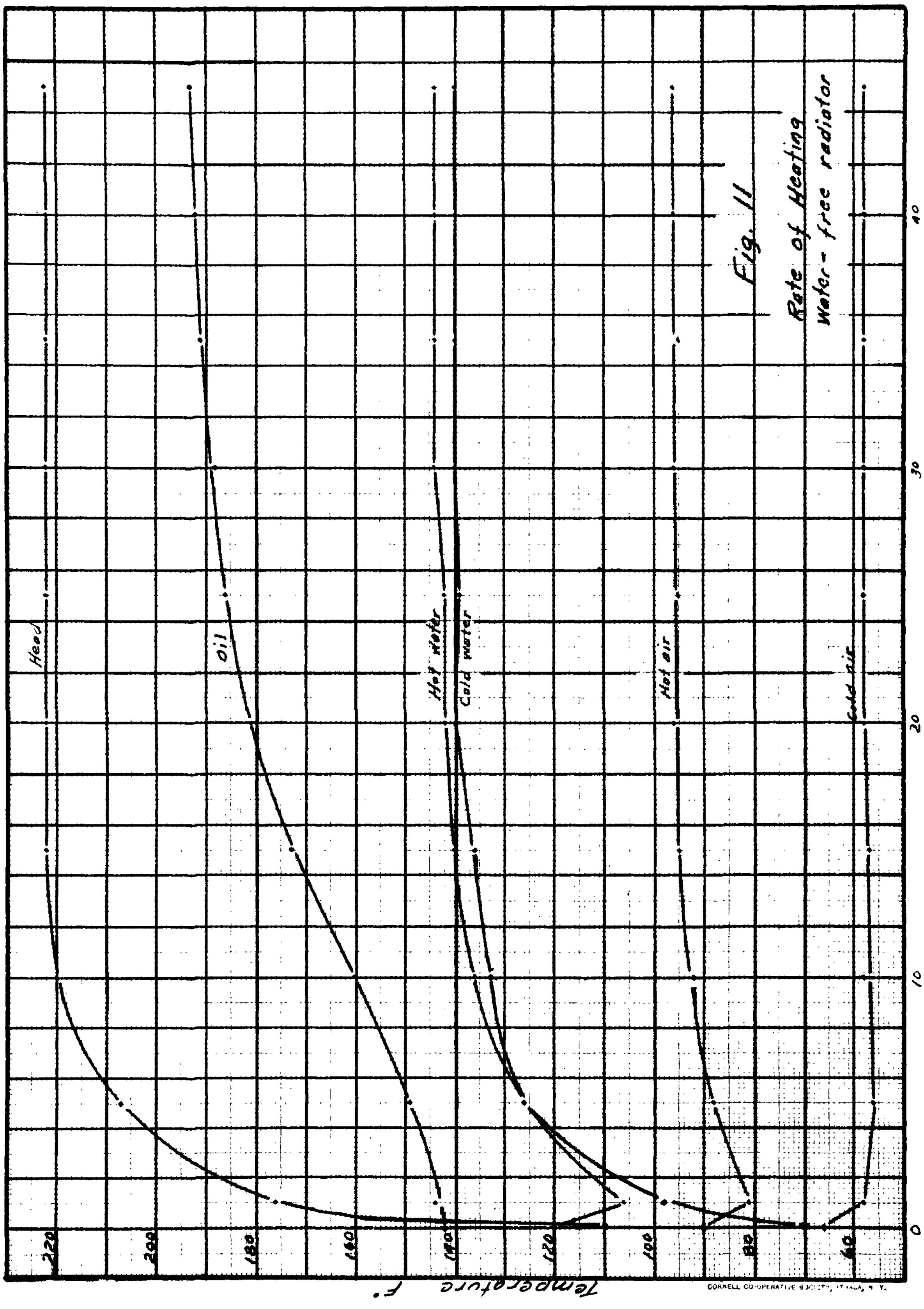


Fig. 11

Rate of Heating

Water - free radiator

Table XIV

Rate of Heating of Motor Using Water with Radiator 1/2 Covered

	Temperatures °F.					
Location Time (min.)	1	2	3	4	5	6
0	142	99	122	66	154	90
1	136	96	196	58	152	128
4	157	106	232	58	160	157
6	170	114	246	58	167	168
8	178	119	254	58	174	178
10	187	124	261	58	182	186
12	189	125	263	58	192	190
14	195	128	265	58	197	195
16	196	130	265	58	202	196
18	197	130	263	58	205	197
20	200	130	263	58	210	200
22	202	131	262	58	214	202
24	203	132	261	58	218	202
26	204	133	261	58	221	202
28	207	134	261	58	223	201
30	206	135	261	58	225	201

For location designation see Table XIII.

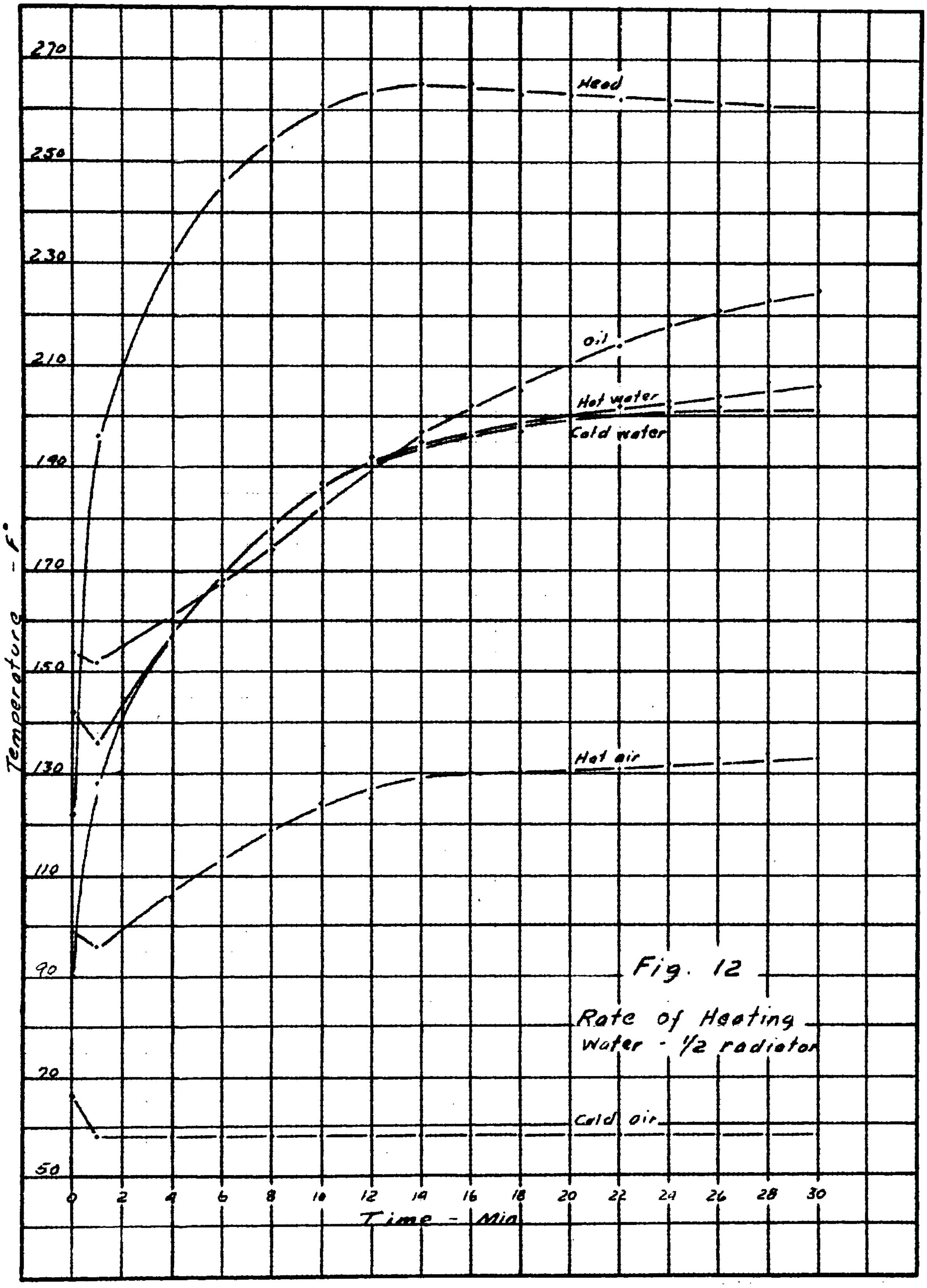


Fig. 12

Rate of Heating
Water - 1/2 radiator

Table XV

Rate of Heating of Motor Using Kerosene with Free Radiator

Location Time (min.)	Temperatures °F. 1	2	3	4	5	6
0	135	86	234	66	100	133
4	154	92	253	62	145	143
9	161	95	260	62	166	149
14	163	95	264	62	180	153
19	167	100	265	(75)	192	156
24	169	100	267	62	198	156
29	169	100	268	62	205	157
34	170	102	269	32	208	158
39	170	100	270	62	213	157
44	172	100	270	62	214	157
49	171	100	270	62	216	157
54	171	100	270	62	218	158
59	171	100	270	62	218	158
64	171	100	270	62	218	157
69	171	100	270	62	219	158

For location designation see Table XIII.

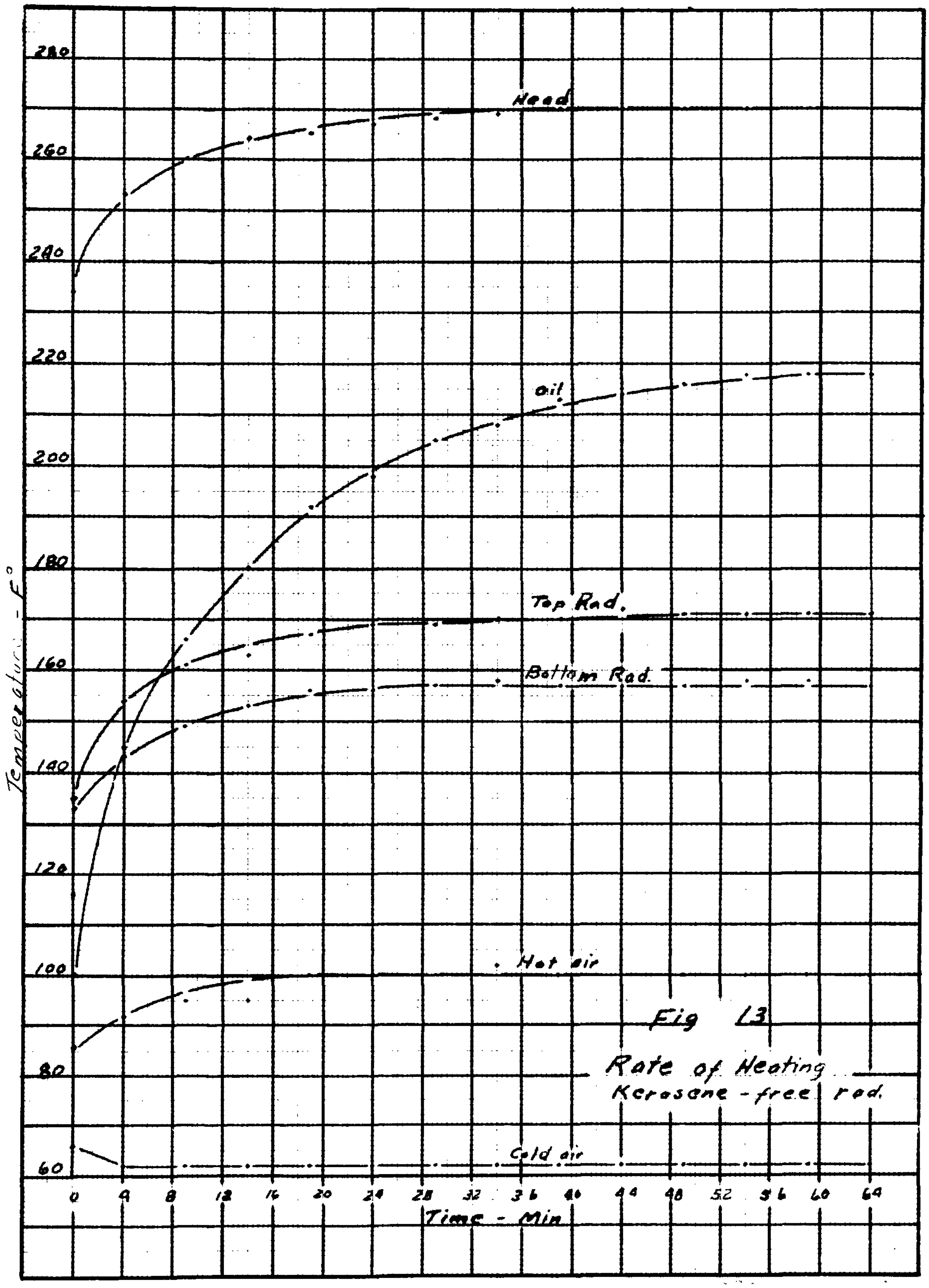


Fig 13

Rate of Heating
Kerosene - free rod.

Table XVI

Rate of Heating of Motor Using Kerosene with Radiator 1/2 Covered

Location Time (min.)	Temperatures °F. 1	2	3	4	5	6
0	131	85	116	70	125	78
1	125	88	201	62	131	111
3	154	97	252	62	147	148
5	176	108	273	62	157	170
7	194	117	288	62	168	186
9	206	122	296	62	177	198
11	212	127	302	62	188	204
13	216	129	307	62	192	206
15	221	133	310	62	203	208
17	221	134	311	62	211	211
19	222	134	311	62	214	211

For location designation see Table XIII.

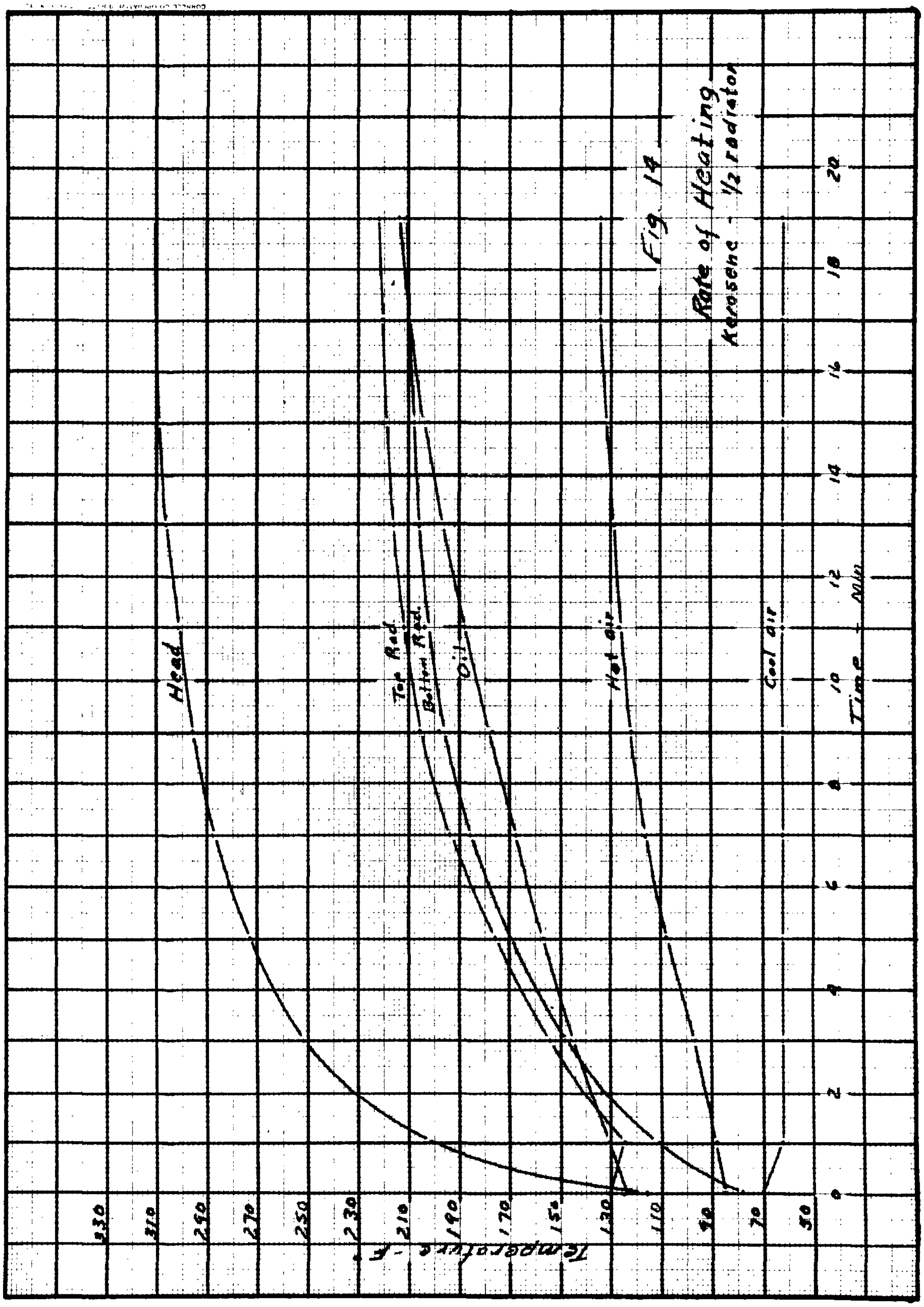


Fig 14

Rate of Heating

Kerosene - 1/2 radiator

Table XVII

Rate of Heating of Motor Using 50% Radiator Alcohol with Free Radiator

Location Time (min.)	Temperatures °F. 1	2	3	4	5	6
0	125	95	122	70	150	92
1	113	85	194	60	150	106
5	130	92	216	60	158	130
10	143	95	227	60	172	144
15	149	97	230	60	177	147
20	151	98	233	60	187	147
25	150	98	232	60	190	147
30	150	98	232	60	194	147
35	150	98	232	60	195	147
40	151	98	232	60	198	147
45	151	98	232	60	200	147

For location designation see Table XIII.

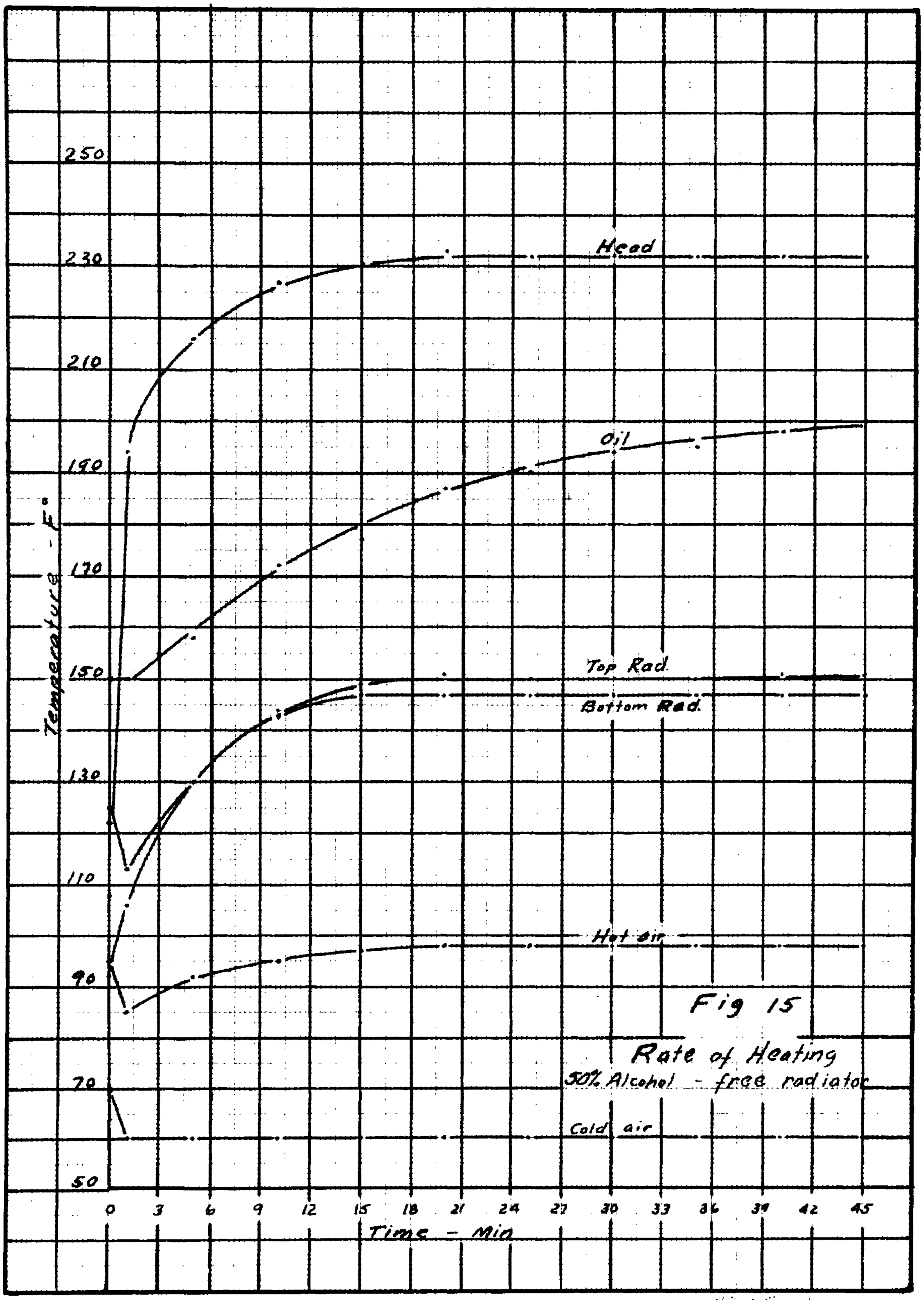


Fig 15

Rate of Heating
50% Alcohol - free radiator

Table XVIII

Rate of Heating of Motor Using 50% Radiator Alcohol with Radiator 1/2 Covered

Location Time (min.)	Temperatures °F. 1	2	3	4	5	6
0	110	84	108	64	118	76
1	109	86	178	58	124	107
4	149	104	230	58	134	150
6	163	112	246	59	147	166
8	180	118	258	59	157	176
10	190	123	263	59	165	178
12	192	126	264	60	178	183
14	194	126	264	60	184	183

For location designation see Table XIII.

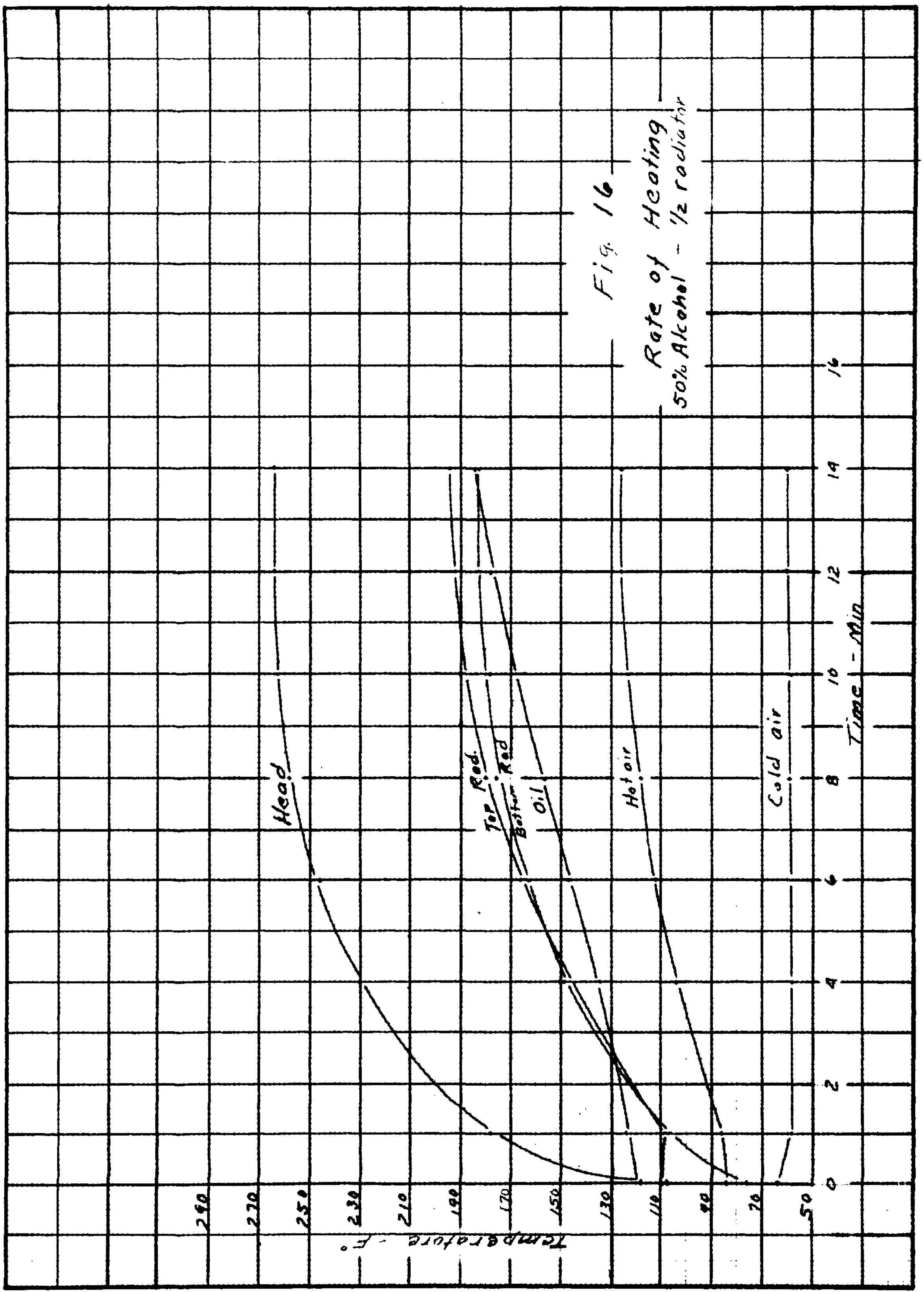


Fig. 16
Rate of Heating
50% Alcohol - 1/2 radiator

Table XIX

Rate of Heating of Motor Using 49% Radiator Glycol with Free Radiator

Location Time (min.)	Temperatures °F. 1	2	3	4	5	6
0	119	91	110	62	154	70
1	110	75	172	56	152	94
5	132	86	204	54	158	128
10	143	91	216	54	168	136
15	147	92	227	54	181	140
20	147	92	223	54	184	140
25	147	92	225	54	188	142
30	149	93	226	54	190	141
35	149	94	226	54	194	141
40	148	94	226	54	195	141
45	148	94	226	54	196	141

For location designation see Table XIII.

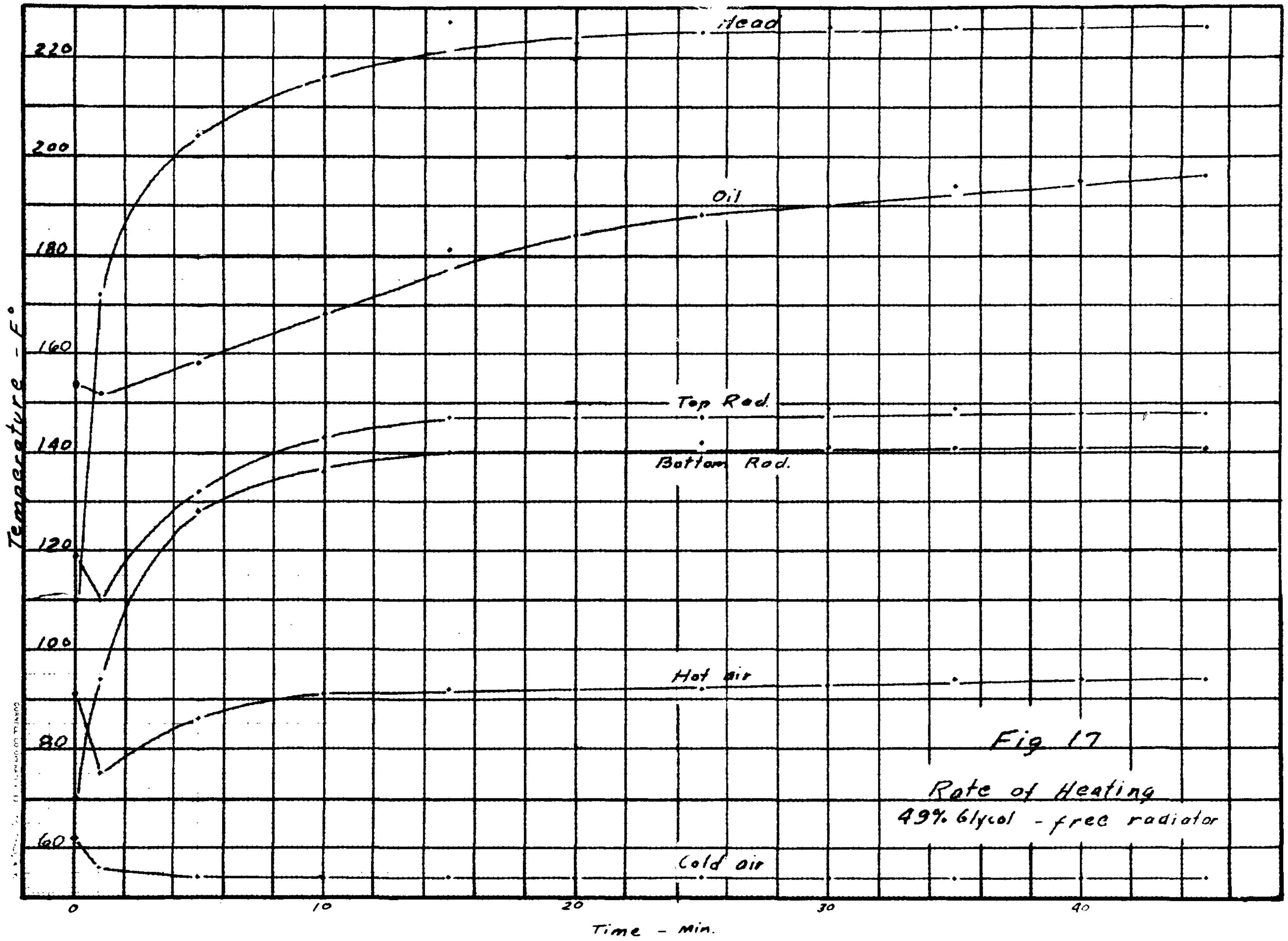


Fig 17

Rate of Heating

49% Glycol - free radiator

Table XX

Rate of Heating of Motor Using 49% Radiator Glycol with Radiator 1/2 Covered

Location Time (min.)	Temperatures °F.					
	1	2	3	4	5	6
0	118	62	105	58	123	68
1	115	82	181	52	127	104
4	151	100	218	54	136	146
6	167	110	240	58	147	162
8	178	117	251	58	157	176
10	190	125	262	58	165	185
12	199	129	267	58	173	193
14	204	132	266	58	182	199
16	210	133	265	57	191	204
18	213	136	261	57	198	208
20	220	136	261	57	202	208

For location designation see Table XIII.

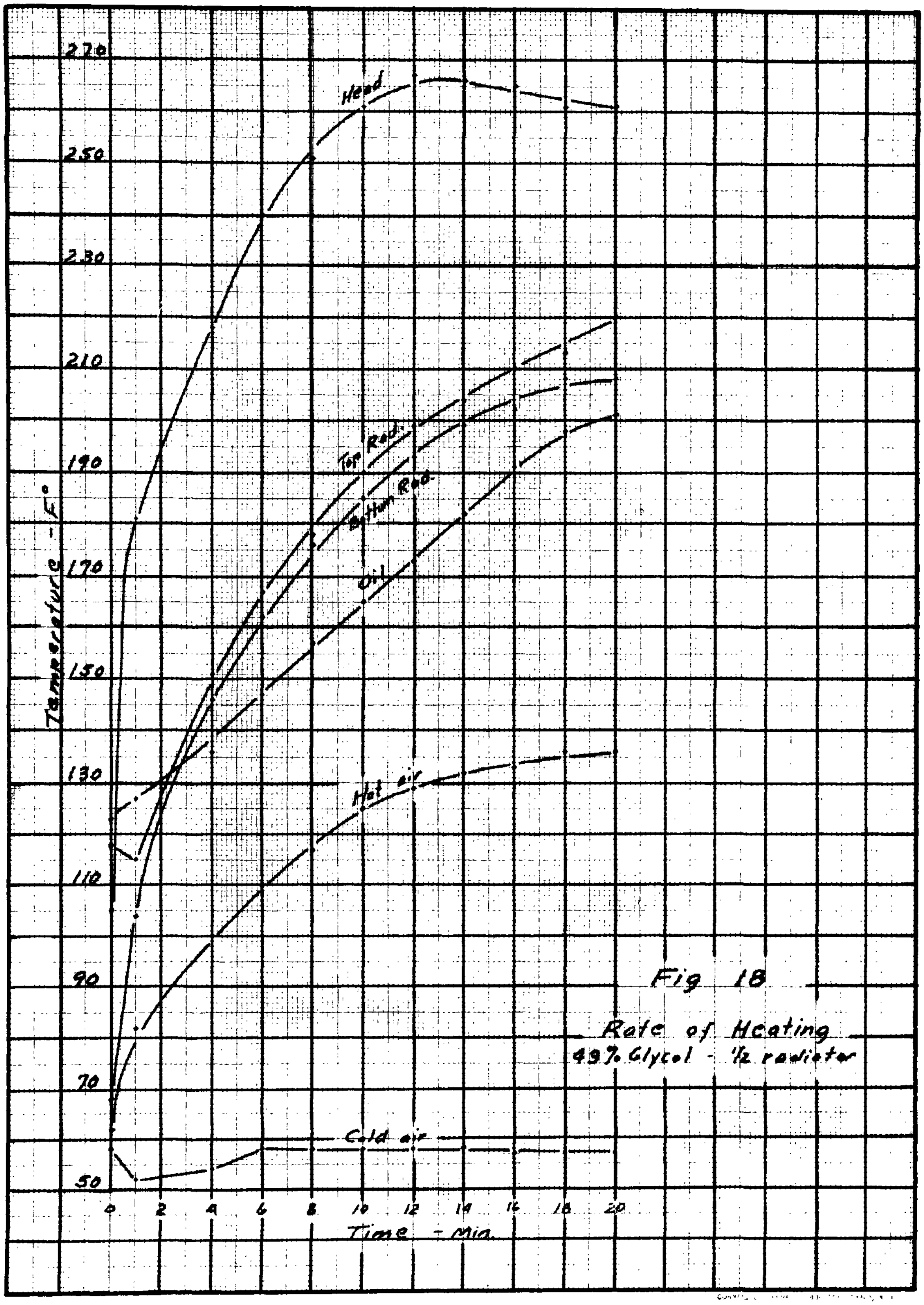


Fig 18

Rate of Heating
49% Glycol - ½ radiator

Figure 19 shows the rate of heating of the oil when each solution is used with a free radiator, and Figure 20 shows the difference in the heating rates of the oil when the different solutions are used in the case of the partially covered radiator.

F. Road Tests

In order to simulate worst possible actual operating conditions, road tests were made in rather warm weather using kerosene, water and radiator glycol. Table XXI shows the results of a test run from Ames, Iowa to Chicago, Illinois, using kerosene in the radiator and Table XXII shows the results of a test run from Chicago to Ames using water in the radiator. In both runs, there were two passengers in addition to the driver. A run was made from Ames to Lincoln, Nebraska, using radiator glycol as the cooling medium, in which four passengers accompanied the driver. These results are presented in Table XXIII.

In all of these tests the same car with the same thermocouples described above was used.

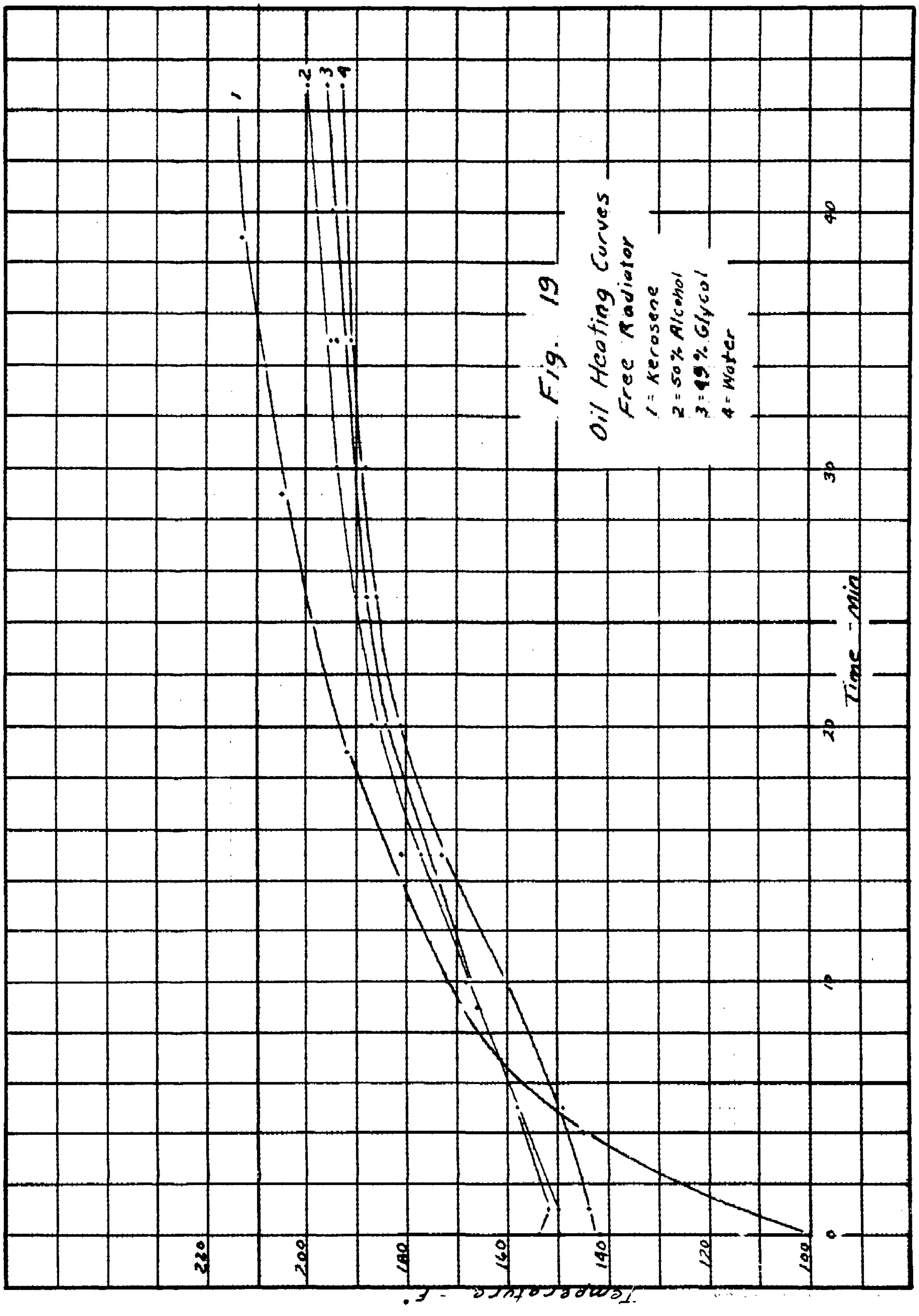


Fig. 19

Oil Heating Curves
Free Radiator

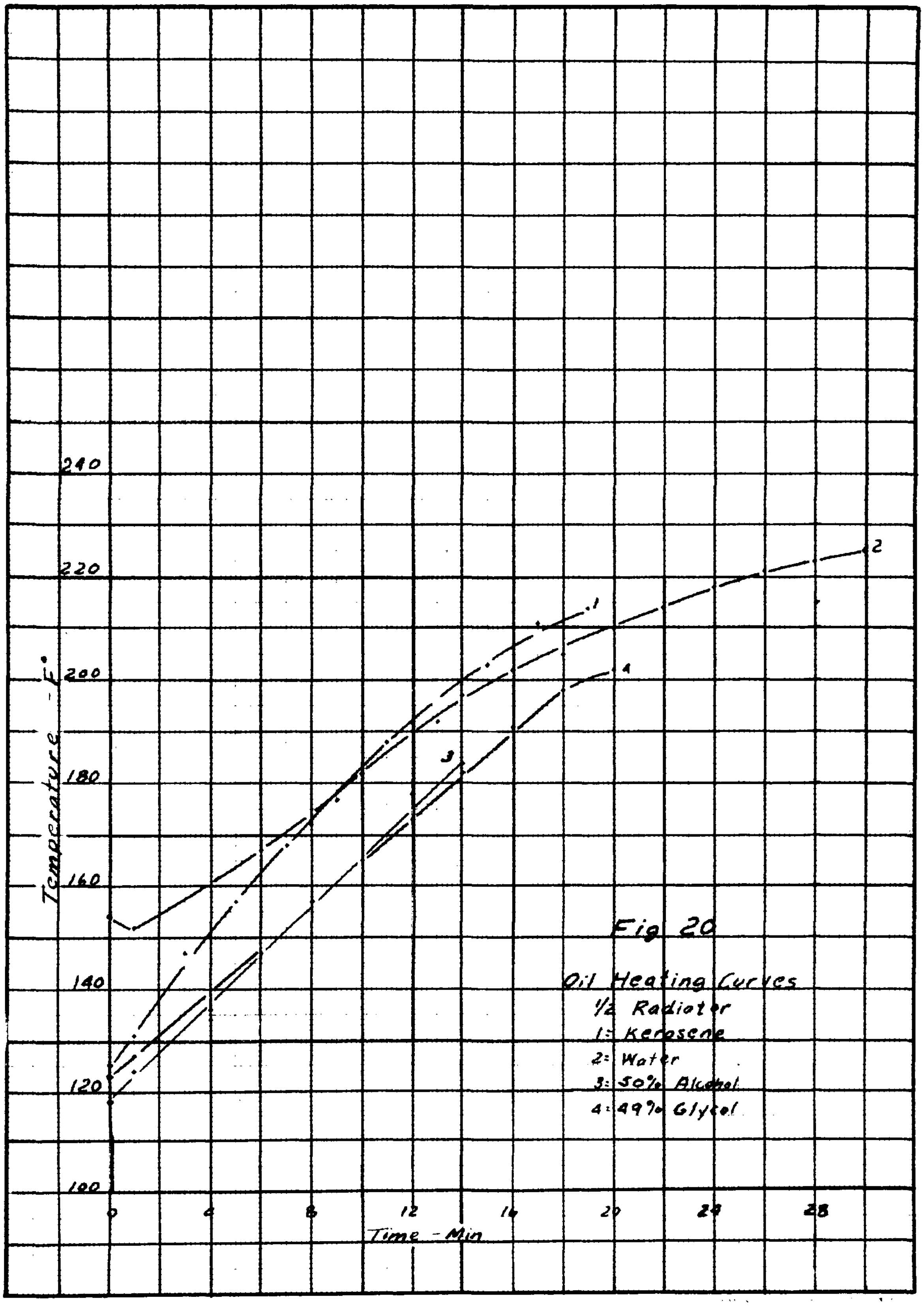


Fig 20

Oil Heating Curves
½ Radiator
1: Kerosene
2: Water
3: 50% Alcohol
4: 49% Glycol

Table XXI

Road Test (Ames to Chicago) Using Kerosene B in Radiator

Δt (min)	Speed (m.p.h)		Temperature °F.								Remarks
	Instant	Ave.	Cool air	Hot air	Air Δt	Top radiator	Bottom radiator	Radiator Δt	Head	Oil	
start	50	--	70	88	18	150	140	10	384	172	Clear weather, no wind, essentially level with slight swells.
5	54	36	65	89	24	170	152	18	353	242	
5	25	48	66	92	26	181	146	35	288	255	Passing through town.
5	53	48	76	92	16	182	154	28	333	276	
5	55	60	73	92	19	184	157	27	337	290	
5	55	48	70	92	22	187	157	30	329	289	
5	52	48	70	92	22	173	152	21	317	288	
5	55	48	71	93	22	195	151	44	330	296	
10	35	42	70	100	30	175	150	25	294	264	Passing through town.
10	45	42	73	78	5	174	150	24	312	279	
10	52	42	73	91	18	183	152	31	317	282	
15	48	52	72	92	20	191	154	37	341	285	
30	58	50	70	90	20	184	153	31	347	301	
25	57	53	73	91	18	191	159	32	350	282	
35	55	53	62	84	22	166	144	22	351	252	Stopped 10 minutes.
30	60	42	67	80	13	181	150	31	345	266	
30	57	52	67	78	11	173	146	27	340	265	Sundown.
45	45	45	66	77	11	173	148	25	367	246	Stopped 10 minutes.
30	58	51	63	82	19	184	163	21	347	267	
30	54	40	58	81	23	178	157	21	367	267	
30	--	50	70	163	93	237	157	80	264	240	Temperatures read 1 min. after stopping; stopped 15 min.
15	55	68	62	96	34	170	144	26	347	249	
45	58	43	58	78	20	173	152	21	386	266	

Table XXII

Road Test (Chicago to Ames) Using Water in Radiator

Δt (min)	Speed (mph) Instant	Speed (mph) Ave.	Temperature °F. Cool air	Temperature °F. Hot air	Temperature °F. Air Δt	Temperature °F. Top radiator	Temperature °F. Bottom radiator	Temperature °F. Radiator Δt	Temperature °F. Head	Temperature °F. Oil	Remarks
8	60	53	66	77	11	144	131	13	330	249	Slight cross wind; clear; essentially level.
12	55	55	62	81	19	133	136	--	297	254	
20	58	48	66	81	15	152	134	18	303	272	
70	55	38	68	88	20	146	139	7	315	254	Stopped 40 minutes.
25	53	46	70	91	21	153	136	17	300	252	
30	52	38	62	86	24	138	128	10	291	236	
45	57	53	62	81	19	143	137	6	329	248	Stopped 20 minutes.
30	60	36	58	83	25	149	140	9	330	254	
30	58	60	54	78	24	146	136	10	320	253	Sundown. No appreciable wind.
30	55	52	58	80	22	133	129	4	294	240	Essentially level with swells.
60	57	44	58	73	15	136	129	7	323	228	Stopped 30 minutes.
35	57	53	57	71	14	132	130	2	317	236	
25	55	50	54	73	19	143	125	18	285	236	
30	58	46	54	77	23	136	126	10	307	230	
30	58	50	54	73	19	136	125	11	313	235	
10	--	54	58	136	78	184	122	62	213	209	One minute after stopping.

Table XXIII
Road Test (Ames to Lincoln and Return) Using 49% Radiator Glycol in Radiator

Δt (min)	Speed (mph)		Temperature °F.								Remarks
	Instant	Ave.	Cool air	Hot air	Air Δt	Top radiator	Bottom radiator	Radiator Δt	Head	Oil	
5	55	36	37	48	11	114	107	7	246	186	Essentially level with swells; strong cross wind; clear.
10	50	48	35	54	19	120	109	11	253	220	
11	53	49	37	52	15	125	114	11	265	232	
9	53	53	37	54	17	129	115	14	277	234	
15	50	52	38	54	16	123	107	16	255	220	
15	52	44	40	54	14	123	107	16	261	221	
30	52	48	40	54	14	130	114	16	284	230	
22	55	55	42	58	16	131	118	13	279	242	
38	53	47	42	58	16	138	122	16	280	227	
20	52	48	42	62	20	140	122	18	260	234	
30	52	44	42	62	20	140	122	18	258	234	
85	--	--	--	--	--	---	---	--	---	---	Leak developed around head couple; repaired by wedging in friction tape, thereby making all later head temperatures too high due to loss of cooling by medium.
15	42	44	48	62	14	132	118	14	357	194	
15	52	48	50	62	12	136	125	11	387	210	
15	52	52	50	66	16	142	129	13	414	223	
30	52	38	45	68	23	140	126	14	399	214	Return trip. Moderate cross wind; clear.
30	52	44	42	58	16	130	112	18	396	197	Sundown.
115	--	--	--	--	--	---	---	--	---	---	Stopped one hour.
20	55	48	40	51	11	124	111	13	426	199	
30	53	36	34	51	17	122	103	19	415	197	
30	54	48	35	49	14	124	111	13	416	205	
30	52	48	35	46	11	128	110	18	437	204	
30	54	50	35	56	21	127	112	15	423	206	Stopped 10 minutes.
30	54	44	35	51	16	124	110	14	422	198	
30	53	40	36	52	16	132	118	14	435	211	
30	55	42	35	48	13	125	110	15	417	201	

G. Effect of Various Solutions on Rubber Radiator Hose

In order to determine the effect of the various solutions on rubber radiator hose, a heater tank and a cooler tank were set up and connected with the hose to be tested (Fig. 21). Each tank was provided with five sets of brass inverted "F" pipes through the side, providing for the circulation of five different liquids at the same time. The top of the inverted "F" was sealed in the heater tank, but was only closed with a stopper in the cooler tank. Short pieces of brass tubing containing thermometer wells were used to enable two sections of hose to be inserted in each circuit at the top and bottom. The bottom tubes were provided with pet cocks for draining the solutions. The tubes were filled through the openings in the cooler tank.

The heater tank was heated by electric hot plates and was provided with a reflux condenser to prevent evaporation of the water within. The cooler tank was cooled by cold water coming up around each pipe through holes in a baffle plate near the bottom.

Two brands of radiator hose (1 1/2") were tested in this manner for 48 days, using kerosene, water, 49% (vol.) radiator glycol and 50% (vol.) solutions of radiator alcohol and glycerine. One hose was a cheap black hose and the other was a high grade red hose. Both were corded.

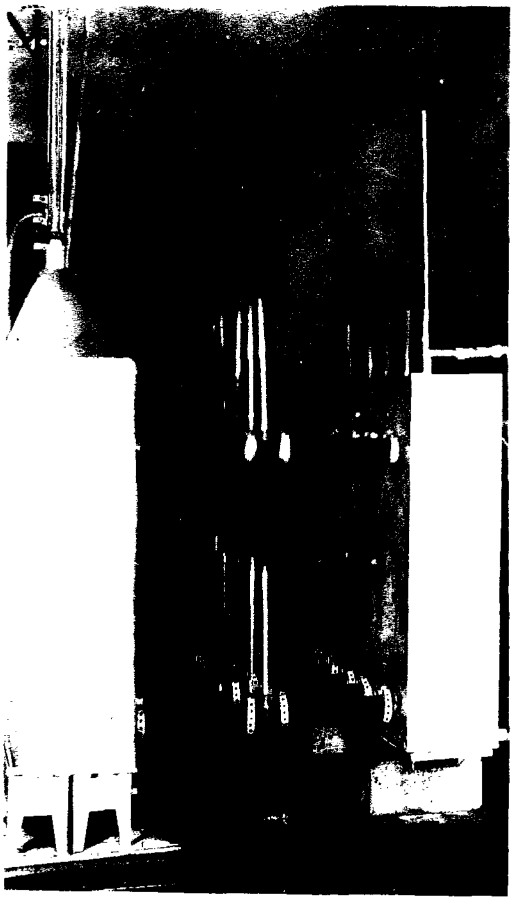


Fig. 21 Apparatus for Testing Hose

Changes in weights, volumes and bursting pressures of the hoses are presented in Tables XXIV and XXV. The changes in diameter, internal and external, were too slight to be significant, especially since some of the hoses tended to flatten, which made such measurements unreliable for such slight differences. The volumes were measured by submersion in water.

The bursting strength of each hose was tested by clamping it onto two short pieces of brass pipe, held securely to a base, one of which was equipped with an ordinary pressure guage and the other connected to a laboratory hydraulic pump (Fig. 22). Bursting was accomplished by pumping water into the air-filled system until rupture occurred, noting the maximum pressure attained.

Table XXIV

Effect of Various Solutions on Black Radiator Hose (48 Days)

Hose #	Solution	Temp. °F.	Bursting Pressure #/in²	Increase in: Wt. %	Vol. %	Nature of failure
15	Kerosene	170	30	22.5	50.6	Inside badly decayed, leak occurred through fabric; could not burst it.
9	"	170	60	23.6	47.1	Inside partially decayed; break normal short spiral split.
13	"	115	55	19.6	37.9	
2	"	115	75	24.0	46.5	
17	Glycol	170	105	3.6	3.6	
10	"	170	95	3.7	5.3	
5	"	115	90	1.5	5.7	
4	"	115	105	4.2	6.8	
11	Water	170	140	5.1	7.2	Rubber firm, break normal short spiral split of outer fabric followed by tearing of rubber.
19	"	170	90	5.2	7.1	
8	"	115	110	1.9	3.3	
20	"	115	135	1.8	2.1	
6	Glycerine	170	140	1.2	3.6	
16	"	170	125	1.3	2.1	
3	"	115	125	0.3	2.1	
12	"	115	145	1.0	2.8	
7	Alcohol	170	110	0.8	5.7	
18	"	170	110	4.3	6.5	
1	"	115	145	3.3	4.2	
14	"	115	135	2.8	3.6	
Original	---	---	125	---	---	

Table XXV

Effect of Various Solutions on Red Radiator Hose (48 Days)

Hose #	Solution	Temp. °F.	Bursting Pressure #/in^2	Increase in: Wt. %	Vol. %	Nature of failure
17	Kerosene	170	105	33.1	54.6	In all cases the rupture was a short spiral split of the outer fabric, followed by tearing of the rubber.
19	"	170	150	29.9	49.2	
18	"	120	240	6.3	7.5	
20	"	120	230	4.3	7.1	
16	Glycol	170	195	4.4	3.5	
10	"	170	240	3.6	4.7	
13	"	120	250	0.6	0.0	
8	"	120	250	3.5	1.3	
11	Water	170	250	7.3	8.4	
2	"	170	245	8.9	10.0	
5	"	120	250	1.6	0.0	
15	"	120	230	1.7	0.0	
4	Glycerine	170	300	4.5	3.9	
12	"	170	255	1.7	0.0	
9	"	120	260	0.3	0.0	
6	"	120	300	0.9	0.0	
3	Alcohol	170	270	2.4	0.7	
1	"	170	250	1.5	0.7	
7	"	120	250	15.8	14.8	End swelling due to outside leak.
14	"	120	260	3.3	0.7	
Original	---	---	200	---	---	

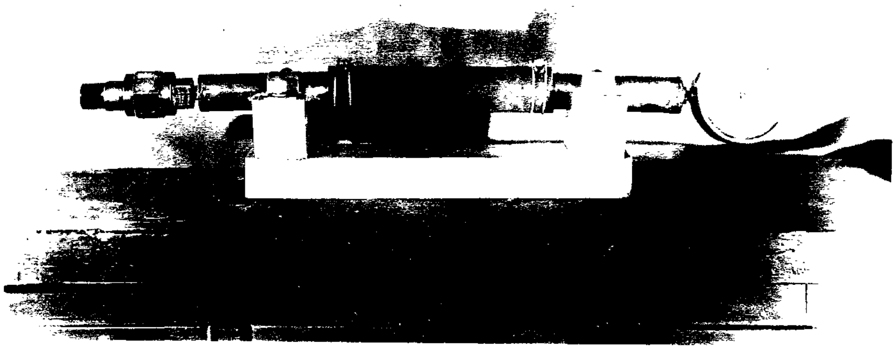


Fig. 22 Hose-Bursting Apparatus

DISCUSSION

The requirements that the cooling medium prevent freezing at the temperatures encountered and have a low viscosity are quite definitely shown to favor the use of petroleum distillates. Corrosion with kerosene is a minor problem, being less than with water, and very decidedly less than with alcohol. The sulphur content of the kerosene probably influences its corrosiveness, but since its sulphur content increases after contact with rubber, the original value is not of great importance. In a few instances not reported in the data, the presence of water in the kerosene caused increased corrosion in the water layer.

The fire hazard of kerosene is shown to be much less than that of alcohol. A case is known to the author in which the top radiator hose was punctured, allowing kerosene to flow down on a hot motor. Only slight fuming took place.

The data show that although cheap radiator hose disintegrates under test, good radiator hose stands up. Cases are known to the author wherein kerosene and other distillates have been used in the radiator, in which the hoses were in good condition after a year's use. One year's service is all that is recommended for radiator hose in use with radiator glycol.

From an examination of the thermal properties of petroleum distillates, the low specific heat and thermal conductivity would indicate their unsuitability as cooling media. However, actual operating conditions show the above factors not to be controlling. The only slight increase in operating temperatures may be explained on the basis of heat transfer through films. In all probability, the water side of the metal in the head is above the boiling point of water. (The thermocouple inserted in the head attempts to measure this temperature). In this case, a film of steam exists through which the heat must be transmitted. In the case of the higher boiling kerosene, a liquid film exists instead of a vapor film, which envolves, then, a comparison of thermal conductivity of a kerosene film (k=0.97 B.T.U. per hr., sq. ft. and F. per in.) with a steam film (k=0.15 B.T.U. per hr., sq. ft. and F. per in.) This comparison shows the advantage of the use of kerosene under such operating conditions.

Another possible explanation lies in the great excess radiator cooling capacity of the automobiles. In cases known to the author wherein the radiator was badly clogged, kerosene did not perform as well. In these cases, the reserve radiator area kept the water from boiling, but was insignificant to prevent the kerosene from boiling. This fact is also brought out by the faster rate of heating of the kerosene compared with water in the half-covered radiator tests. In present radiator design, with much smaller diameter tubing, faster cooling should make this difference even less.

The slight increase in operating temperature of the motor should produce more efficient motor operation during the cold weather. This effect should be determined by dynamometer tests. In addition, tests should also be made on the various grades of lubricating oils to determine what effect the slight increase in oil temperatures has upon viscosity and other oiliness properties. These investigations would complete the study from all angles.

CONCLUSIONS

The foregoing data justify the following conclusions:

1. Kerosene is less viscous at low temperatures than any of the materials commonly used as cooling media.
2. Kerosene is less dangerous as a fire hazard than a 50% alcohol solution.
3. Kerosene offers no corrosion problem when in contact with metal surfaces.
4. Kerosene is more severe than other cooling media on rubber hose, but a quality product stands up both in laboratory tests and under actual conditions.
5. Kerosene causes a motor to heat up slightly faster than the other solutions and attains a temperature of 15°F. higher under no load.
6. Kerosene can be used satisfactorily as a cooling medium in actual operation, even in quite warm weather, causing the motor to run about 30°F. hotter than with water.

SUMMARY

When kerosene or other petroleum distillates are used as cooling media for internal combustion engines, the danger from freezing, fire or corrosion is nil.

When used with a quality grade of radiator hose, only slight deterioration takes place, and hoses have shown satisfactory condition after one year's use.

The increase in the operating temperature of the motor is only slight and should produce an advantage during the cold weather.

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