A COMPARISON OF VARIOUS VEGETABLE OILS AS FUELS FOR COMPRESSION-IGNITION ENGINES

A THESIS

Submitted in partial fulfillment
of the requirements for the degree
of Master of Science in Mechanical Engineering

by

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Atlanta, Georgia
1946

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Approved:

Date Approved by Chairman June 12, 1946

ACKNOWLEDGEMENTS

On the completion of this work I wish to express my thanks to Dr. R. L. Sweigert for his suggestion of the problem and for his most valuable guidence during its prosecution. Also I would like to thank the Dawson Cotton Oil Company, of Dawson Georgia, for the peanut oil which they contributed to the investigation; Dr. R. S. King, of the Mechanical Engineering department at Georgia Tech, for his council; and Dr. C. D. Shiah, of the National Resources commission of China, for his interest. My gratitude is also extended to professors H.B. Duling, A.D. Holland, H.W. Mason, R.L. Allen, C.R. Weeden, and O.M. Harrelson for the part they had in making this project a sucess.

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Introduction

The compression-ignition type engine has been one of the most efficient heat engines in use since Doctor Rudolph Diesel first conceived the idea over fifty years ago. It was Doctor Diesel's idea to use powdered coal for this engine, but he ran into problems with his powdered coal system which have not yet been solved. The fuel which he finally selected was petroleum, and when diesel engines came into general use, petroleum was the logical choice for a fuel.

The United States is one of the few countries in the world fortunate enough to have large supplies of petroleum, which its inhabitants have used none too wisely. The effects of this wastefulness can be seen in the diminishing supply of oil accompanied by an increase in consumption; therefore, the study of substitute fuels is of great importance. Vegetable oils loom as a notable possibility for engines of compression-ignition class. Chief among the vegetable oils for use as engine fuels are peanut, soy bean and cottonseed oils, which may be secured in untold abundance from several agricultural areas of the United States, thus assuring an adequate supply of these oils at all times.

It is realized that the actual substitution of vegetable oils for petroleum products is a matter for future contingency, but a study and realization of the problems involved is an absolute necessity both from the engineering and economic points of view. Present planning will obviate possible future stop-gap types of engineering research.

Section I

General Test Material

A: Test Engine:

Manufacturer --- Fairbanks Morse Model 36A

Number of cylinders --- 1

Type --- Four Stroke Cycle

Rating --- 10 horsepower

Bore --------- 4-1/4 inches

Stroke ------- 6 inches

Rated Speed ---- 1200 Revolutions Per Minute

Compression Ratio ----------- 14.5 - 1

Photographs appear on pages 4 and 5.

B: Special Equipment:

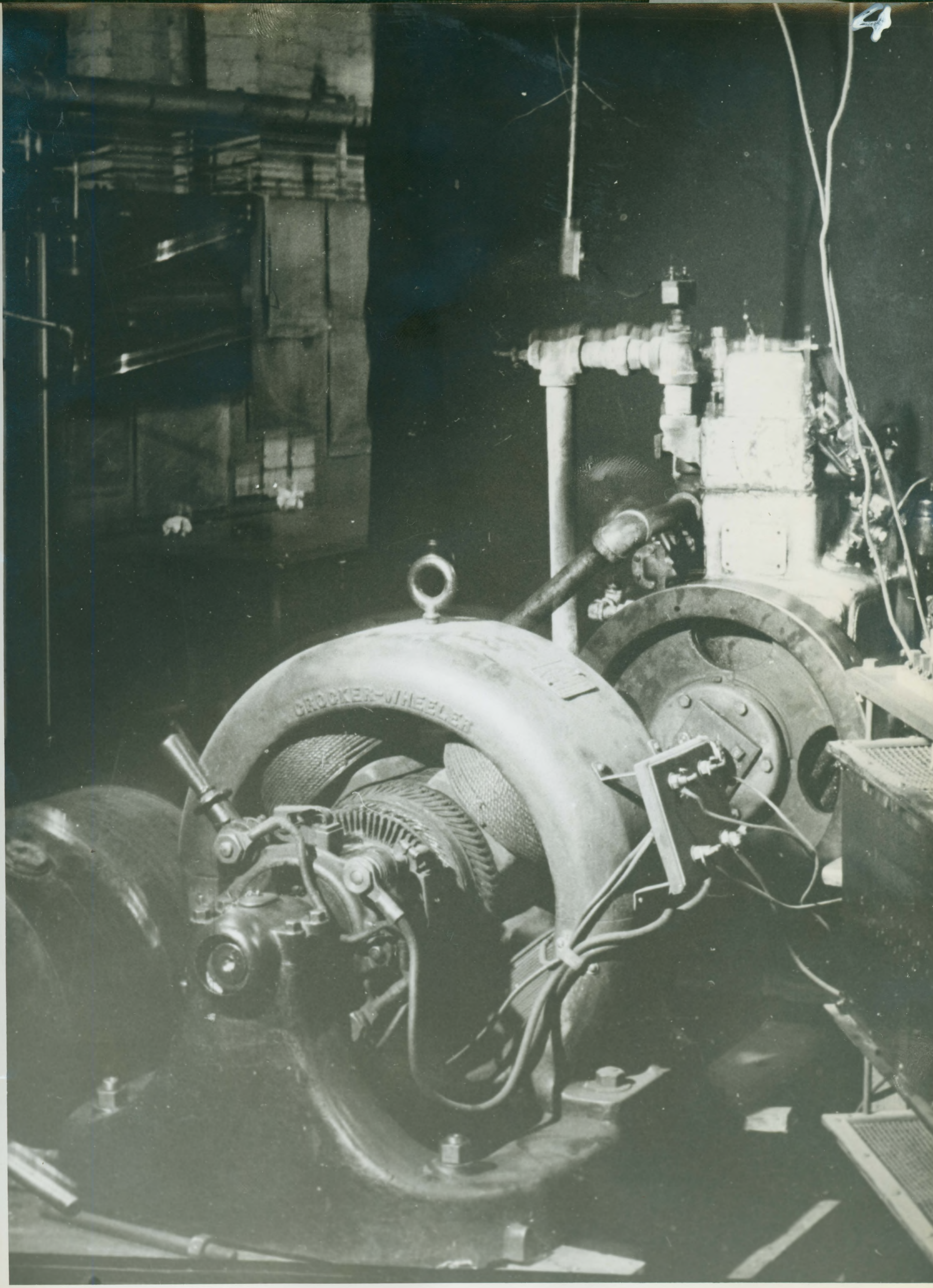
Injection Pump ---- Bosch type, constant stroke.

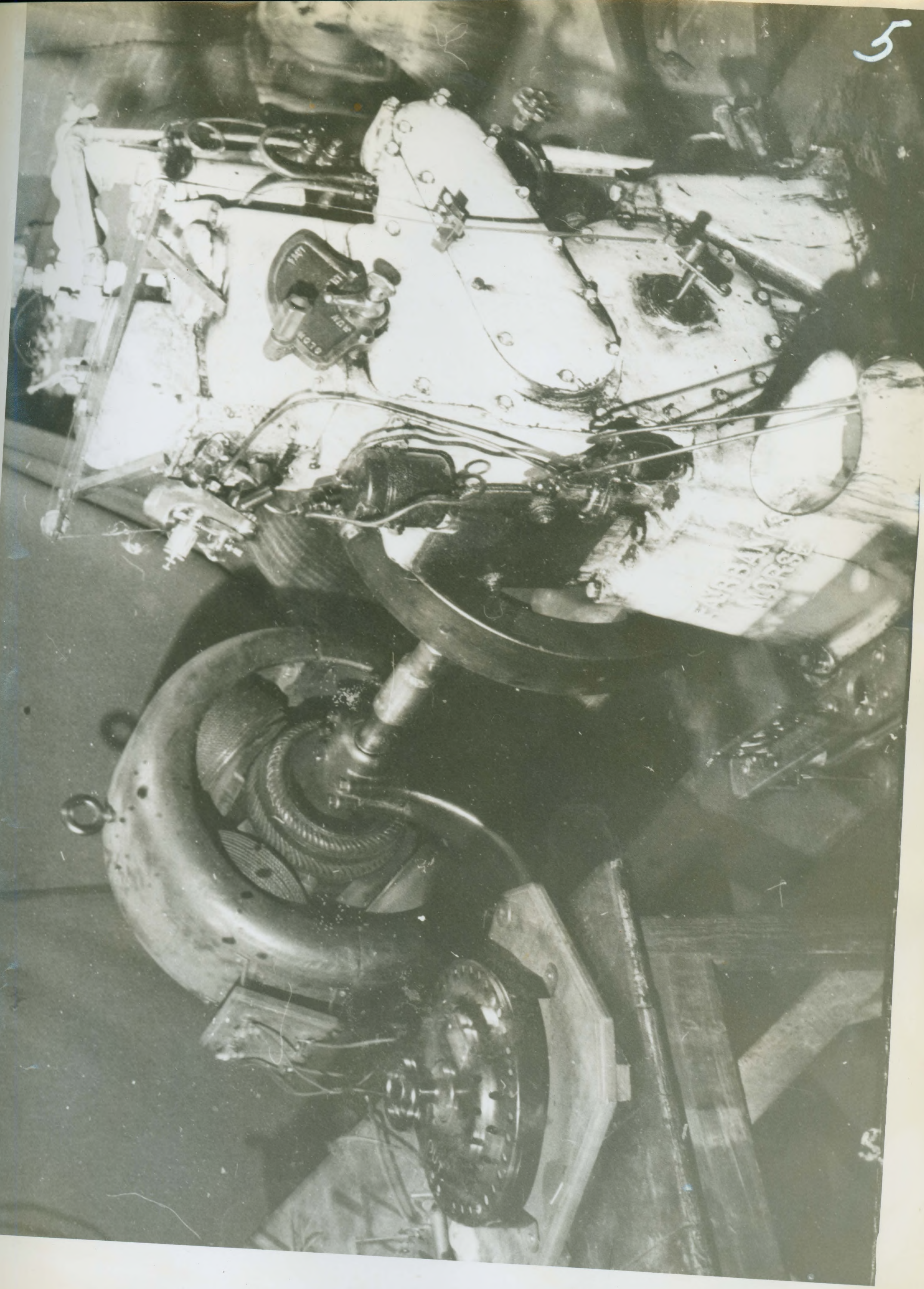
Injection Nozzle ---- Pintle type, which discharges into the pre-combustion chamber.

C: Auxiliary Equipment:

(a) Electrical System:

The test engine was loaded with a direct current generator directly connected to the engine shaft. The field of the generator was excited from a separate 110 volt source. Power generated was dissipated through a system of resistances. The wiring diagram is shown in Figure 1.


CROCKER-WHEELER



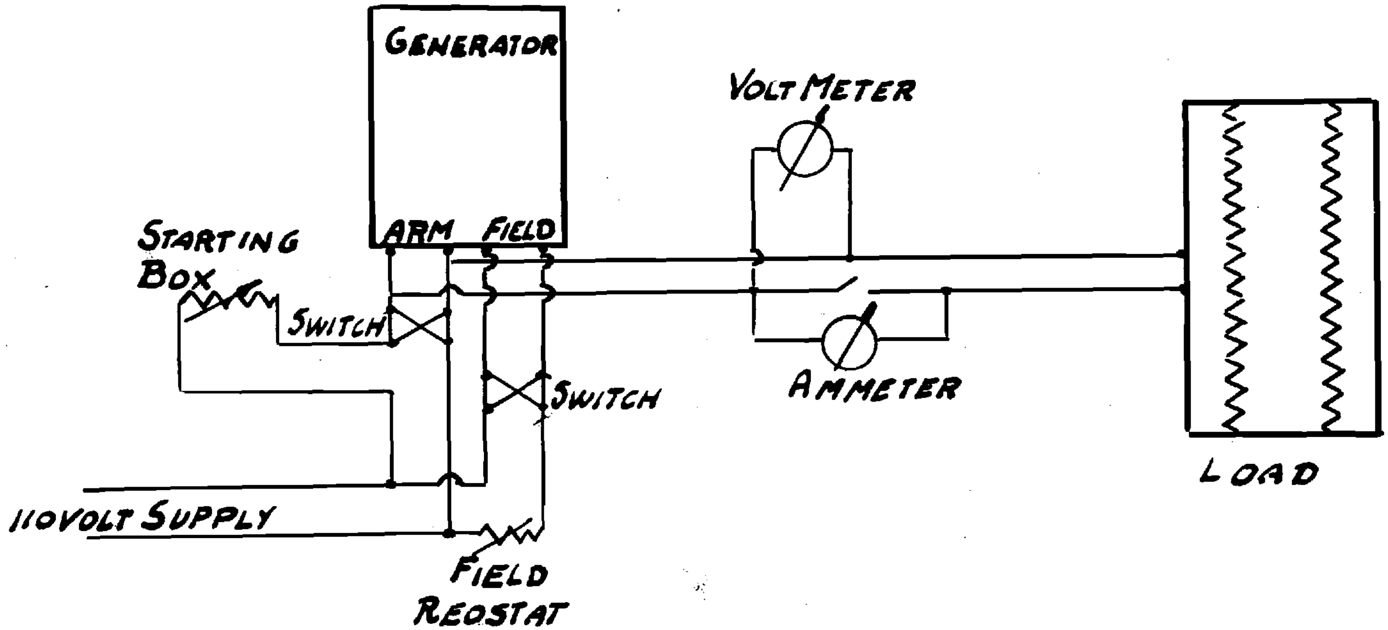


FIG. 1

ELECTRICAL SYSTEM
WIRING DETAILS

(b) Air metering system:

The intake air for the engine was measured by an orifice constructed and installed according to the method of J.L. Hodgson[1], and flow equations used were obtained from Hodgson's data. To eliminate pulsating flow caused by a periodic demand for air a fifty gallon drum was included in the air intake system.

(c) Indicator mechanism:

Indicator cards were taken with a Mahak high speed indicator which utilizes a cantilever type spring. The indicator was attached to the engine where a starting cartridge would ordinarily go. The drum of the indicator was connected to the crank shaft by means of a steel tape. The attachment to the crank shaft and method of installation is shown in Figure 2.

D: Test Fuels:

(a) Experimental:

1. Peanut Oil -- Obtained from the Dawson Cotton Oil Company, Dawson, Georgia
2. Soy Bean Oil -- Obtained from Swift & Co., Atlanta, Ga.
3. Cottonseed Oil -- Obtained from Buckeye Cotton Oil Company, Atlanta, Georgia.

(b) Standard:

Diesel Fuel -- Obtained from the Standard Oil Co., Atlanta, Ga. (For physical properties see Section III)

[1]Ower, E. The Measurement of Air Flow (London, Chapman, and Hall Ltd. 1927) pp 56-57.

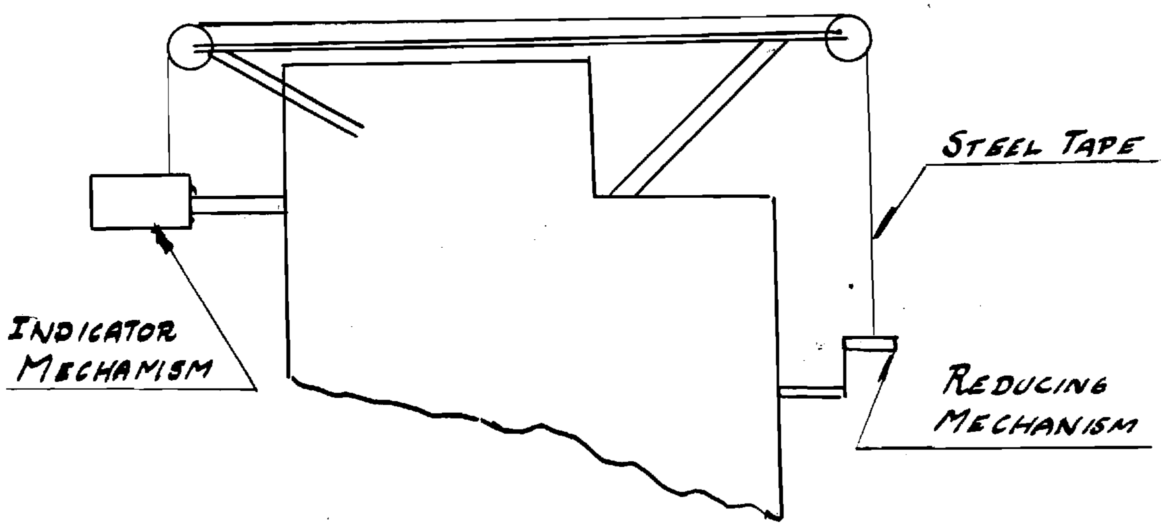


FIG 2

SKETCH OF INDICATOR MECHANISM SET-UP

E: Test Proceedure:

(a) Instruments:

Standard Taylor Mercury-in-glass thermometers were used for the following readings:

1. Wet and Dry bulb temperatures of the atmosphere.
2. Engine cooling water temperatures.
3. Air temperature ahead of air meter.

A pyrometer operating from the thermocouple in the exhaust gas line was used to measure the exhaust gas temperature.

(b) Test Conditions:

1. Heating values - oil.

The heating value of each of the oils used was determined in an Emerson Bomb calorimeter. A measured amount of oil was burned in an atmosphere of oxygen under a pressure of three hundred pounds per square inch. The temperature rise of the water surrounding the bomb was measured and the heating value calculated.

2. Miscellaneous physical tests:

The viscosity determinations of the oils were in terms of Saybolt-Seconds Universal. To make these determinations a Saybolt Universal viscosimeter was used. The viscosity was the time in seconds for sixty milliters to flow through the orifice of the viscosimeter.

The flash and fire points were determined in an open cup tester.

The specific gravity was determined by two methods. The first was a ratio of the weight of oil to the weight of an equal volume of water; the second was by means of a hydrometer. All values were determined at sixty degrees Fahrenheit.

The carbon residue was determined by the Conradson method. The residue was expressed as a percentage of the original weight of oil.

3. Performance tests:

Time ----- 30 minutes

Range ---- 3.0 Brake horsepower to maximum obtainable under operating conditions.

Number of tests: --- one for each vegetable oil and one for the diesel oil.

These tests were carried out under reasonably controlled conditions throughout.

4. Sustained run tests:

The testing period varied from 20 to 46½ hours. The load was the maximum obtainable for duration of run.

The length of each run was conditioned by the available supply of fuels.

Section II

Tabulation of Results

The following tables give the physical properties and the performance data for all oils under consideration.

Table I: Heating Value:

Diesel Oil	19,890 Btu per pound.
Peanut Oil	18,075 Btu per pound.
Soy Bean Oil	17,640 Btu per pound.
Cottonseed Oil	16,860 Btu per pound.

Table II: Flash and Fire Points:

	Flash	Fire
Diesel Oil	211°F	223°F
Peanut Oil	470°F	542°F
Soy Bean Oil	571°F	627°F
Cottonseed Oil	512°F	602°F

Table III: Carbon Residue:

Diesel Oil	Indeterminable with available equipment.
Peanut Oil	0.365%
Soy Bean Oil	0.409%
Cottonseed Oil	0.549%

Table IV: Specific Gravity (60°F)

Diesel Oil	0.856	34°Baume
Peanut Oil	0.915	23°Baume
Soy Bean Oil	0.918	22°Baume
Cottonseed Oil	0.915	23°Baume

Table V: Viscosity (Saybolt-seconds Universal)

Temp. °F	Diesel Oil	Peanut Oil	Soy Bean Oil	Cottonseed Oil
70	56	280	252	310
90	46	200	185	210
110	38	150	140	150
130	32	115	110	110
150	29	93	90	90
170	26	75	75	72
190	24	65	64	60
210	21	55	56	50

Table VI: Performance Data-----Diesel Oil:

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Ther. eff.	Vol. eff.
B.H.P	Pounds	Pounds	Per Cent	Per Cent
3.01	2.16	0.716	17.9	77.5
4.24	2.54	0.599	21.4	77.3
5.55	3.06	0.552	23.2	76.3
6.96	3.58	0.514	24.9	76.5
8.75	4.32	0.493	26.1	76.2

Table VII: Performance data-----Peanut Oil:

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Ther. Eff.	Vol. Eff.
B.H.P.	Pounds	Pounds	Per cent	Per cent
3.18	2.78	0.874	16.14	78.0
4.10	3.22	0.785	17.98	77.3
5.46	3.74	0.685	20.60	77.2
7.11	4.56	0.640	22.00	76.3
8.22	5.10	0.620	23.10	75.8

Table VIII: Performance data-----Soy Bean Oil:

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Ther. Eff.	Vol. Eff.
B.H.P.	Pounds	Pounds	Per cent	Per cent
3.01	3.02	1.002	14.40	90.0
4.52	3.54	0.784	18.44	80.8
5.81	4.30	0.740	19.50	79.8
7.35	5.12	0.696	20.55	78.3
8.30	6.06	0.731	19.75	76.8

Table IX: Performance data-----Cottonseed Oil;

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Ther. Eff.	Vol. Eff.
B.H.P.	Pounds	Pounds	Per cent	Per cent
3.01	2.72	0.915	16.7	79.0
4.20	3.44	0.815	18.53	77.8
5.89	4.42	0.750	20.15	76.4
7.14	5.14	0.720	20.95	75.2

To compare the vegetable oils with diesel oil the fuel rate, fuel rate per horsepower hour, and thermal efficiency were expressed as a percentage of these values which occured at the maximum thermal efficiency obtainable with diesel oil.

Table X: Diesel oil performance values which occured at maximum thermal efficiency.

Load	10 Horsepower
Fuel rate	4.8 Pounds per hour
Pounds of fuel per horsepower hour	0.490
Maximum thermal efficiency	26.3%

The following tables give the performance data expressed as a percentage of the performance values at maximum thermal efficiency for diesel oil.

Table XI: Performance data of peanut oil expressed as a percentage of the value at maximum diesel thermal efficiency.

Load	Pounds fuel per hour	Pounds fuel per H.P. hour	Thermal Efficiency
Per cent	Per cent	Per cent	Per cent
31.8	57.9	178.1	61.4
41.0	67.1	160.2	68.3
54.6	76.3	139.7	78.4
71.1	95.0	130.5	83.7
82.2	106.2	126.5	87.8

Table XII: Performance data of soy bean oil expressed as a percentage of the values at maximum diesel thermal efficiency.

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Thermal Efficiency
Per cent	Per cent	Per cent	Per cent
30.1	63.0	205.0	54.3
45.2	73.8	160.0	70.3
58.1	89.6	151.0	74.1
73.5	106.7	142.0	76.7
83.0	126.3	149.2	79.7

Table XIII: Performance data of cottonseed oil expressed as a percentage of the values at maximum diesel thermal efficiency.

Load	Pounds fuel per hour	Pounds fuel per H.P. hr.	Thermal Efficiency
Per cent	Per cent	Per cent	Per cent
30.1	56.7	186.5	63.5
42.0	71.3	166.5	70.5
58.9	92.0	153.0	76.7
71.4	107.0	147.0	79.7

Table XIV

Sustained Run Data - Peanut Oil

Time	Load	Lbs. per. hour	Lbs. per H,P. hour	Ther. eff.	Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.
Hr Mn	H.P.			%	Hr Mn	H.P.			%
00	7.54				11:30	8.53	5,32	0.624	22.6
0:30	7.54	4.18	0.554	25.3	12:00	8.53	5.36	0.624	22.6
1:00	7.54	4.58	0.605	23.3	12:30	8.53	5.36	0.624	22.6
1:30	7.54	4.38	0.580	24.3	13:00	8,53	5.36	0.624	22.6
2:00	7.54	4.28	0.566	24.9	13:30	8.53	5.12	0.602	23.4
2:30	7.54	4.48	0.593	23.8	14:00	8.53	5.12	0.602	23.4
3:00	7.54	4.38	0.596	23.5	14:30	8.53	5.10	0.598	23.5
3:30	7.54	4.30	0.572	24.7	15:00	8.53	5.18	0.607	23.2
4:00	7.54	4.52	0.600	23.5	15:30	8.53	5.14	0.603	23.4
4:30	7.54	4.36	0.588	24.0	16:00	8.53	5.10	0.598	23.6
5:00	7.54	4.36	0.588	24.0	16:30	8,53	5.24	0.615	22.9
5:30	7.80	4.82	0.607	23.2	17:00	8.53	5.28	0.620	22.7
6:00	7.80	4.78	0.607	23.2	17:30	8.53	5.22	0.613	23.0
6:30	7.80	4.82	0.603	23.4	18:00	7.90	4.92	0.623	22.7
7:00	7.80	4.82	0.618	22.8	18:30	7.90	4.92	0.623	22.7
7:30	7.80	4.80	0.618	22.8	19:00	7.90	4.88	0.617	22.8
8:00	7.80	4.82	0.616	22.9	19:30	7.90	4.90	0.620	22.7
8:30	7.80	4.80	0.618	22.8	20:00	7.90	4.78	0.605	23.3
9:00	7.80	4.82	0.619	22.9	20:30	7.90	4.84	0.613	23.0
9:30	8.53	5.44	0.637	22.1	21:00	7.90	4.88	0.617	22.9
10:00	8.53	5.44	0.637	22.1	21:30	7.90	4.84	0.613	23.3
10:30	8.53	5.46	0.650	22.0	22:00	7.90	4.86	0.615	22.9
11:00	8.53	5.54	0.641	22.0	22:30	7.90	4.86	0.615	22.9

Sustained Run Data - Peanut oil Continued

Time Hr Mn	Load H.P.	Lbs. per hour	Lbs. per H.P. hour	Ther. eff. %	Time Hr Mn	Load H.P.	Lbs. per hour	Lbs. per H.P. hour	Ther. eff. %
23:00	7.90	4.82	0.612	23.3	30:00	8.28	4.92	0.594	23.7
23:30	7.90	4.84	0.613	23.5	30:30	8.28	4.92	0.594	23.7
24:00	7.90	4.86	0.615	23.0	31:30	8.03	4.66	0.580	24.3
24:30	8.28	4.98	0.603	22.9	31:30	8.03	4.66	0.581	24.4
25:00	8.28	4.98	0.603	23.6	32:00	8.03	4.74	0.578	22.7
25:30	8.28	4.96	0.590	23,5	32:30	8.03	4.64	0.621	22.6
26:00	8.28	4.82	0.582	24,2	33:00	8.03	4.98	0.623	22,0
26:30	8.28	4.86	0.586	24,1	33:30	8.03	5.00	0.640	22.2
27:00	8.28	4,86	0.586	24.1	34:00	8,03	5.16	0.636	22.2
27:30	8.28	4.88	0.589	23.9	34:30	8.03	5.10	0.665	21.2
28:00	8.28	4.92	0.594	23.8	35:00	8.03	5.34	0.682	20.7
28:30	8.28	4.86	0.586	24.1	35:30	8.03	5.46	0.682	20.7
29:00	8.28	4.82	0.582	24.2	36:00	8.03	5.90	0.735	19.2
29:30	8.28	4.94	0.597	23.6					

Table XV

Sustained Run Data - Soy Bean Oil

Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.	Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther eff.
Hr Mn	H.P.			%	Hr Mn	H.P.			%
00	8.45				11:30	6.87	4.44	0.645	22.4
0:30	8.45	6.34	0.750	19.3	12:00	6.87	4.46	0.649	22.2
1:00	8.45	6.02	0.713	20.3	12:30	6.87	4.58	0.888	21.6
1:30	8.45	5.98	0.707	20.4	13:00	6.98	5.00	0.715	20.2
2:00	7.25	5.92	0.817	17.7	13:30	6.98	5.00	0.715	20.2
2:30	7.25	5.50	0.759	19.0	14:00	6.98	4.86	0.696	20.7
3:00	7.25	5.12	0.707	20.4	14:30	6.98	4.82	0.688	21.0
3:30	7.25	5.02	0.692	20.8	15:00	6.98	4.84	0.693	20.9
4:00	7.25	5.16	0.713	20.2	15:30	6.98	4.60	0.659	21.9
4:30	7.25	5.28	0.727	19.9	16:00	6.98	4.88	0.699	20.6
5:00	7.25	5.24	0.723	20.0	16:30	6.98	4.80	0.687	21.0
5:30	7.25	5.34	0.737	19.6	17:00	6.98	4.80	0.687	21.0
6:00	7.25	5.40	0.745	19.4	17:30	6.98	4.84	0.691	20.9
6:30	7.25	5.00	0.690	20.9	18:00	6.98	4.92	0.705	20.5
7:00	7.25	5.20	0.718	20.1	18:30	6.98	4.82	0.690	20.9
7:30	6.33	4.88	0.773	18.7	19:00	6.98	4.78	0.683	21.2
8:00	6.33	4.88	0.773	18.7	19:30	6.98	4.88	0.698	20.6
8:30	6.33	4.76	0.755	19.1	20:00	6.98	5.02	0.718	20.1
9:00	6.33	4.62	0.730	19.8	20:30	6.98	5.04	0.722	20.0
9:30	6.33	5.42	0.857	16.9	21:00	6.98	4.86	0.698	20.7
10:00	6.08	4.84	0.795	18.2	21:30	6.98	5.36	0.768	18.8
10:30	6.87	4.44	0.645	22.4	22:00	6.85	4.62	0.672	21.5
11:00	6.87	4.50	0.655	22.0	22:30	6.85	4.62	0.672	21.5

Sustained Run Data - Soy Bean Oil Continued

Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.	Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.
Hr Mn	H.P.			%	Hr Mn	H.P.			%
23:00	6.85	4.62	0.672	21.5	35:00	7.69	5.12	0.666	21.7
23:30	6.85	4.64	0.674	21.4	35:30	7.69	5.10	0.669	21.8
24:00	6.85	4.44	0.670	21.5	36:00	7.69	5.16	0.672	21.5
24:30	6.85	4.52	0.670	21.5	36:30	7.69	5.16	0.672	21.5
25:00	6.85	4.68	0.683	21.2	37:00	7.69	5.12	0.666	21.7
25:30	6.85	4.80	0.700	20.6	37:30	7.69	5.42	0.704	20.5
26:00	6.85	4.68	0.683	21.2	38:00	7.69	5.24	0.682	21.2
26:30	6.85	4.82	0.703	20.6	38:30	6.85	4.94	0.721	20.1
27:00	6.85	4.76	0.693	20.8	39:00	6.85	4.94	0.721	20.1
27:30	6.85	4.92	0.718	20.1	39:30	6.85	4.60	0.672	21.5
28:00	5.82	5.48	0.943	15.3	40:00	6.85	4.94	0.721	20.1
28:30	5.82	4.80	0.855	17.3	40:30	6.85	4.80	0.700	20.5
29;00	5.82	4.82	0.829	17.4	41:00	6.85	4.66	0.680	21.3
29:30	5.82	5.10	0.877	16.5	41:30	6.85	4.60	0.671	21.2
30:00	5.82	5.26	0.904	16.0	42:00	6.85	4.62	0.673	21.5
30:30	4.92	5.08	1.032	14.0	42:30	6.85	4.70	0.686	21.1
31:00	4.04	4.58	1.132	12.7	43:00	6.85	4.56	0.676	21.4
31:30	4.04	4.48	1.111	13.0	43:30	6.85	4.72	0.689	21.0
32:00	4.04	4.36	1.080	13.4	44:00	6.85	4.74	0.692	20.9
32:30	4.04	4.28	1.060	13.6	44:30	6.85	4.98	0.729	19.8
33:00	4.04	4.44	1.100	13.1	45:00	6.85	4.96	0.723	20.0
33:30	7.69	5.30	0.689	21.0	45:30	6.85	4.78	0.699	20.7
34:00	7.69	5.30	0.689	21.2	46:00	6.85	4.90	0.715	20.2
34:30	7.69	5.24	0.682	21.7	46:30	6.85	5.08	0.742	19.5

Table XVI

Sustained Run Data - Cottonseed Oil

Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.	Time	Load	Lbs. per hour	Lbs. per H.P. hour	Ther. eff.
Hr Mn	H.P.			%	Hr Mn	H.P.			%
00	7.14				11:30	4.19	4.32	1.032	14.6
0:30	7.14	5.16	0.723	20.9	12:00	5.89	4.16	0.706	21.4
1:00	7.14	4.94	0.693	21.8	12:30	5.89	4.16	0.772	19.7
1:30	7.14	5.40	0.757	20.0	13:00	6.92	4.28	0.618	24.5
2:00	7.14	5.40	0.757	20.0	13:30	6.92	4.28	0.618	24.5
2:30	5.89	4.72	0.788	19.2	14:00	6.92	4.56	0.659	23.0
3:00	5.89	4.72	0.788	19.2	14:30	6.92	4.70	0.679	22.5
3:30	5.89	4.76	0.808	18.7	15:00	6.92	4.52	0.653	23.3
4:00	5.89	4.76	0.830	18.2	15:30	6.92	4.94	0.714	21.3
4:30	4.19	4.22	1.005	15.1	16:00	6.92	4.82	0.697	21.7
5:00	4.19	4.02	0.963	15.8	16:30	6.92	5.06	0.731	20.7
5:30	4.19	3.85	0.918	16.5	17:00	6.92	5.06	0.670	22.6
6:00	4.19	4.02	0.963	15.7	17:30	6.92	5.14	0.742	20.4
6:30	4.19	3.98	0.952	15.9	18:00	5.89	4.38	0.746	20.3
7:00	4.19	3.78	0.903	17.5	18:30	5.89	4.54	0.774	19.3
7:30	4.19	4.18	1.00	15.1	19:00	5.89	4.38	0.746	20.3
8:00	4.19	4.20	1.00	15.1	19:30	5.89	4.48	0.763	19.9
8:30	4.19	4.40	1.050	15.9	20:00	5.89	4.66	0.775	19.5
9:00	4.19	4.54	1.085	16.0	20:30	5.89	4.54	0.774	19.6
9:30	4.19	4.06	1.064	14.3					
10:00	4.19	4.24	1.012	15.0					
10:30	4.19	4.44	1.060	14.3					
11:00	4.19	4.56	1.087	14.0					

Section III

Discussion

A: Physical properties:

The heating values of the vegetable oils vary from 16,860 Btu per pound for cottonseed oil to 18,075 Btu per pound for peanut oil, as shown in Table I. All of these values are appreciably less than the diesel oil value. As might be expected, the fuel consumption per horsepower hour for these vegetable oils varied with the heating value.

The flash and fire point temperatures of these vegetable oils were observed to be higher than those of the diesel oil, as shown in Table II.

The viscosities of the vegetable oils were observed to be higher than that for the diesel oil, as shown in Table V and Figure 3. The higher viscosities of the vegetable oils were not observed to have caused an injection lag. All of the oils were injected into the engine at approximately the same degree of crank angle.

The carbon residue values for the vegetable oils were observed to range from 0.365%, for the peanut oil, to 0.549%, for the cottonseed oil, The establishment of the carbon residue value for the diesel oil was not possible with the available test equipment but the observations with this available equipment indicate that it was an extremely low value.

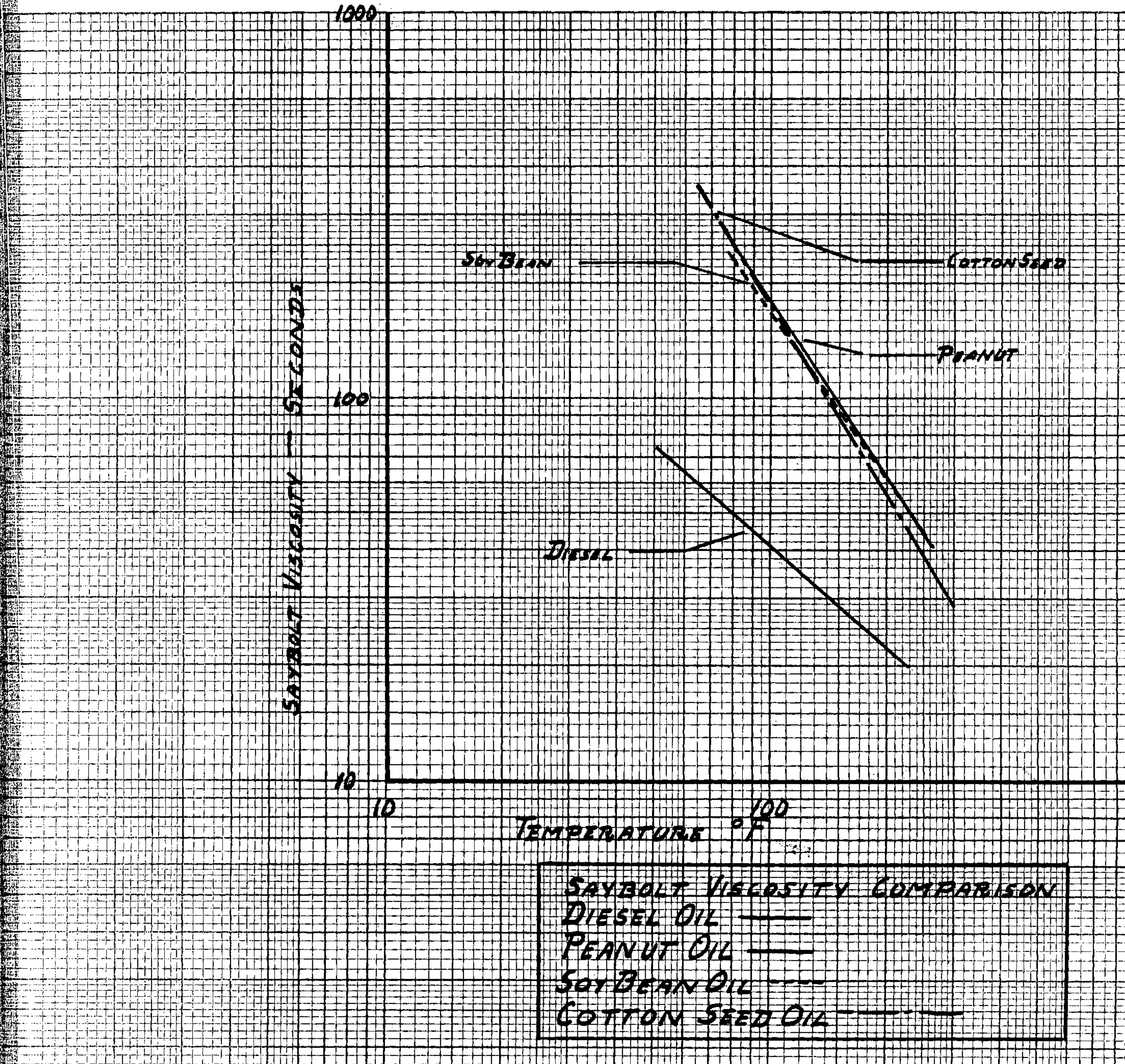

1000
100
10
10
100
SAYBOLT VISCOSITY — SECONDS
TEMPERATURE °F
SOY BEAN
COTTON SEED
PEANUT
DIESEL
SAYBOLT VISCOSITY COMPARISON
DIESEL OIL
PEANUT OIL
SOY BEAN OIL
COTTON SEED OIL

FIG. 3

B: Performance:

(a) Variable load conditions:

The fuel rate in pounds per horsepower was observed to be higher for the vegetable oils than for the diesel oil, as shown in Figure 4. The term, most economical diesel value, noted in the legend of Figure 4, is defined as the highest thermal efficiency for diesel oil. The fuel rate for peanut oil was less than the fuel rate for soy bean or cottonseed oils, which were approximately the same.

The tested vegetable oils showed pressure decreases following the compression stroke, as shown by the indicator cards in Figures 7 through 12. This condition was more pronounced in the case of soy bean and cottonseed oils than for peanut oil. No measurable decrease in pressure for diesel oil was observed in this portion of the cycle. The pressure decreases on the part of the vegetable oils is probably due to late ignition characteristics and could probably be remedied by advancing the point of fuel injection.

The load range for the vegetable oils was observed to be lower than the load range for diesel oil, as shown in Figure 4. In this connection it should be noted that the test engine was designed for an oil that has the characteristics of diesel fuel. The use of oils which have lower heating values and different combustion characteristics tend to make the load range lower than that obtainable with diesel oil. Indications are that the redesigning of the engine to meet heating value and combustion characteristics of these vegetable oils would probably extend the load range.

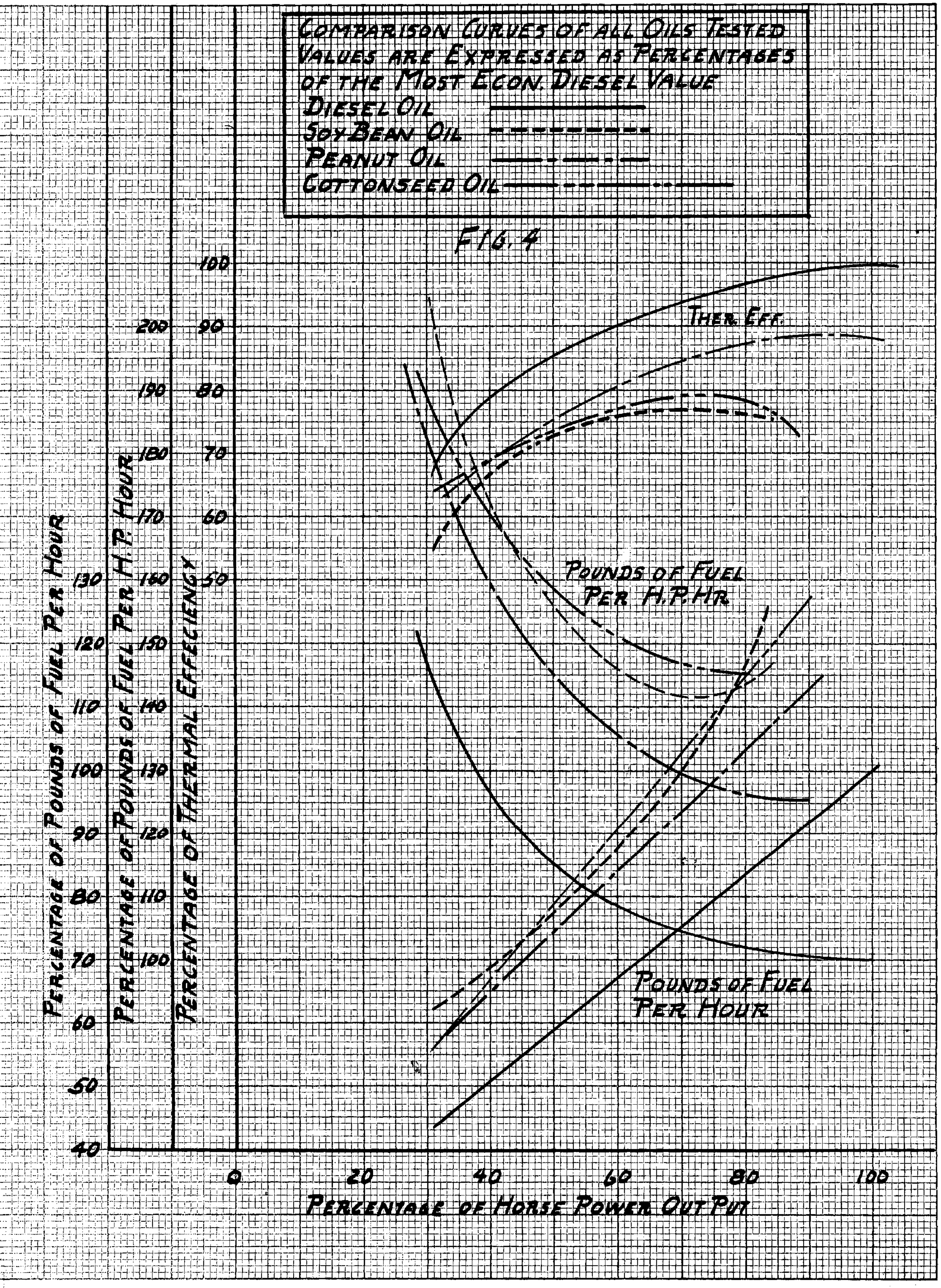

COMPARISON CURVES OF ALL OILS TESTED
VALUES ARE EXPRESSED AS PERCENTAGES
OF THE MOST ECON. DIESEL VALUE
DIESEL OIL
SOY BEAN OIL
PEANUT OIL
COTTONSEED OIL
THER. EFF.
POUNDS OF FUEL PER H.P. HR.
POUNDS OF FUEL PER HOUR
PERCENTAGE OF POUNDS OF FUEL PER HOUR
PERCENTAGE OF POUNDS OF FUEL PER H.P. HOUR
PERCENTAGE OF THERMAL EFFECIENCY
PERCENTAGE OF HORSE POWER OUT PUT
0
20
40
60
80
100

FIG. 4

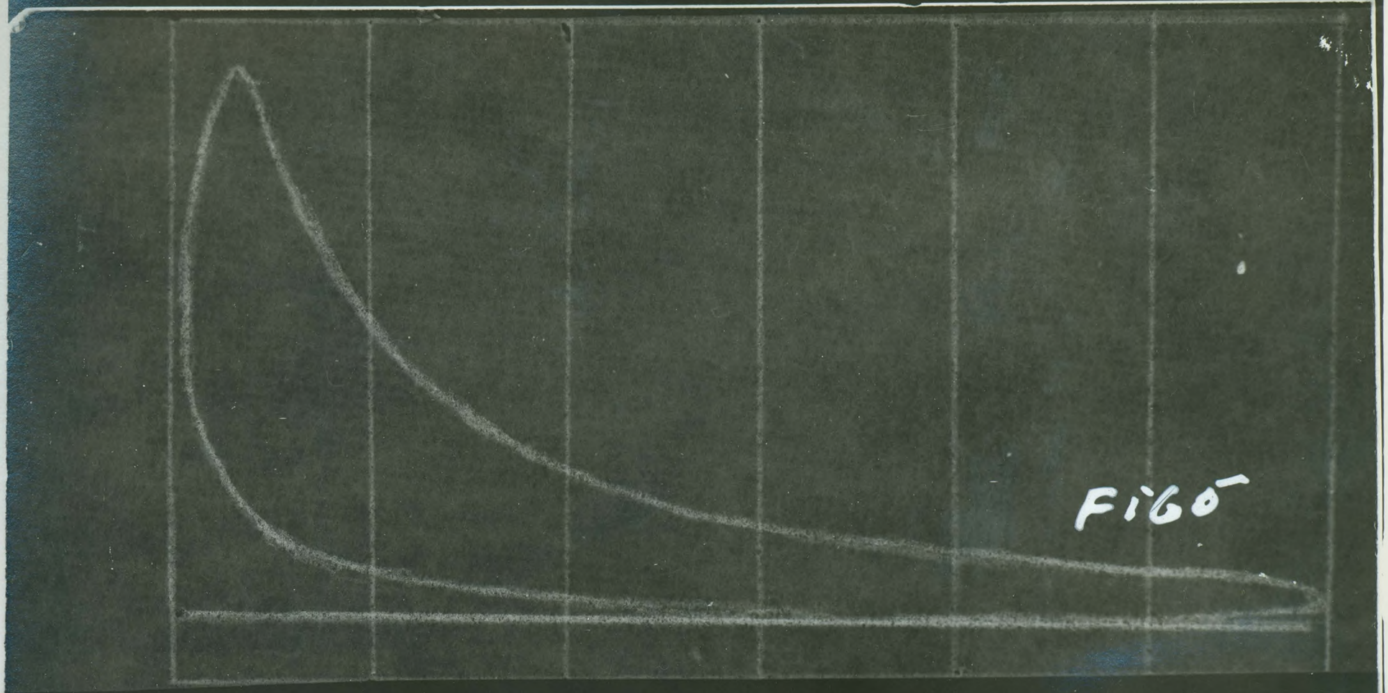


FIG 5

DIESEL OIL
1240 R.P.M
8.15 B.H.P.

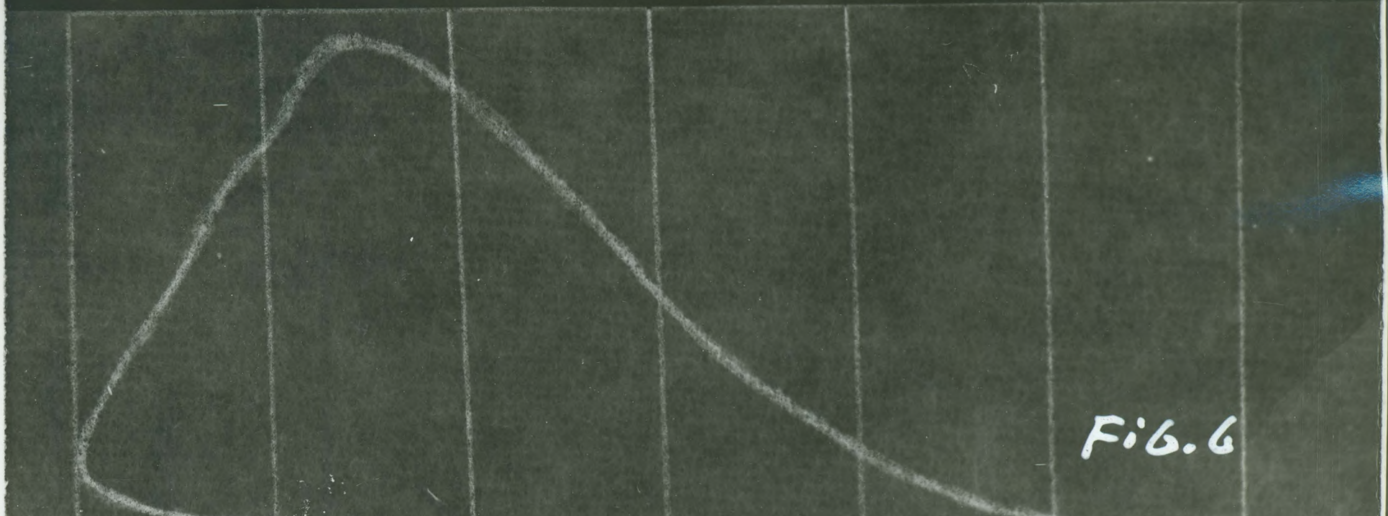


FIG. 6

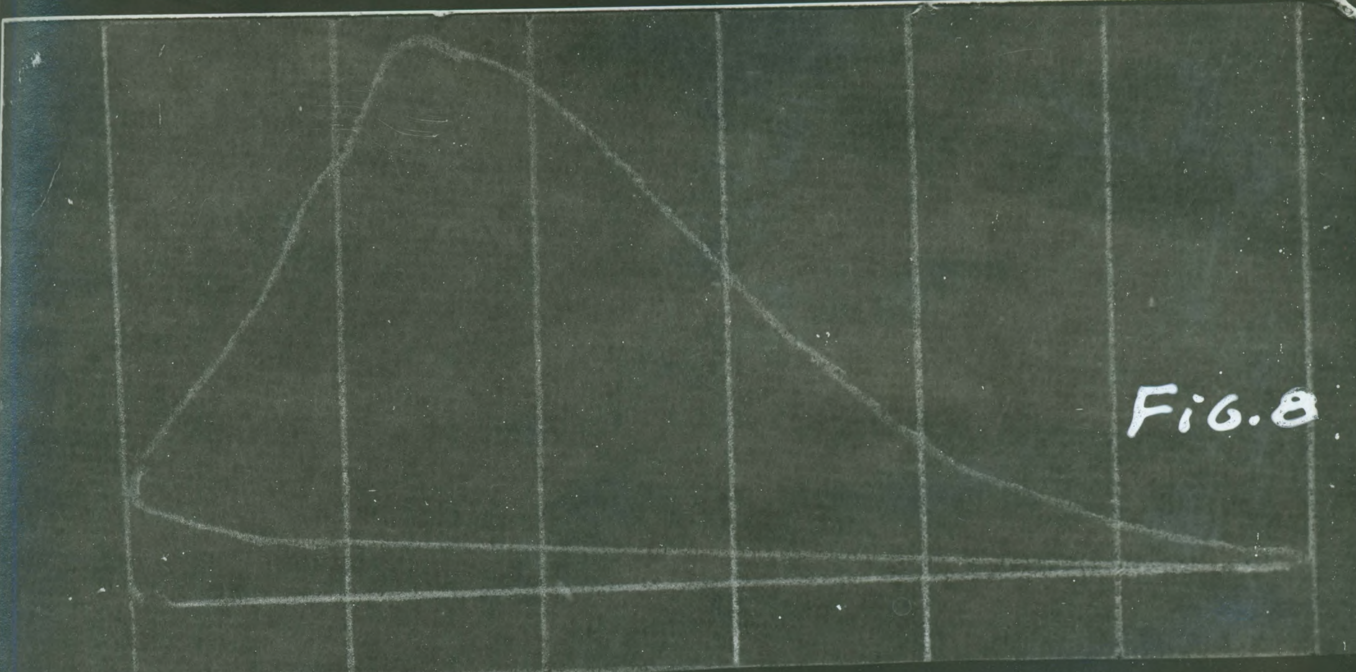


Fig. 8

PEANUT OIL
1240 R.P.M.
8.15 B.H.P

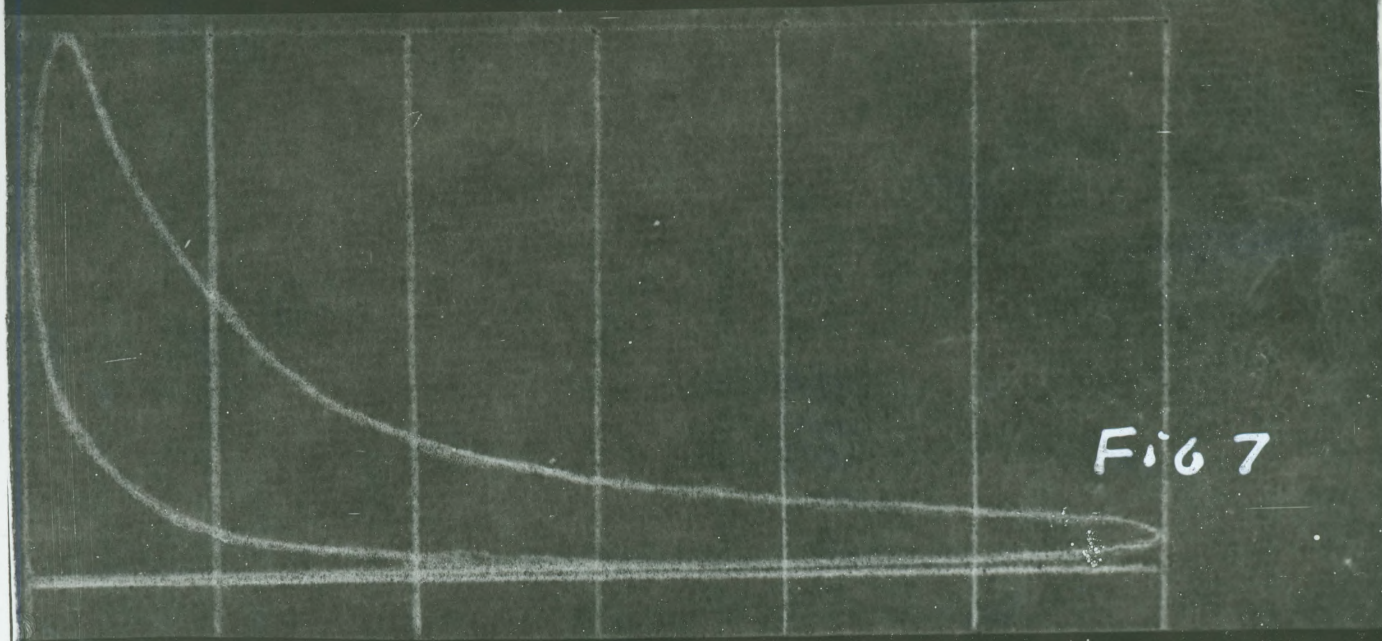


Fig 7

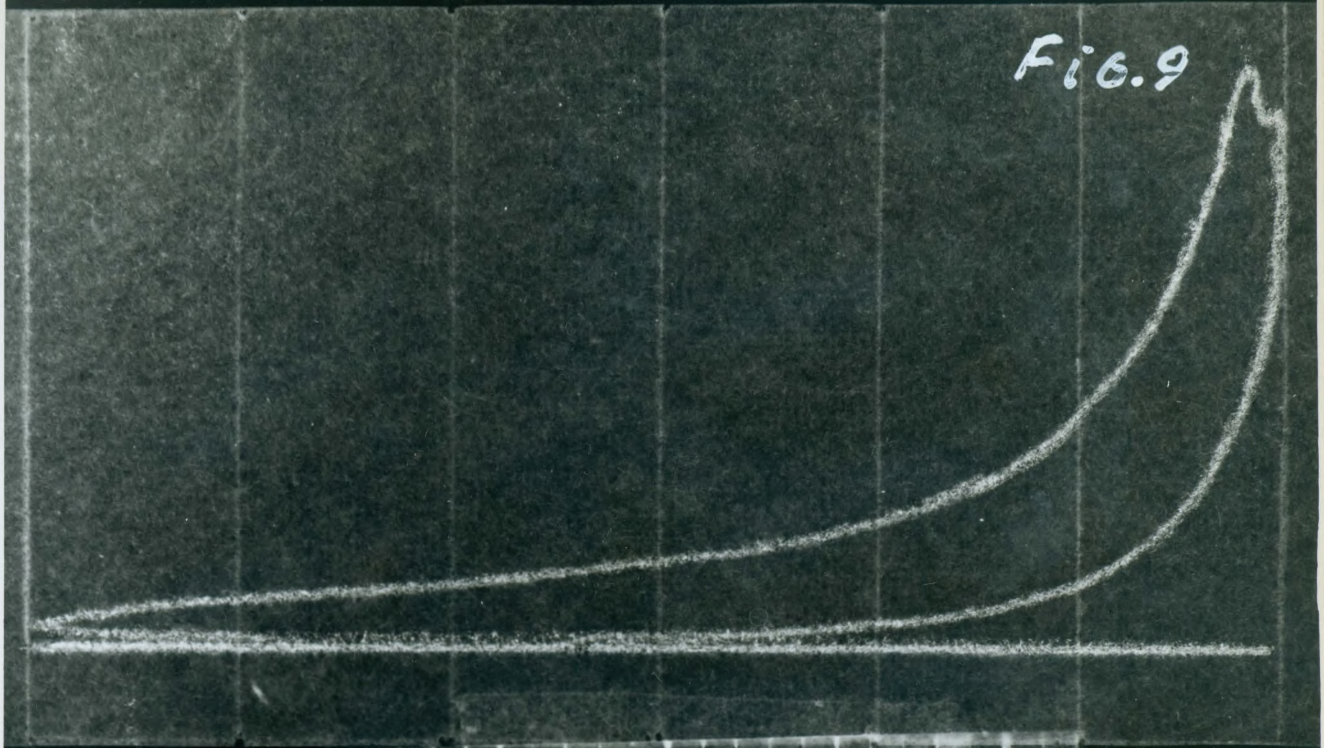


Fig. 9

Soy Bean Oil
1240 R.P.M.
2.25 B.H.P.

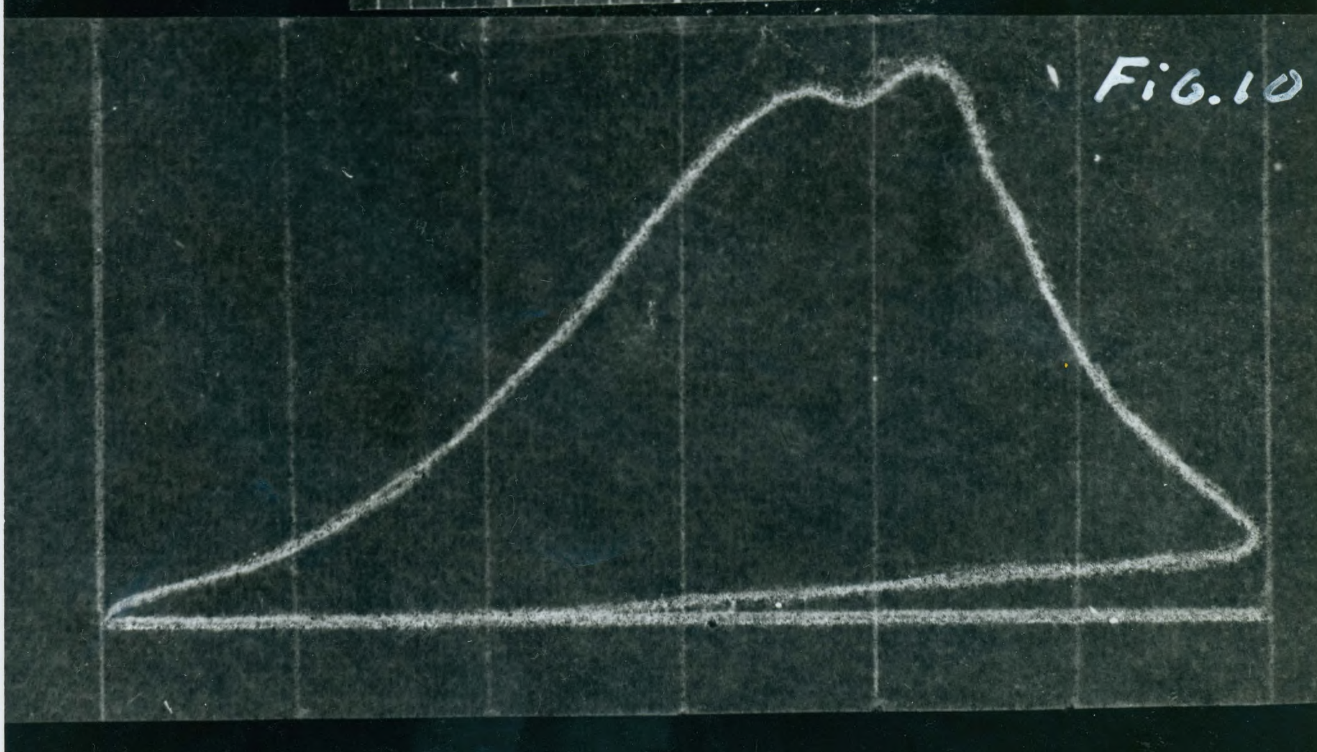


Fig. 10

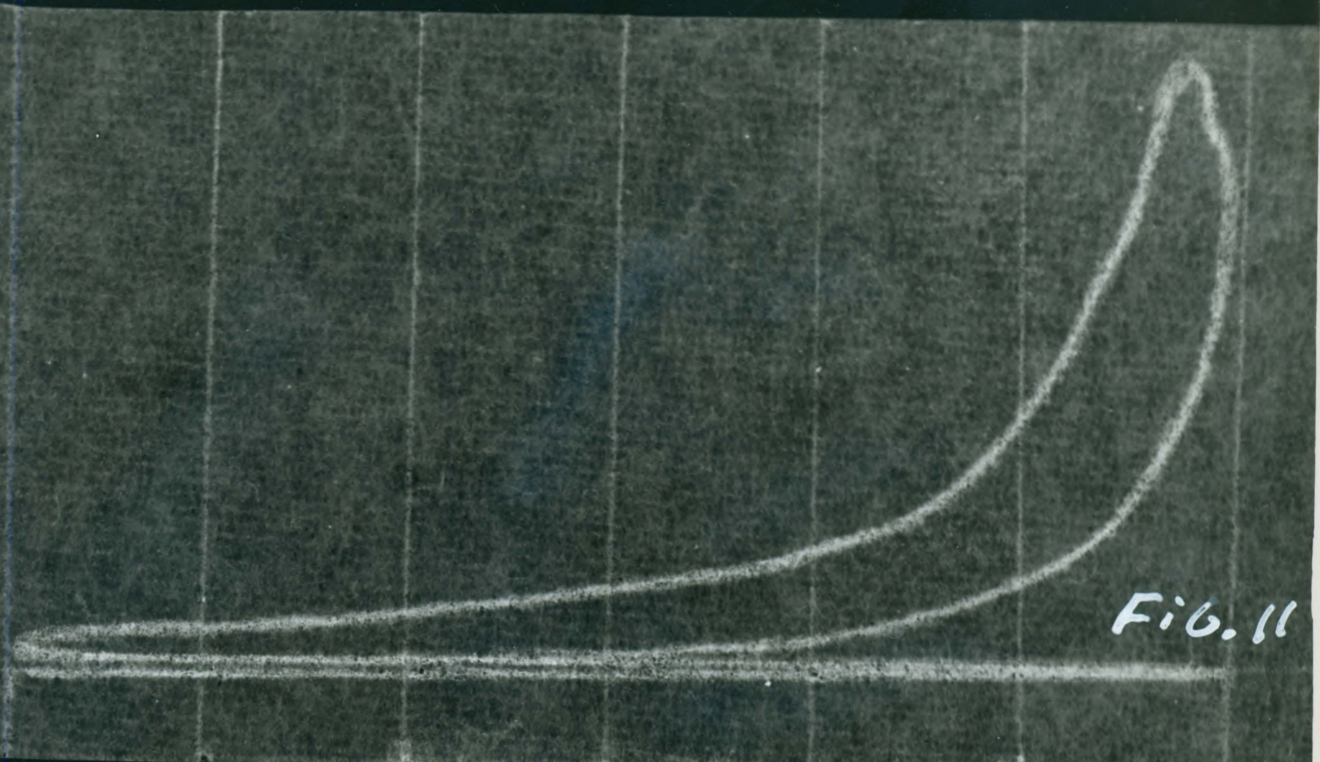


Fig. 11

Cottonseed Oil
1240 R.P.M
1.273 B.H.P.

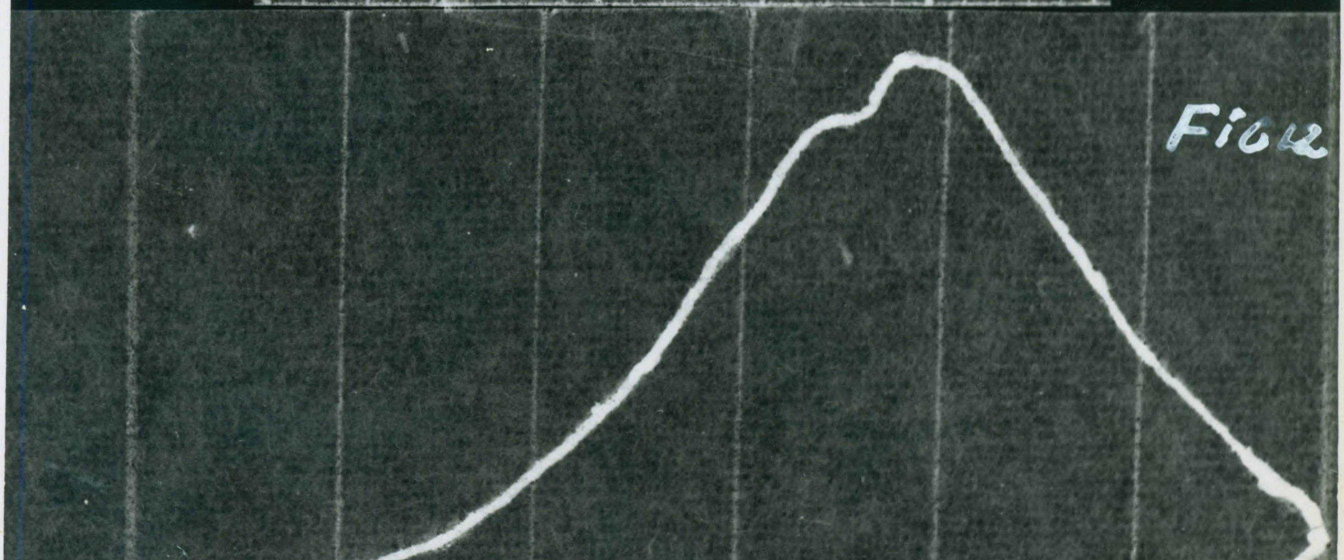


Fig 12

(b) Sustained load characteristics:

It was observed that there was a variation in sustained load characteristics among the three vegetable oils. High values of exhaust gas temperatures were noted at different times in the running of each of the test fuels. In the case of peanut oil this occurred at the end of the run; in the case of soy bean oil, before the twenty-eighth hour; in the case of cottonseed oil, before the fourth hour. Exhaust gas temperatures are tabulated in Tables XVIII, XIX, and XX in the appendix. Engine performance was observed to become erratic at the above hours. A decline in thermal efficiency came simultaneously with the above conditions, as shown in Tables XIV, XV, and XVI. To regain stable operating conditions and reduce exhaust gas temperatures the engine load was reduced.

It was possible to re-load the engine at the thirty-third hour for soy bean oil and at the twelfth hour for cottonseed oil.

At the conclusion of the peanut oil run, a formation of carbon of approximately ¼" in length was observed on the end of the injection nozzle. It would seem that this condition occurred in the test run at the time of erratic performance and high exhaust gas temperatures. These tips were not found upon break-down after the soy bean oil and cottonseed oil test runs. Therefore, it is indicated that these formations were destroyed at the hour that original load conditions were regained for these two oils. In the case of peanut oil the original load characteristics were not regained because the test period was concluded.

No other unusual conditions were observed during, or as a result of these tests. Carbon deposits on the cylinder head and walls were average.

The engine performance with peanut oil was better than the performance with either soy bean or cottonseed oil, as indicated by the tabulations in Tables VII, VIII, and IX and the curves in Figure 4. More power was obtained from peanut oil for a greater period of time before load reductions became necessary. The carbon formation of the tip of the injection nozzle came at a later hour and load reductions because of this formation were small. The performance curves show the fuel rate per horsepower hour for peanut oil to be less than the fuel rate per horsepower hour for either of the other two vegetable oils. From the standpoint of this investigation, peanut oil can be used as a fuel for compression-ignition type engines.

C: Conclusions:

(a) Test results indicate that the vegetable oils investigated are possible fuels for compression-ignition class engines. Of these oils peanut oil is superior to either soy bean or cottonseed oil which approximate each other in performance.

Before any of these vegetable oils could be substituted for diesel oil they would have to be refined to a condition approximating the diesel oil standard. Research as to effect of cylinder head temperature on carbon tip formation would be necessary. Possible corrosion problems in connection with extended sustained load operation would have to be investigated.

(b) Aside from the use of vegetable oils from an engineering standpoint the economic problem must be considered. The cost of diesel fuel is approximately $0.08 per gallon against approximately $1.00 per gallon for the vegetable oils, at present day market prices. However, these oils might be used to advantage in other parts of the world where petroleum fuels are expensive, scarce, and vegetable oils are available in quantity.

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Appendix I

Calibration Data

A: Thermometers:

The thermometers used in this series of tests were calibrated against thermometers certified by the bureau of standards. All thermometers were calibrated for complete emergence except those noted otherwise. To correct for the emergence necessary in the calibration, the following equation was used.

$$1.\ K = 0.000088\ (T - t)\ D$$

K is the correction factor to be added to the observed reading.

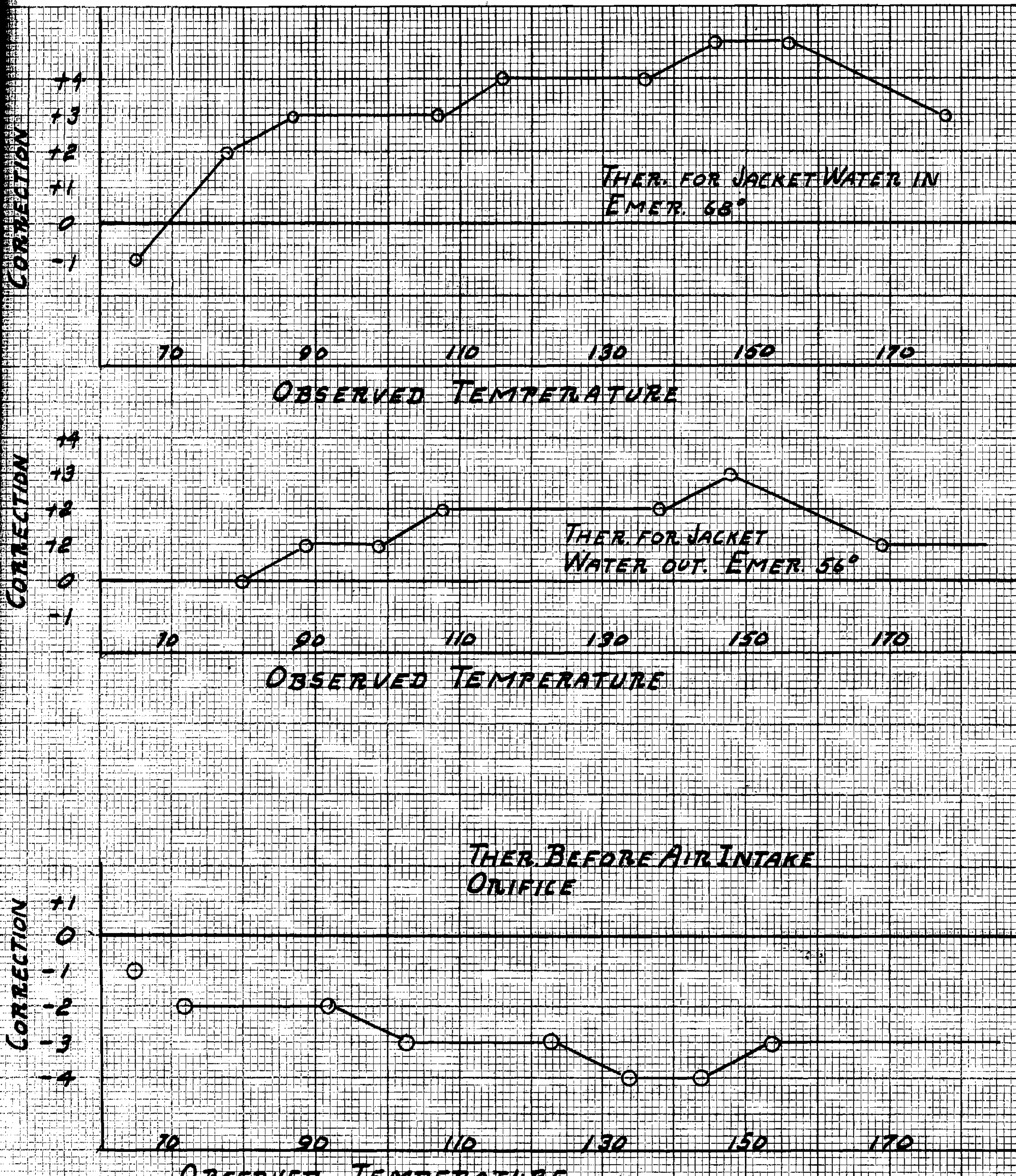
0.000088 is the difference between the volume coefficient of expansion for glass and the volume coefficient of expansion for glass.

T is the observed temperature.

t is the temperature of the air surrounding the thermometer stem.

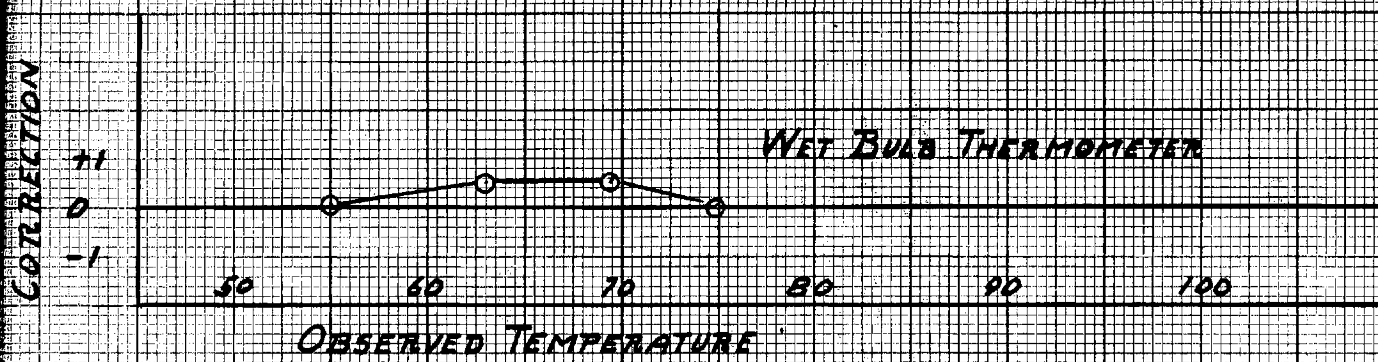
D is the difference between the observed reading and the emergence temperature.

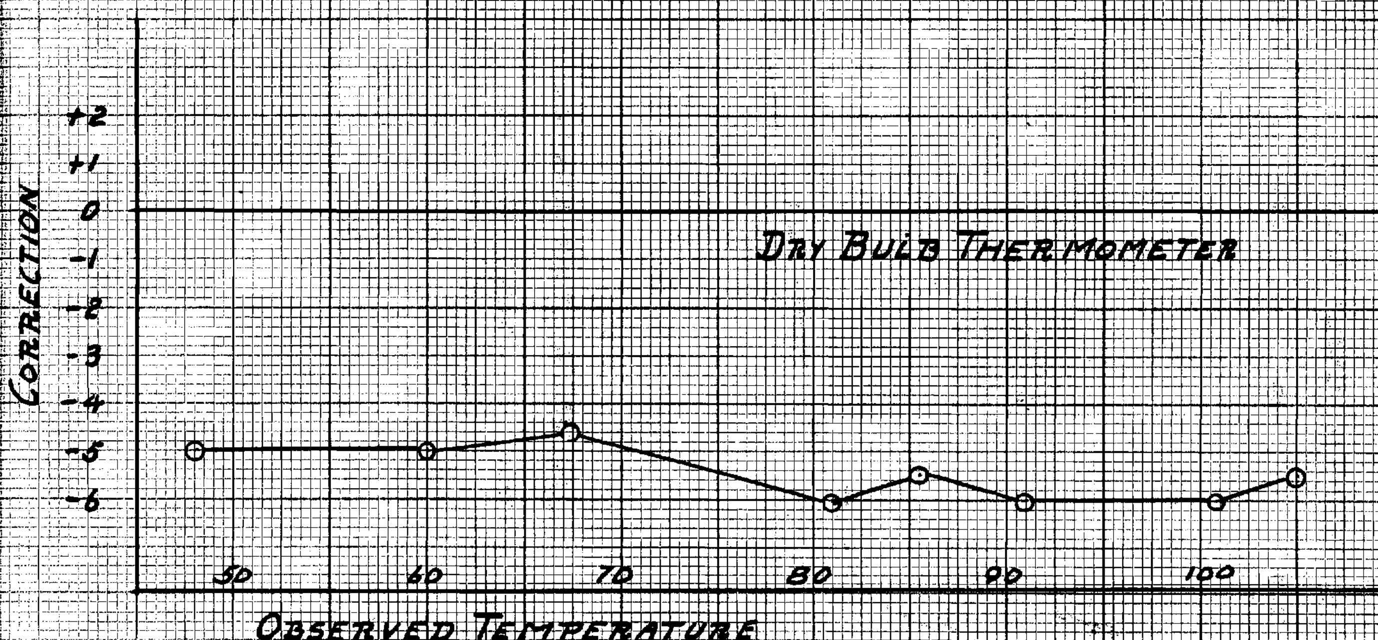
Correction curves for all thermometers used in this investigation are shown in Figures 13-15. These thermometers were calibrated as accurately as it was possible to read them.



CORRECTION CURVES
CALIBRATED AGAINST
BUREAU OF STANDARDS
No. N.B.S. 72854

FIG. 13





CORRECTION CURVES
CALIBRATED AGAINST
BUREAU OF STANDARDS
No. N.B.S. 72854

FIG. 14

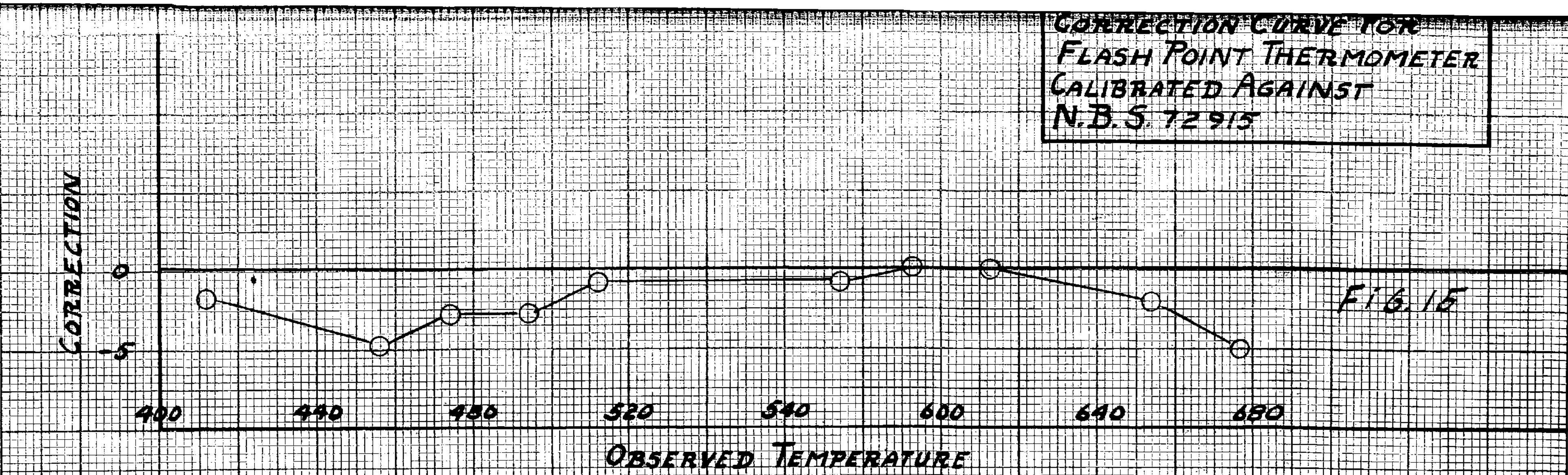

CORRECTION CURVE FOR
FLASH POINT THERMOMETER
CALIBRATED AGAINST
N.B.S. 72915
CORRECTION
0
-5
400
440
480
520
560
600
640
680
OBSERVED TEMPERATURE

FIG. 15

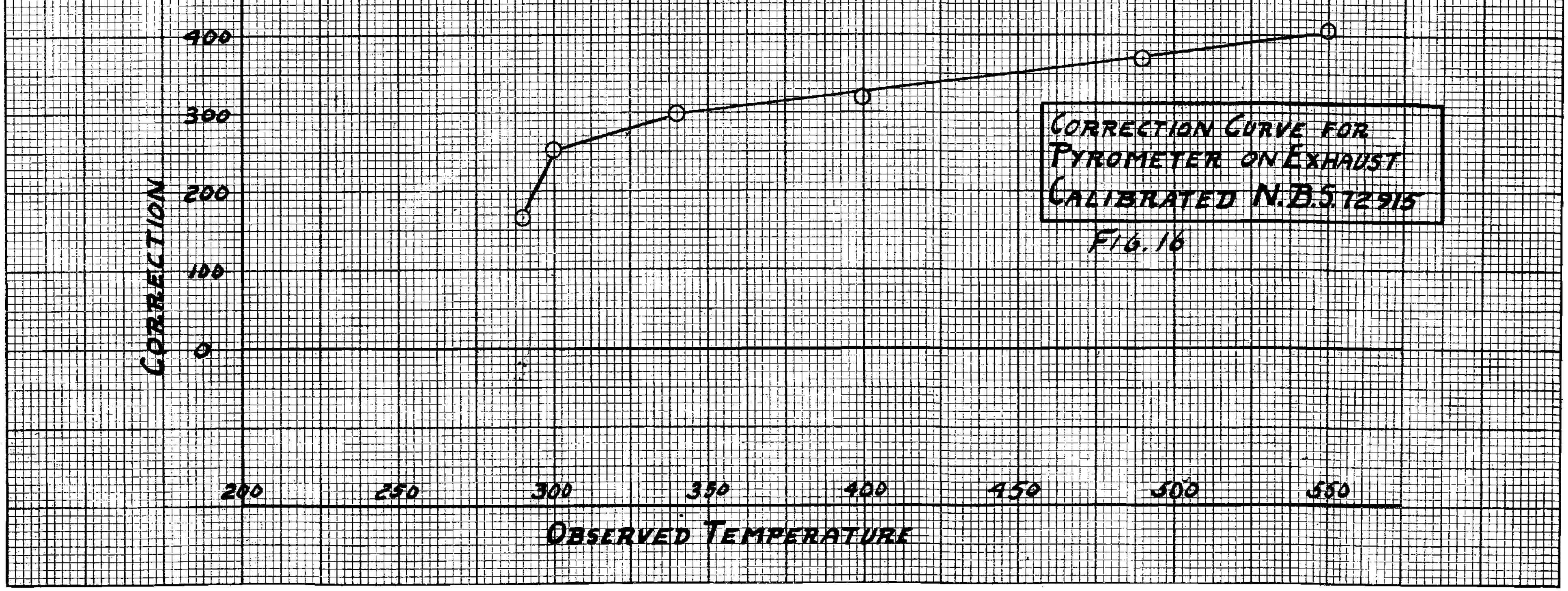

CORRECTION CURVE FOR
PYROMETER ON EXHAUST
CALIBRATED N.B.S. 72915
CORRECTION
400
300
200
100
0
200
250
300
350
400
450
500
550
OBSERVED TEMPERATURE

FIG. 16

B: Air metering system:

To measure the air drawn in on the intake stroke of the engine a flat plate orifice was used. Sketches showing the dimensions of this orifice and the installation details are given in Figures 17 and 18.

The orifice was installed in a nominal 1½" diameter pipe line, just ahead of a fifty gallon drum. The inside diameter of the pipe is 1.61 inches and diameter of the orifice is 0.805 inches. This gives a ratio of diameters of two and a ratio of areas of four.

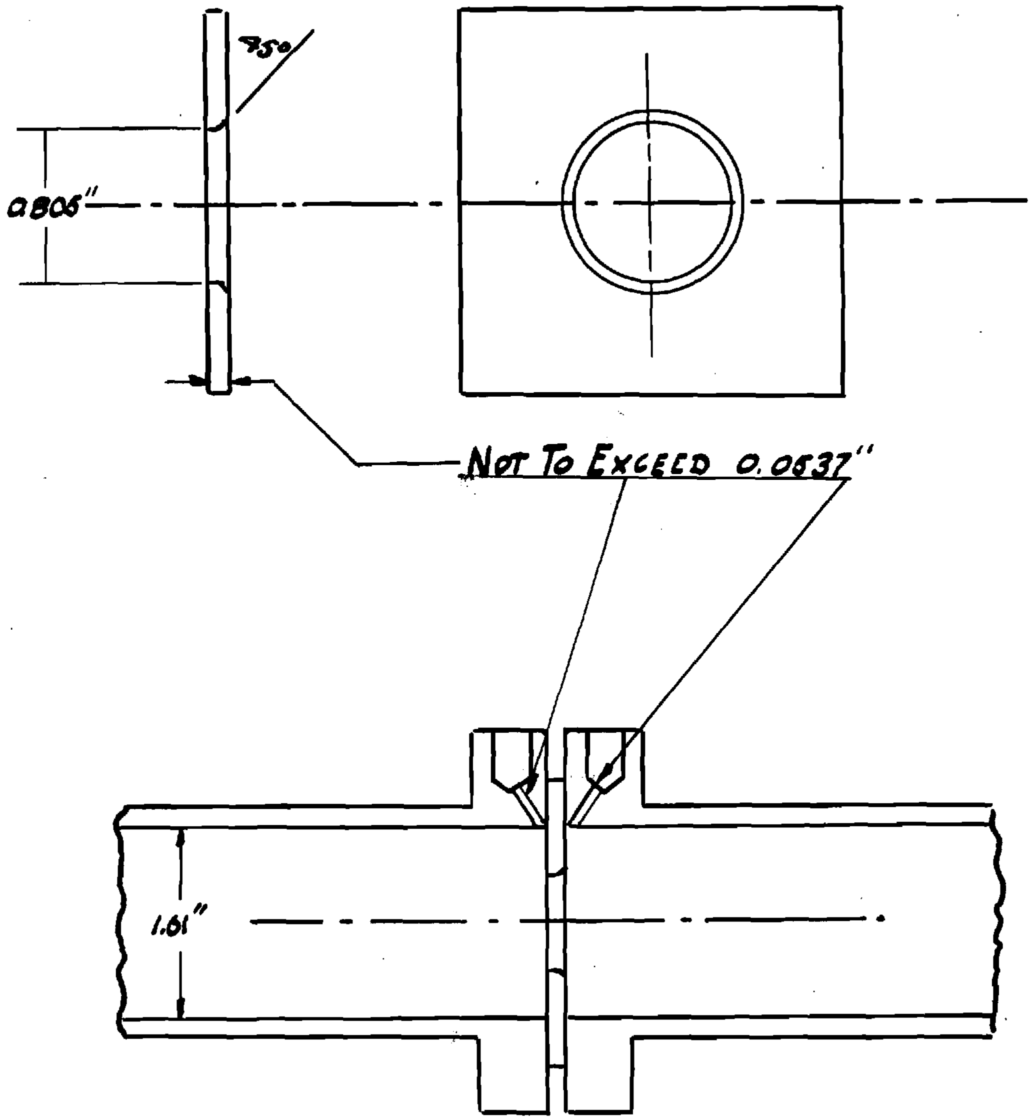
The expansion of air was assumed to follow the perfect gas equation for an isentropic expansion.

$$2.\quad P\,V^{k} = K$$

P is the pressure in pounds per square inch absolute.
V is the volume in cubic feet.
k is the ratio of specific heats.
K is a constant.

Assuming that equation 2 holds and that the same weight of air passes each point in the intake line, the following relationship can be derived.

$$3.\quad q = ag\sqrt{\frac{2Wr^{2}\,(P_1 - P_2)}{r^{2} - 1}} \qquad (C)$$



INSTALLATION DETAILS

FIG. 17

DETAILS OF AIR FLOW METER

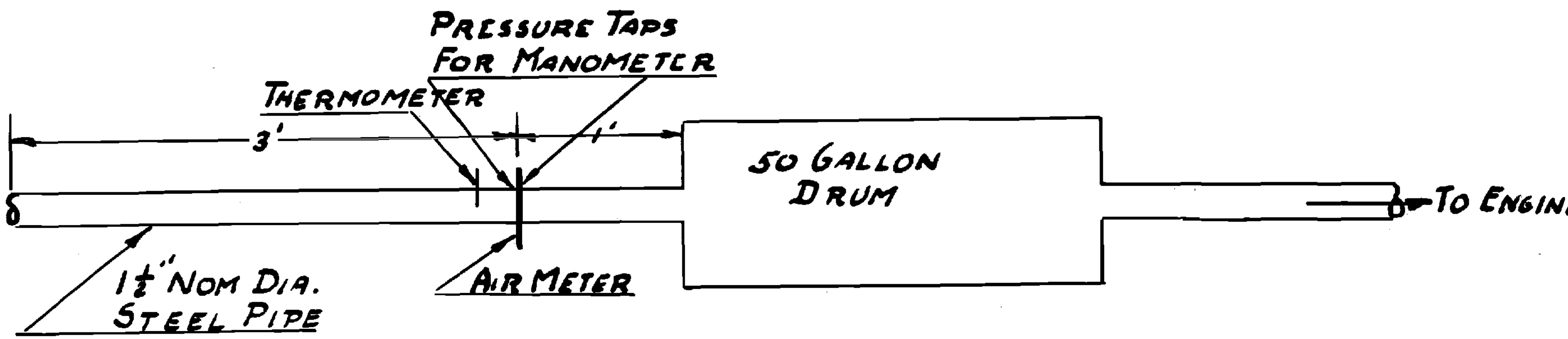


FIG. 18

DETAILS OF AIR
MEASURING SYSTEM

q is the quantity of air flowing in pounds per second.

a is the area of the orifice in square feet.

g is the acceleration of gravity.

r is the ratio of pipe area to orifice area.

$(P_1 - P_2)$ is the pressure drop across the orifice in pounds per square foot.

C is the compressibility factor.

By rearranging the terms in equation 3 the following equation obviously follows.

$$4. \quad Q = 7.62 \, aa' \sqrt{\frac{wr^2 \, (h_1 - h_2)}{r^2 - 1}} \quad (C)$$

Q is the quantity of flow in pounds per minute.

a is the area of the orifice in square inches.

a' is the coefficient of discharge for the orifice.

w is the upstream density in pounds per cubic feet.

r is the ratio of the upstream pipe to the orifice area.

$(h_1 - h_2)$ is the pressure drop across the orifice in inches of water.

C is the compressibility factor.

7.62 is a constant obtained from taking all conversion factors and other constants and combining them into one.

The coefficient of discharge for this orifice was taken from Hodgson's data.and the conditions which he imposed upon construction and installation were observed.

Hodgson concluded that if the ratio of areas was greater than 1.7 and the pressure on the down stream side of the orifice was not less than 98% of the total pressure a coefficient of discharge of 0.61 could be used with only small errors. Also if the above conditions were observed the compressibility factor could be neglected. Accordingly an orifice was designed for a pressure drop of eight inches of water and a ratio of areas of four. The final equation dealing only the pressure drop and the density of the upstream air follows.

$$5.\quad Q = 2.44\sqrt{w\,(h_1 - h_2)}$$

Q is the flow in pounds per minute.

w is the density of the upstream air in pounds per cubic feet.

$(h_1 - h_2)$ is the pressure drop across the orifice in inches of water.

In equation 5 the only terms which have to be determined are the pressure drop across the orifice and the density of the upstream air. The pressure drop can be read from a differential manometer, and the density of the upstream air may be obtained from the barometer reading and the wet and dry bulb temperatures of the atmosphere.

To find the density of the air it is necessary to know the amount of moisture in the air. This may be read from a psychometric chart with reasonable accuracy. The density of the air was found from perfect gas relations after calculating a value for the perfect gas constant. The gas constant was obtained using the values 55.34 as the gas constant for air, and the value 85.7 as the gas constant for water vapor. The equation used is as follows:

$$6. \quad R = \frac{R_a + R_v\,(W_v)}{W_a + W_v}$$

R is the perfect gas constant.

R_a is the gas constant for air.

R_v is the gas constant for water vapor.

W_v is the weight of water vapor per pound of dry air.

W_a is the weight of dry air, one pound.

The density follows from the perfect gas equation.

$$7. \quad W = \frac{P}{R\ T}$$

W is the density of the air in pounds per cubic foot.

P is the absolute pressure in pounds per square foot.

R is the perfect gas constant.

T is the temperature in degrees Fahrenheit absolute.

C: Generator calibration:

A direct current generator directly connected to the engine shaft was used as a method of varying the load. A direct current generator affords one of the most flexible means of varying the load on a test engine, but it has the disadvantage of having many variables to consider in the calibration. The generator selected for test purposes was calibrated carefully at a number of different speeds.

The losses associated with the generation of a direct current are mechanical losses such as brush and bearing friction; losses caused by eddy currents in the generator; the power loss necessary to overcome the resistance of the armature and field; and the loss due to a slight sparking at the brushes. This particular generator was separately excited so there was no direct loss due to a voltage drop across the field.

The stray power loss and the mechanical losses can be combined into one loss which the author has chosen to call stray power losses. When this term appears hereafter it refers to this combination. To evaluate the stray power losses quantitatively the author ran the generator as a motor. This operation was carried out at various speeds and with the same field current that was used when the motor ran as a generator. The power required to run the motor with no load was the stray power loss at that particular speed. These observations were made at several different speeds, and a curve was plotted giving power loss versus speed, as shown in Figure 19.

The resistance of the armature was determined by causing current to flow through the armature and by observing

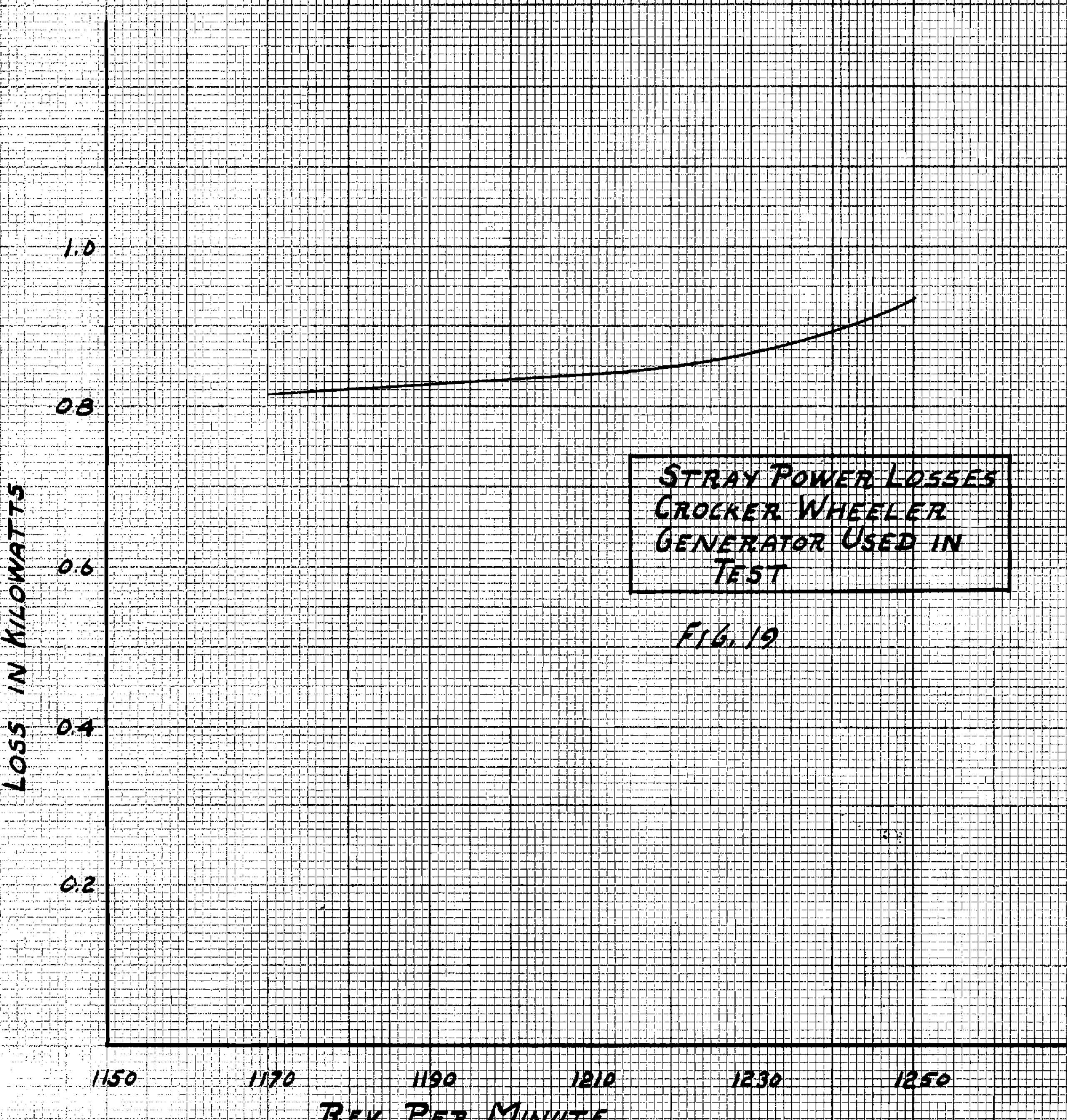

STRAY POWER LOSSES
CROCKER WHEELER
GENERATOR USED IN
TEST
LOSS IN KILOWATTS
1.0
0.8
0.6
0.4
0.2
1150
1170
1190
1210
1230
1250
REV. PER MINUTE

FIG. 19

the voltage drop. The resistance was then obtained from Ohm's law.

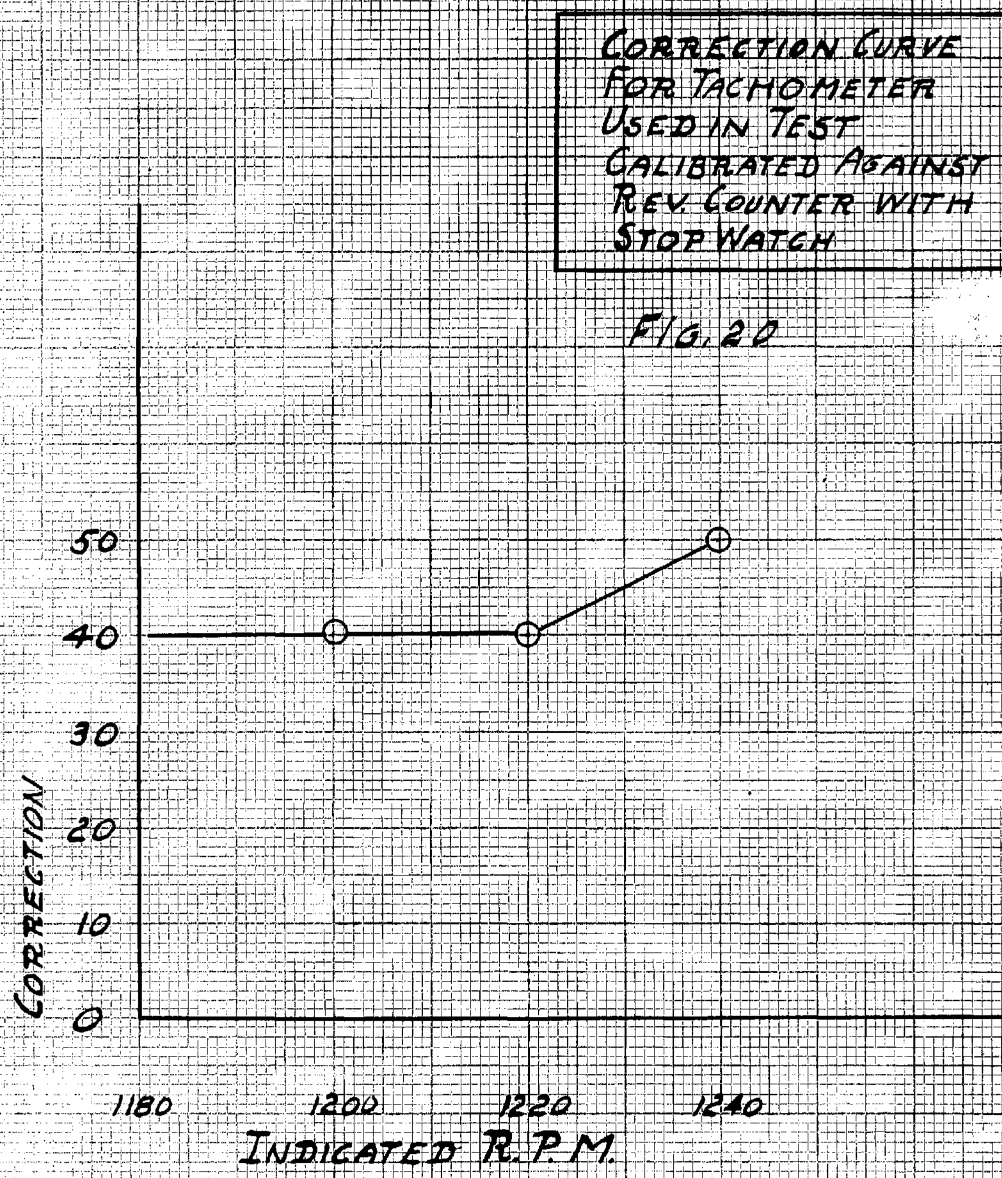

CORRECTION CURVE
FOR TACHOMETER
USED IN TEST
CALIBRATED AGAINST
REV. COUNTER WITH
STOP WATCH
50
40
30
20
10
0
CORRECTION
1180
1200
1220
1240
INDICATED R.P.M.

FIG. 20

Appendix II

Sample Calculations

A: Heating value calculations:

The temperature in the following observed data for soy bean oil refers to the temperature of the water surrounding the bomb in an Emerson Bomb calorimeter.

Observed Data Soy Bean Oil

Time Min.-Sec.	Temperature °C
00:	0.570
1:00	0.580
2:00	0.585
3:00	0.590
4:00	0.595
5:00	0.600
5:30	0.94
6:00	2.55
6:30	3.34
7:00	3.64
7:30	3.84
8:00	3.92
8:30	3.98
9:00	4.010
9:30	4.030
10:00	4.035
10:30	4.040

Observed Data Soy Bean Oil (Continued)

Time	Temperature
11:00	4.040
12:00	4.040
13:00	4.035
14:00	4.030
15:00	4.025
16:00	4.020

Weight of pan:-----------------------------------6.5123 grams

Weight of pan and Sucrose---------------------7.5714 grams

Weight of pan, sucrose and oil----------------7.5759 grams

Weight of water----------------------------1900 grams

Heating value of sucrose*------------3942 Calories per gram

The initial temperature of the water was three degrees Fahrenheit below the temperature of the surroundings, so that radiation would change sign at about six tenths of the total temperature rise. Sucrose was added to the oil to form a base from which the oil could be burned.

8. Heating value $= \dfrac{(t_1 - t_2)(W_h \quad W_b) - H_s W_s}{W_o}$ (1.8)

$(t_1 - t_2)$ is the corrected temperature difference of the water which surrounds the bomb in the calorimeter, in $^{\circ}C$.

W_h is the weight of the water in the calorimeter in grams.

W_b is the water equivalent of the calorimeter in grams.

H_s is the heating value of the sucrose in calories per gram.

W_o is the weight of the oil in grams.

---

* Bureau of Standards calibration.

W_s is the weight of the sucrose in grams.

1.8 is the conversion factor which changes calories per gram to Btu per pound.

The temperature rise was corrected for radiation.

Initial rate of radiation: $\frac{0.600 - 0.570}{5 \text{ min.}} = 0.006^\circ C$ per min.

Final rate of radiation: $\frac{4.040 - 4.020}{5 \text{ min.}} = 0.004^\circ C$ per min.

Total observed rise: $4.040 - 0.600 = 3.440^\circ C$

Temperature at which radiation changes sign:

$$0.6\ (3.440) + 0.600 = 2.664^\circ C$$

This temperature occurs at 6.286 minutes, as found by using a straight line interpolation on the observed data.

Time for initial radiation: 6.286 - 5.000 = 1.286 minutes

Time for final radiation: 11.000 - 6.286 = 4.714 minutes

Corrected initial temperature: $0.600 + 1.286\ (0.006) = 0.608^\circ$

Corrected final temperature: $4.040 + 4.714\ (0.004) = 4.059^\circ$

Corrected temperature rise: $4.059 - 0.608 = 3.451^\circ$ Centigrade

Water equivalent of Calorimeter: 450 grams

Weight of sucrose: 7.5714 - 6.5123 = 1.0591 grams

Weight of oil: 7.9759 - 7.5714 = 0.4045 grams

Heating value: $\frac{[3.451\ (1900 + 450) - 1.0591\ (3941)]\ \ 1.8}{0.4045} = 17{,}850$ Btu per pound.

The method of determining the water equivalent of the calorimeter was similar to the method used in determining the heating value. A coal of known heating value was burned in the bomb under the same conditions as were the oils. Knowing the heat released by the coal, the water equivalent of the calorimeter follows from equation 8.

B: Carbon residue:

To determine the carbon residue a sample of oil was vaporized and the residue weighed. The residue was expressed as a percentage of the original weight. A typical example of the method of calculation will be given here.

Type of oil ------------------------------Soy bean

Weight of dry crucible--------------------16.2406 grams

Weight of crucible plus oil---------------29.4163 grams

Weight of crucible after burning oil-------16.2948 grams

Per cent carbon residue: $\frac{16.2948 - 16.2406}{29.4163 - 16.2406}$ 100 = 0.411%

C: Calculation of performance data:

The following series of calculations shows the method used for establishing performance characteristics. Only enough data are presented here to show the typical calculations for performance. One run is shown and it only in part. For the rest of the observed performance data see Table XVII in this section of the appendix.

Soy Bean Oil

Time	Volts	Amperes	Fuel Weight
Min.			Pounds
00	220	6	14.35
0:10	220	6	
0:20	220	6	
0:30	220	6	12.84

Pounds of fuel per hour: $2\,(14.35 - 12.84) = \underline{3.02}$

Power at generator terminals: $\frac{220\,(6)}{1000} = 1.320$ kw.

R.P.M. 1240

Stray power loss: 0.900 kw.

Armature resistance: 0.303 Ohms.

Copper loss in armature: $\frac{(6)^2\,0.303}{1000} = 0.012$ kw.

Voltage drop across brushes: 2

Brush arc loss: $\frac{2\,(6)}{1000} = 0.012$ kw.

Total losses: 0.924 kw.

Power generated at engine shaft: 1.320 + 0.924 = 2.244 kw.

Horsepower generated at engine shaft: $\frac{2.244}{0.746} = \underline{3.010 \text{ H.P.}}$

Pounds of fuel per Horsepower hour: $\frac{3.02}{3.010} = \underline{1.002}$

Heating value of fuel: 17,640 Btu per pound.

Thermal efficiency: $\frac{2545}{1.002\,(17640)} = \underline{14.4\%}$

2545 is the number of Btu in one horsepower hour.

For comparison purposes, all values were expressed in terms of the equivalent diesel oil values.

Diesel load at maximum thermal efficiency:------ 10 H.P.

Diesel fuel rate at maximum thermal efficiency:---4.80

Fuel rate per H.P. hour at maximum diesel efficiency----0.490

Maximum diesel thermal efficiency:-------26.3%

Using the above diesel values the points for the performance curves were determined.

Horsepower: ----$\frac{3.01\,(100)}{10} = 30.1\%$

Fuel rate: $\frac{3.02\,(100)}{4.80} = 61.7\%$

Fuel rate per H.P. hour: $\frac{1.002\ (100)}{0.490} = 205\%$

Thermal efficiency: $\frac{14.4\ (100)}{26.3} = 54.6\%$

D: Air meter calculations:

Barometer 29,12" Hg. or 14.30 pounds per square inch

Temperatures: Wet bulb 63°F Dry bulb 79°F

Specific humidity: 0.0086 pounds per pound of dry air.

Gas constant: $R = \frac{53.34 + 85.7\ (0.0086)}{1.0086} = 53.7$

Manometer difference: 7.3 inches of water.

Density of air vapor mixture: $\frac{14.30\ (144)}{53.7\ (76 + 460)} = 0.0714$

Weight of Air: $2.44\sqrt{0.0714\ (7.3)}$ = 1.76 pounds per min.

Cylinder dimensions: $4\frac{1}{4}$" bore; 6" stroke

Cylinder volume: $\frac{(4.25)^2\ 3.14}{4(144)}\ \frac{6}{12}$ = 0.0492 cubic feet

R.P.M. 1240

Intake strokes per revolution: 0.5

Displacement: 0.0492 (1240) 0.5 = 30.5 cubic feet per min.

Volumeteric efficiency: $\frac{1.76 \text{ pounds per min.}}{30.5\ (0.0714 \text{ pounds per cuft.})} = 80.9\%$

Table XVII

Observed Performance Data

Time	Bar.	Temperatures °F						Manom.		Load		Weights		R.P.M.
		Room		Jacket		Orf	Exh			Volt	Amps	Fuel	H_2O	
Min.	"Hg	W	D	In	Out			L	R					
Diesel Oil:														
00	29.24	49	64	82	151	64	340	-3.5	3.4	224	6.2	8.22	85	1240
10				81	153	65	340	-3.5	3.4	224	6.2			1240
20				80	154	66	330	-3.5	3.4	224	6.2			1240
30				80	154	65	330	-3.5	3.4	224	6.2	7.14	174	1240
00	29.24	52	65	77	159	65	470	-3.4	3.3	221	10	6.49	86	1240
10				77	158	64	470	-3.4	3.3	221	10			1240
20				76	158	65	470	-3.4	3.3	221	10			1240
30				75	156	65	470	-3.4	3.3	221	10	5.22	173	1240
00	29.36	48	67	77	138	67	600	-3.5	3.4	210	15	7.49	85	1240
10				74	138	67	600	-3.5	3.4	210	15			1240
20				73	135	67	600	-3.5	3.4	210	15			1240
30				75	136	67	600	-3.5	3.4	210	15	5.96	195	1240
00	29.23	52	64	75	155	65	640	-3.5	3.2	213	19	12.87	86	1240
10				69	156	64	640	-3.5	3.2	213	19			1240
20				68	155	64	640	-3.5	3.2	213	19			1240
30				68	156	64	640	-3.5	3.2	213	19	11.28	224	1240
00	29.23	53.5	71	63	147	70	870	-3.45	3.35	198	27	10.86	86	1240
10				60	145	71	870	-3.45	3.35	198	27			1240
20				60	147	71	870	-3.45	3.35	198	27			1240
30				65	147	69	870	-3.45	3.35	198	27	8.70	229	1240
Peanut Oil														
00	29.18	61	69.5	91	158	69	430	-3.4	3.6	219	6.1	15.52	85	1250
10				90	157	69	420	-3.4	3.6	219	6.1			1250
20				89	158	70	410	-3.4	3.6	219	6.1			1250
30				89	157	69	410	-3.4	3.6	219	6.1	13.13	184	1250
00	28.87	56	72.5	62	150	75	590	-3.45	3.35	216	9.7	15.47	85	1240
10				55	148	76	590	-3.45	3.35	216	9.7			1240
20				54	144	73	570	-3.45	3.35	216	9.7			1240
30				56	144	73	570	-3.45	3.35	216	9.7	13.86	181	1240
00	28.97	55.5	76	58	140	74	670	-3.3	3.4	214	14.4	10.21	87	1240
10				58	136	73	670	-3.3	3.4	214	14.4			1240
20				58	138	76	670	-3.3	3.4	214	14.4			1240
30				60	138	76	670	-3.3	3.4	214	14.4	8.34	217	1240
00	28.97	53.5	79	63	151	74	790	-3.2	3.35	208	20.3	15.97	85	1240
10				63	150	76	790	-3.2	3.35	208	20.3			1240
20				65	152	77	790	-3.2	3.35	208	20.3			1240
30				65	152	77	790	-3.2	3.35	208	20.3	13.69	212	1240
00	28.98	58.5	82	70	151	79	910	-3.15	3.3	202	24.5	15.13	86	1240
10				68	149	78	910	-3.15	3.3	202	24.5			1240
20				68	149	78	910	-3.15	3.3	202	24.5			1240
30				68	149	78	910	-3.15	3.3	202	24.5	12.53	237	1240

Table XVII Continued

Time	Bar.	Temperatures °F						Manom.		Load		Weights		R.P.M.
		Room		Jacket		Orf	Exh			Volt	Amp	Fuel	H_2O	
Min	"Hg	W	D	In	Out			L	R					
Soy Bean Oil														
00	29.12	63	79	95	175	78	460	-3.9	3.4	220	6	14.35	81	1240
10				94	160	78	460	-3.9	3.4	220	6			1240
20				93	158	75	500	-3.9	3.4	220	6			1240
30				93	158	75	500	-3.9	3.4	220	6	12.84	145	1240
00	29.12	62.5	77	88	149	75	620	-3.9	3.35	217	11.1	14.80	90	1240
10				84	142	75	620	-3.9	3.35	217	11.1			1240
20				80	138	75	620	-3.9	3.35	217	11.1			1240
30				77	134	74	620	-3.9	3.35	217	11.1	12.71	256	1240
00	29.12	65.5	77	76	142	75	740	-3.85	3.35	215	15.5	14.46	85	1240
10				74	136	75	740	-3.85	3.35	215	15.5			1240
20				74	136	74	740	-3.85	3.35	215	15.5			1240
30				75	136	75	740	-3.85	3.35	215	15.5	12.31	261	1240
00	29.12	63.5	76	74	144	75	890	-3.7	3.2	207	21.4	14.03	83	1240
10				74	144	75	890	-3.7	3.2	207	21.4			1240
20				74	144	75	890	-3.7	3.2	207	21.4			1240
30				75	144	75	890	-3.7	3.2	207	21.4	11.47	254	1240
00	29.12	63	75	75	156	75	1050	-3.55	3.1	202	25	13.47	98	1240
10				74	155	75	1050	-3.55	3.1	202	25			1240
20				74	156	75	1080	-3.55	3.1	202	25			1240
30				77	156	75	1100	-3.55	3.1	202	25	10.94	267	1240
Cottonseed Oil:														
00	29.20	68.5	80.5	98	147	79	460	-3.4	3.6	220	6	14.97	86	1240
10				98	137	80	460	-3.4	3.6	220	6			1240
20				97	134	80	460	-3.4	3.6	220	6			1240
30				95	140	78	460	-3.4	3.6	220	6	13.61	200	1240
00	29.20	70.5	81	97	142	79	590	-3.3	3.5	218	10	14.77	86	1240
10				98	137	80	610	-3.3	3.5	218	10			1240
20				84	134	80	610	-3.3	3.5	218	10			1240
30				83	140	78	610	-3.3	3.5	218	10	13.06	251	1240
00	28.96	70	85	87	150	85	760	-3.15	3.3	212	16	13.30	87	1240
10				84	140	84	760	-3.15	3.3	212	16			1240
20				86	145	85	740	-3.15	3.3	212	16			1240
30				86	147	85	730	-3.15	3.3	212	16	11.19	251	1240
00	28.98	71	87	85	147	85	950	-3.05	3.2	208	20.5	15.81	85	1240
10				84	144	86	960	-3.05	3.2	208	20.5			1240
20				84	144	86	960	-3.05	3.2	208	20.5			1240
30				82	142	86	980	-3.05	3.2	208	20.5	13.24	279	1240

Table XVIII

Sustained Run Test Data - Peanut Oil

Time	Bar.	Temperatures °F						Manom.		Load		Fuel Wt		RPM
		Room		Jacket		Orf	Exh			Volt	Amp			
Hr Mn	"Hg	W	D	In	Out			L	R			Begn.	End	
00	29.13	69.5	72.5	77	150	68	850	-3.6	3.7	204	22.5	13.60		1240
0:30	29.13	66	70.5	66	139	67	770	-3.6	3.7	202	22.4	11.51	11.51	1250
1:00	29.13	64.5	70.5	66	143	67	770	-3.6	3.7	202	22.4	9.22	9.22	1250
1:30	29.13	65	72	68	149	67	790	-3.5	3.6	202	22.4	14.17	7.03	1250
2:00	29.13	65	70.5	70	151	68	790	-3.5	3.6	202	22.4	12.03	12.03	1250
2:30	29.13	58.5	69.5	70	149	67	770	-3.5	3.6	202	22.4	9.79	9.79	1250
3:00	29.13	58.5	67.5	68	149	67	840	-3.5	3.5	201	22.3	13.94	7.60	1250
3:30	29.13	60.5	69	68	149	66	820	-3.4	3.5	202	22.3	11.79	11.79	1250
4:00	29.13	61.5	68	69	149	67	840	-3.4	3.5	202	22.3	9.53	9.53	1250
4:30	29.13	57.5	71	70	151	68	820	-3.4	3.4	201	22.1	14.05	7.35	1250
5:00	29.13	60	71	71	161	68	920	-2.8	2.8	196	21.5	14.05	11.85	1250
5:30	29.34	72.5	74	91	155	76	920	-3.7	3.7	210	23	15.36	11.85	1250
6:00	29.34	63.5	75.5	68	134	70	840	-3.7	3.7	209	23.0	15.78	13.15	1250
6:30	29.34	66.5	76	65	137	73	850	-3.7	3.7	209	23.0	13.39	13.39	1250
7:00	29.34	61.5	78	64	139	73	870	-3.7	3.7	207	22.7	15.53	10.98	1250
7:30	29.34	61.5	74	65	139	73	870	-3.7	3.7	206	22.7	13.12	13.12	1250
8:00	29.34	60	75.5	66	139	74	870	-3.7	3.7	206	22.7	15.17	10.72	1250
8:30	29.34	60	76	64	136	74	870	-3.7	3.7	207	22.6	13.26	13.26	1250
9:00	29.34	60	76	65	136	74	870	-3.7	3.7	206	22.6	13.36	10.86	1250
9:30	29.17	58.5	84	84	139	70	1070	-3.6	3.6	205	22.5	15.13	10.86	1240
10:00	29.17	56	67	65	144	65	1020	-3.6	3.6	205	25.4	12.41	12.41	1240
10:30	29.17	54	65.5	64	142	63	1020	-3.55	3.55	203	25.4	13.02	13.02	1240
11:00	29.17	51	66	65	146	64	1020	-3.5	3.5	204	25.5	10.29	10.29	1250
11:30	29.17	53	66.5	65	147	65	1020	-3.5	3.5	204	25.5	12.88	12.88	1250
12:00	29.17	52.5	69	66	146	66	1020	-3.5	3.5	203	25.5	15.66	10.23	1240
12:30	29.17	50.	67	65	143	67	1020	-3.6	3.6	202	25.3	12.98	12.98	1250
13:00	29.16	55	67	66	146	71	1020	-3.6	3.6	204	25.5	16.00	10.30	1250
13:30	29.16	52	72.5	68	148	70	980	-3.6	3.6	203	25.4	13.44	13.44	1250
14:00	29.16	52	71.5	68	147	69	950	-3.6	3.6	203	26.4	10.88	10.88	1250
14:30	29.16	51.5	71.5	70	148	68	970	-3.6	3.6	202	25	13.28	13.28	1250
15:00	29.16	51.5	72	70	149	68	920	-3.6	3.6	204	25.5	15.94	10.69	1250
15:30	29.15	51	71.5	70	149	70	950	-3.6	3.6	202	25.3	13.37	13.37	1250
16:00	29.15	51.5	72	70	149	68	950	-3.6	3.6	203	25.4	15.73	10.82	1250
16:30	29.15	51.5	71.5	70	150	68	970	-3.6	3.6	202	25.3	13.11	13.11	1250
17:00	29.15	51	70.5	70	150	68	970	-3.6	3.6	203	25.4	13.88	10.47	1250
17:30	29.15	51	70.5	70	149	71	940	-3.6	3.6	204	25.5	13.88	11.27	1250
18:00	29.28	56	68.5	84	142	66	920	-3.75	3.5	217	22.3	15.68	11.27	1240
18:30	29.28	53	66	68	133	64	900	-3.75	3.5	217	22.4	15.97	13.32	1240
19:00	29.26	54.5	69	68	132	66	890	-3.75	3.55	216	22.3	13.53	13.53	1250
19:30	29.25	55	70	66	132	66	890	-3.75	3.5	218	22.3	15.97	11.08	1250
20:00	29.24	56	71	65	130	68	870	-3.75	3.6	216	22.2	13.58	13.58	1250
20:30	29.23	57	71.5	68	132	69	850	-3.75	3.6	216	22.2	15.79	11.16	1250
21:00	29,22	58	73	68	132	71	850	-3.75	3.6	215	22.1	13.35	13.35	1250
21:30	29.21	58	73	68	133	71	870	-3.75	3.55	216	22.1	15.84	10.93	1250
22:00	29.20	58	73	66	132	72	890	-3.75	3.55	215	22.0	13.41	13.41	1250
22:30	29.19	60	75	69	134	73	850	-3.75	3.55	215	22.0	16.00	10.03	1250
23:00	29.18	61	75	70	133	73	850	-3.75	3.55	216	22.1	13.64	13.64	1250
23:30	29.17	62.5	76.5	70	133	75	850	-3.75	3.55	215	22.0	15.96	11.22	1250
24:00	29.16	64	78.5	68	131	75	920	-3.7	3.5	213	21.7	13.53	13.53	1250
24:30	29.11	62.5	85	86	164	81	990	-3.65	3.5	214	24.0	15.68	13.19	1240
25:00	29.11	61.5	84	82	164	81	920	-3.6	3.45	214	23.9	15.65	13.19	1240
25:30	29.11	60.5	86.5	71	129	82	920	-3.65	3.5	212	23.8	13.17	13.17	1240
26:00	29.12	60.5	87	75	157	82	920	-3.65	3.5	212	23.6	15.80	10.76	1240
26:30	29.12	57.5	82	77	158	79	900	-3.7	3.5	212	23.8	13.37	13.37	1240
27:00	29.13	59.5	85	79	160	81	900	-3.7	3.5	210	23.7	15.87	10.94	1240
27:30	29.13	59.5	84	71	132	79	900	-3.7	3.5	211	23.6	13.43	13.43	1240
28:00	29.13	59.5	84.5	73	143	78	900	-3.7	3.7	211	23.5	15.78	10.97	1240
28:30	29.14	61.5	85.5	74	144	80	900	-3.5	3.75	211	23.5	13.35	13.35	1250
29:00	29.14	61.5	86	74	146	80	900	-3.5	3.75	211	23.5	15.43	10.93	1250
29:30	29.15	61.5	85	75	146	81	920	-3.5	3.75	210	23.7	13.46	13.46	1250
30:00	29.15	61	84.5	75	146	80	920	-3.5	3.75	209	23.5	15.65	11.00	1250
30:30	29.16	61	85	75	146	79	940	-3.5	3.75	209	23.5	15.65	13.19	1250
31:00	29.28	61.5	81.5	91	147	76	890	-3.75	3.5	204	23.6	13.67	13.67	1250
31:30	29.38	59.5	82	76	133	75	870	-3.8	3.5	204	23.4	16.00	11.34	1250
32:00	29.28	55	80	72	142	74	870	-3.8	3.5	201	23.3	13.63	13.63	1250
32:30	29.27	55	81.5	72	142	74	870	-3.8	3.5	200	23.1	11.31	11.31	1250
33:00	29.27	55	79.5	72	147	74	940	-3.7	3.4	204	23.6	13.33	13.33	1250
33:30	29.27	55	79.5	71	147	76	950	-3.7	3.4	206	23.7	15.97	10.83	1250
34:00	29.26	59.5	79.5	72	149	73	950	-3.7	3.4	206	23.5	13.39	13.39	1250
34:30	29.26	54.5	79.5	72	150	73	990	-3.7	3.5	207	23.8	16.02	10.84	1250
35:00	29.25	54.5	79.5	72	151	72	1030	-3.7	3.4	207	23.8	13.38	13.38	1250
35:30	29.25	55	78.5	71	141	71	1030	-3.7	3.4	208	23.8	15.85	10.65	1250
36:00	29.25	54	76	71	143	72	1180	-3.7	3.4	208	23.6	12.90	12.90	1250

Table XXII

Sustained Run Test Data - Cottonseed Oil

Time	Bar	Temperatures °F						Manom.		Load		Fuel Wt.	
		Room		Jacket		Orf	Exh			Volt	Amp		
Hr Mn	"Hg	W	D	In	Out			L	R			Begn	End
0:0	28.90	77	89	95	155	86	1080	-3.0	3.2	208	20.5	15.00	
0:30	28.90	73	85.5	93	155	84	1020	-3.0	3.15	208	20.5	14.85	12.42
1:00	28.90	71.5	84.5	86	148	83	1040	-3.1	2.95	208	20.5	15.05	12.38
1:30	28.90	70.5	84	84	155	82	1212	-2.7	2.9	208	20.5	15.27	12.35
2:00	28.90	69.5	83.5	84	155	82	1130	-2.9	3.0	212	16.0	15.38	12.57
2:30	28.94	74	83.5	94	147	81	970	-6.7	0.2	212	16.0	14.79	12.57
3:00	28.94	68.5	83.5	89	147	81	940	-6.7	0.2	212	16.0	15.04	12.32
3:30	28.94	65	82	83	144	81	1020	-6.5	0.0	212	16.0	14.78	12.74
4:00	28.95	64.5	81.5	82	148	79	1080	-6.4	-0.1	218	10.0	14.75	12.39
4:30	28.95	63	80.5	82	144	78	840	-6.7	0.1	218	10.0	14.98	12.42
5:00	28.96	63.5	79	84	151	78	830	-6.7	0.1	218	10.0	15.16	12.58
5:30	28.96	63	78.5	84	157	76	870	-6.7	0.2	218	10.0	14.91	12.83
6:00	28.97	65.5	82.0	84	152	76	870	-6.6	0.1	218	10.0	14.88	12.61
6:30	28.97	65.5	82	84	152	76	870	-6.6	0.1	218	10.0	14.88	12.61
7:00	28.97	65.5	76	83	151	76	870	-6.7	0.2	218	10.0	15.06	12.56
7:30	28.98	66.5	74.5	73	153	73	950	-6.6	0.1	218	10.0	15.12	12.82
8:00	28.98	64.5	72.5	80	151	73	1020	-6.4	-0.1	218	10.0	14.98	12.75
8:30	28.98	64.5	73	80	147	73	1020	-6.3	-0.2	218	10.0	15.25	12.49
9:00	28.99	66.5	73	79	147	73	1040	-6.3	-0.2	218	10.0	14.92	12.77
9:30	29.00	68.5	72.5	79	150	72	950	-6.3	-0.2	218	10.0	14.84	12.56
10:00	29.00	63.5	71.5	78	150	70	970	-6.5	0.0	218	10.0	15.02	12.49
10:30	29.21	63.5	71.5	78	149	70	900	-6.5	0.0	218	10.0	15.62	12.48
11:00	29.01	65.5	71.5	76	151	70	890	-6.5	0.0	218	10.0	15.14	12.88
11:30	29.02	63.5	71	76	137	70	870	-6.8	0.1	218	10.0	15.53	12.78
12:00	29.03	65	72	78	143	70	870	-6.7	0.2	212	16.0	15.19	13.15
12:30	29.03	69.5	72.5	79	144	71	890	-6.6	0.1	212	16.0	15.29	12.65
13:00	28.81	79.5	89.5	95	155	88	820	-6.6	0.2	212	16.2	15.11	13.18
13:30	28.81	76	88.5	86	155	87	770	-6.6	0.3	210	16.5	15.15	13.10
14:00	28.81	75.5	88	86	152	86	920	-6.5	0.1	210	20.0	15.31	13.23
14:30	28.81	74.5	86	86	153	85	920	-6.6	0.2	210	20.0	15.64	13.30
15:00	28.82	74	87	86	153	85	920	-6.5	0.1	210	20.0	15.16	13.65
15:30	28.82	74	88	86	155	86	950	-6.5	0.1	210	20.0	15.47	13.27
16:00	28.82	73.5	86.5	86	153	85	900	-6.6	0.2	210	20.0	15.18	13.38
16:30	28.82	73	84	84	155	81	990	-6.4	0.1	210	20.0	15.14	13.08
17:00	28.83	73	84.5	83	150	83	940	-6.5	0.1	210	20.0	15.51	12.94
17:30	28.83	70.5	83	83	155	80	1090	-6.5	0.1	212	20.0	15.26	13.24
18:00	28.83	70.5	81	81	138	81	840	-6.8	0.3	212	16.5	15.08	13.03
18:30	28.83	69.5	81.5	81	141	78	870	-6.6	0.2	215	16.5	15.42	12.96
19:00	28.84	70.0	81.5	81	142	78	890	-6.6	0.2	208	16.0	15.00	13.20
19:30	28.84	69.5	80.5	81	140	77	870	-6.6	0.2	216	16.0	15.62	12.72
20:00	28.84	69.5	80	81	144	77	890	-6.4	0.0	212	16.0	15.64	13.46
20:30	28.84	70	80.5	81	138	76	950	-6.6	0.2	208	16.0	15.49	13.06

Note: the engine speed was constant at 1240 R.P.M. for this test.