THESIS

The Effect of Water Injection on the Fuel Consumption of a Gasoline Engine.

by

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TABLE OF CONTENTS.

INTRODUCTION.

The object of this thesis was to determine the effect of water injection upon the fuel consumption of a gasoline engine.

Before beginning the tests it was necessary to design and construct a new reducing motion for the indicator, the old one having proven unsatisfactory. This new reducing motion, drawings of which may be found in the appendix, consists of an eccentric mounted on the main shaft, connecting rod, crosshead guides, etc. Care was taken in the design of this motion to keep the ratio of the throw to the length of the connecting rod the same as that of the engine itself, this being necessary in order to obtain an accurate reproduction of the motion of the piston.

Duplicate tests were made at loads ranging from zero to full load of the engine and a comparison of the results obtained will be found in the balance of this thesis.

Difficulties encountered in the construction and attachment of the reducing motion and the limited time available for this thesis made it impossible to secure enough data from which to draw positive conclusions. However, the results obtained are sufficient to indicate what may be expected from the use of water injection devices.

SPECIFICATIONS OF ENGINE.

TYPE of ENGINE. - Stationary, Horizontal, Single Cylinder, Four Cycle.

DIMENSIONS. - (a) Single Acting.

(b) Cylinder diameter - 5 inches.

(c) Stroke of piston - 10 inches.

(d) Compression space - 35% of piston displacement.

(e) H.p. constant for 1 lb. m.e.p. and 1 r.p.m. - 0.000496

RATED CAPACITY. - Five horsepower at 325 revolutions per minute.

MAKERS. - Fairbanks Morse Company.

DATE. - May 1915.

FUEL. - Union Oil Company's Gasoline.

METHOD OF MAKING TESTS.

The power from the engine was absorbed by a rope brake placed on the flywheel.

In certain of the tests water was injected into the fuel mixture by means of a Schebler carburetor placed on the air intake of the engine. The quantity of water injected was determined by weighing.

The quantities of fuel and of cooling water used were also determined by weighing.

Explosions were counted by means of a Veeder counter, so placed as to be operated by the exhaust valve rod.

All temperatures were determined by means of thermometers.

The engine was run under test conditions for some time before starting each test in order that all temperatures, etc., might become constant.

After the engine had been thoroly warmed up, the tests were started and readings were taken every ten minutes of:- (1) the number of explosions; (2) the weight of gasoline used; (3) the weight of cooling water used; (4) the temperature of the water going into the exhaust cooler; (5) the temperature of the water leaving the exhaust cooler and going into the cylinder jacket; (6) the temperature of the water leaving the jacket;

(7) the temperature of the exhaust gases leaving the engine and, (8) the temperature of the exhaust gases leaving the cooler.

In those tests in which water injection was used, the weights of injection water were taken at the beginning and end of each run and the weight of water consumed was found from the difference.

The "hit and miss" governor used on this engine holds the exhaust valve open during the idle strokes, therefore the temperature readings of the exhaust gases at no load and at light loads are low because of the few explosions.

Indicator diagrams were taken every ten minutes with a Crosby New Indicator Number 3 using a two hundred pound spring. Continuous indicator diagrams, showing clearly the method of governing, were also taken during some of the tests.

The speed of the engine was determined by means of a Schuchardt & Schutte Tachometer several times during each test, the governor keeping it practically constant at three hundred and thirty-five revolutions per minute.

FORMULAS USED.

Heat Value of Fuel.

The higher heat value of United States petroleum and its distillates varies quite regularly with the Specific Gravity of the material and may be expressed by the formula:

British Thermal Units per pound is equal to 18650 plus 40(B -- 10).

B is the Specific Gravity of the material in the Baume' scale.

This formula, which is taken from page 469 of "Elements of Heat-Power Engineering" by Hirshfeld & Barnard, may be assumed correct within less than two percent as shown by E.S.Gardiner in his thesis of June 1914.

Indicated Horsepower.

The indicated horsepower is $\frac{PLAN}{33000}$, in which

P is the Mean Effective Pressure in pounds per square inch.

L is the length of stoke in feet.

A is the area of the piston in square inches.

N is the average number of explosions per minute.

Mean Effective Pressure is found by multiplying the area of the indicator diagram, in square inches, by the scale of the spring used, in pounds per square inch, and

dividing by the length of the card in inches.

Delivered Horsepower.

The dilivered horsepower is $\frac{2\pi RNP}{33000}$, in which,

π is 3.1416

R is the length of the brake arm in feet.

N is the speed in revolutions per minute.

P is the net pressure on the brake arm.

DATA AND RESULTS OF TESTS.

A.S.M.E. Code of 1912, Short Form.

No. of Test	3	4	9	14
Duration (min.)	60	60	60	60
Barometer "Hg.	29.18	29.18	29.22	28.97
Temperature of cooling water - °F.				
(a) Into exhaust cooler	68	68	68.3	62
(b) Into jacket	102.1	107.4	111.5	99.7
(c) Out of jacket	146.5	153.4	163.8	143.6
Temperature of air °F	78.4	75.6	79.4	62.3
Temperature of exhaust gases °F				
(a) From engine	279	301	324.5	326.6
(b) From cooler	78	78.8	82	70
TOTAL QUANTITIES.				
Gasoline consumed - lbs.	2.52	2.66	2.80	2.84
Water injected per pound of gasoline - lbs.	0.0	0.185	0.0	0.176
Cooling water used - lbs.	215	215	193	354
Calorific value of gasoline B.T.U. per pound.	20730	20730	20690	20690
HOURLY QUANTITIES.				
Gasoline per hr. - lbs.	2.52	2.66	2.80	2.84
Cooling water per hr. lbs.	215	215	193	354
INDICATOR DIAGRAMS.				
Pressures in pounds per square inch above atmosphere.				
Maximum pressure	279.4	272.6	285.7	283.
Mean effective pressure	83.6	80.8	80.8	84.
SPEED AND EXPLOSIONS.				
Revolutions per minute.	335	335	335	335
Average no. of exp. per min.	43.3	44.8	56.4	58.3
POWER.				
Indicated horsepower.	1.795	1.795	2.26	2.43
Brake horsepower	0.0	0.0	1.0	1.0
Friction horsepower by difference	1.795	1.795	1.26	1.43

DATA AND RESULTS (cont'd.)

No. of Test	3	4	9	14
Friction horsepower by friction diagrams.	1.795	1.795	1.795	1.795
Percentage of indicated horsepower lost in friction.	100%	100%	55.7%	58.8%
ECONOMY RESULTS.				
Heat units consumed by engine per hour.				
(a) Per indicated horsepower	29100	30600	25850	24150
(b) Per brake horsepower			58000	58750
Pounds of gasoline consumed per hour.				
(a) Per indicated horsepower	1.4	1.48	1.24	1.17
(b) Per brake horsepower			2.8	2.84
EFFICIENCIES.				
Percent thermal efficiency On the brake.			4.39	4.33
Percent mechanical efficiency.			44.25	41.15

DATA AND RESULTS OF TESTS.

A.S.M.E. Code of 1913, Short Form.

No. of Test	7	8	5	6
Duration (min.)	60	60	60	60
Barometer "Hg.	29.16	29.22	29.18	29.1
Temperature of cooling water - °F				
(a) Into exhaust cooler	66.5	66.6	67	67
(b) Into jacket	102.7	104.4	100.9	107
(c) Out of jacket	150.5	148.7	145.8	153.5
Temperature of air - °F	70.9	80.7	77.4	72
Temperature of exhaust gases - °F				
(a) From engine	415.5	407.3	502	488
(b) From cooler	75.6	79.2	77.2	78.5
TOTAL QUANTITIES.				
Gasoline consumed - lbs.	3.11	3.19	3.67	3.55
Water injected per pound of gasoline - lbs.	0.0	0.235	0.0	0.2705
Cooling water used - lbs.	360	360	525	442
Calorific value of gasoline B.T.U. per pound.	20690	20690	20690	20690
HOURLY QUANTITIES.				
Gasoline per hr.- lbs.	3.11	3.19	3.67	3.55
Cooling water per hr. lbs.	360	360	525	442
INDICATOR DIAGRAMS.				
Pressures in pounds per square inch above atmosphere.				
Maximum pressure	271.4	276.6	283.	268.3
Mean effective pressure	80.4	79.2	77.5	77.5
SPEED AND EXPLOSIONS.				
Revolutions per minute	335	335	335	335
Average no. of exp. per min.	80.4	84.75	109.2	114.3
POWER.				
Indicated horsepower	3.45	3.33	4.2	4.4
Brake horsepower	2.	2.	3.	3.
Friction horsepower by difference	1.45	1.33	1.2	1.4

DATA AND RESULTS (cont'd.)

No. of Test.	7	8	5	6
Friction horsepower by friction diagrams.	1.795	1.795	1.795	1.795
Percentage of indicated horsepower lost in friction.	42%	39.5%	28.6%	31.8%
ECONOMY RESULTS.				
Heat units consumed by engine per hour.				
(a) Per indicated horsepower	18650	19800	18100	16700
(b) Per brake horsepower	32200	33000	25300	24500
Pounds of gasoline consumed per hour.				
(a) Per indicated horsepower	.908	.958	.873	.807
(b) Per brake horsepower	1.555	1.595	1.222	1.184
EFFICIENCIES.				
Percent thermal efficiency on the brake.	7.9	7.7	10.06	10.38
Percent mechanical efficiency.	58	60	71.5	68.2

DATA AND RESULTS OF TESTS.

A.S.M.E. Code of 1912, Short Form.

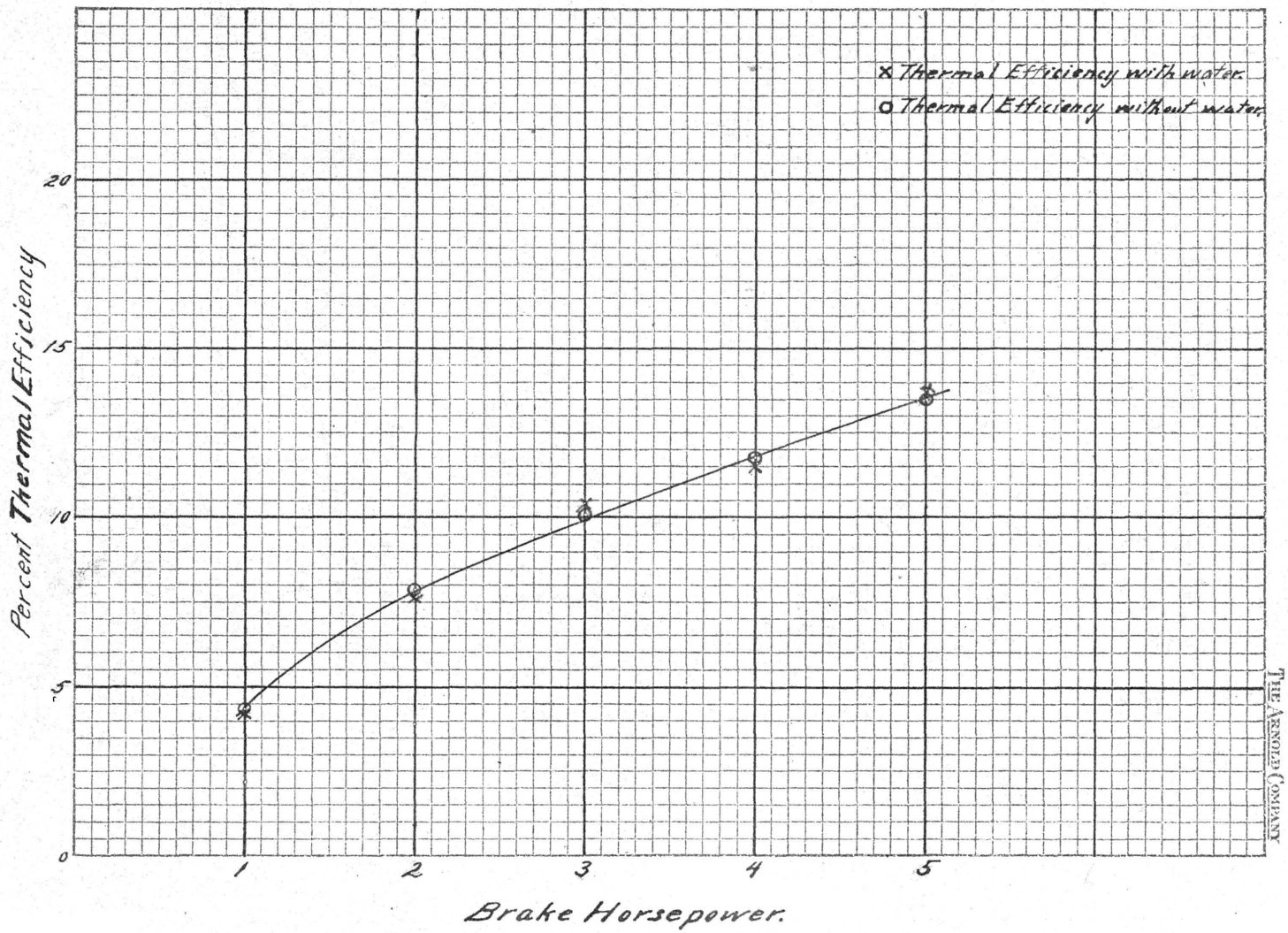
No. of Test	10	11	12	13
Duration (min.)	60	60	60	30
Barometer "Hg.	29.1	29.1	28.95	28.95
Temperature of cooling water - °F.				
(a) Into exhaust cooler	65	65	66	65
(b) Into jacket	99.2	101	102.1	102.75
(c) Out of jacket	143.7	142	151.3	145
Temperature of air - °F.	66	68.5	80.3	76.75
Temperature of exhaust gases - °F				
(a) From engine	534.3	520.8	606.6	606
(b) From cooler	74.7	75.8	78.7	79.
TOTAL QUANTITIES.				
Gasoline consumed - lbs.	4.19	4.25	4.53	2.24
Water injected per pound of gasoline - lbs.	0.0	.271	0.0	.31
Cooling water used - lbs.	636	631	686	358
Calorific value of gasoline B.T.U. per pound.	20690	20690	20690	20690
HOURLY QUANTITIES.				
Gasoline per hr. - lbs.	4.19	4.25	4.53	4.48
Cooling water per hr. lbs	636	631	686	716
INDICATOR DIAGRAMS.				
Pressures in pounds per square inch above atmosphere.				
Maximum pressure	284	277.7	283.3	284
SPEED AND EXPLOSIONS.				
Revolutions per minute	335	335	335	335
Average no. of exp. per min.	141.6	139.35	165.66	163.3
POWER.				
Indicated horsepower	5.49	5.45	6.05	6.18
Brake horsepower	4.	4.	5.	5.
Friction horsepower by difference	1.49	1.45	1.05	1.18

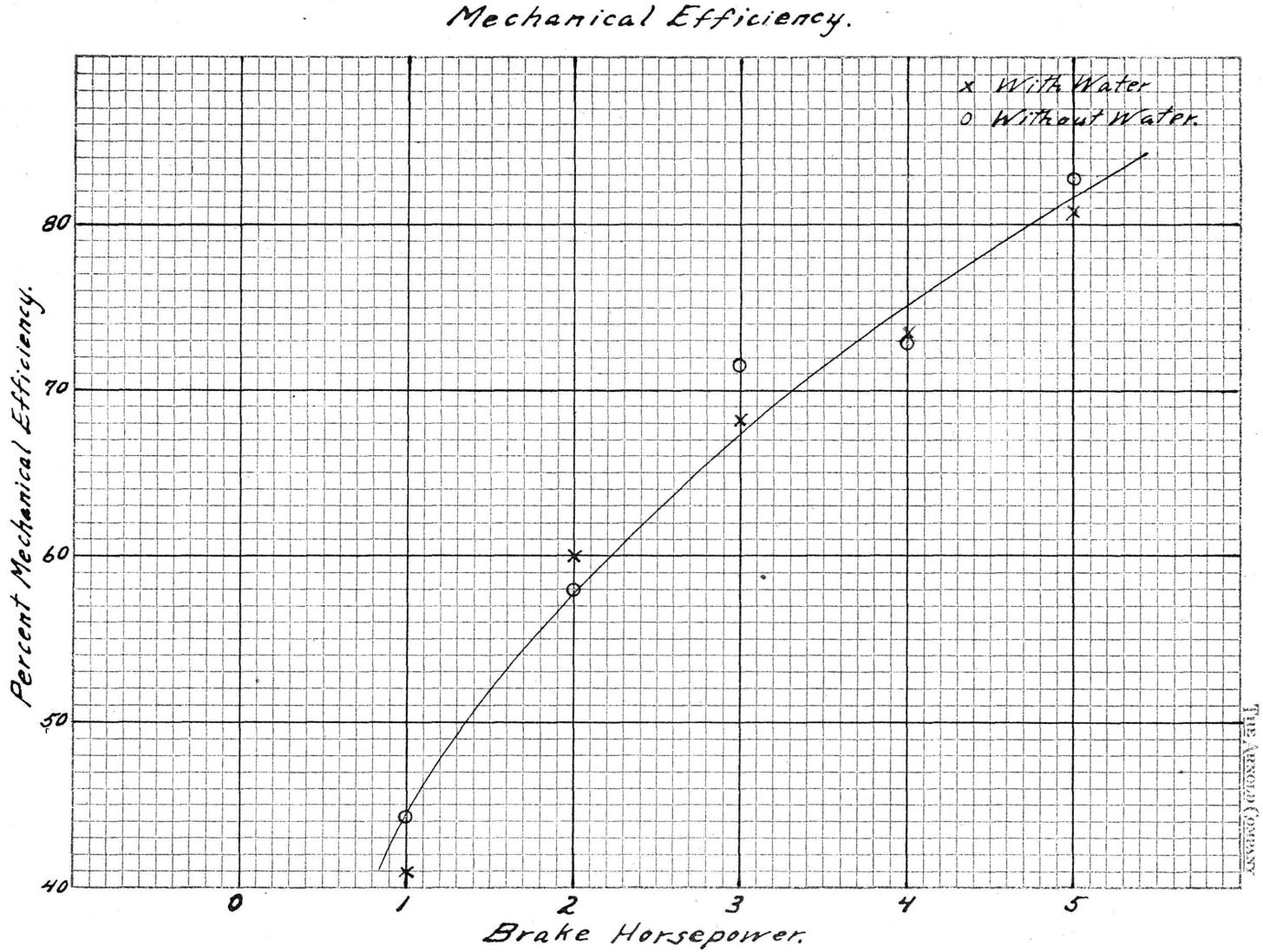
DATA AND RESULTS (cont'd.)

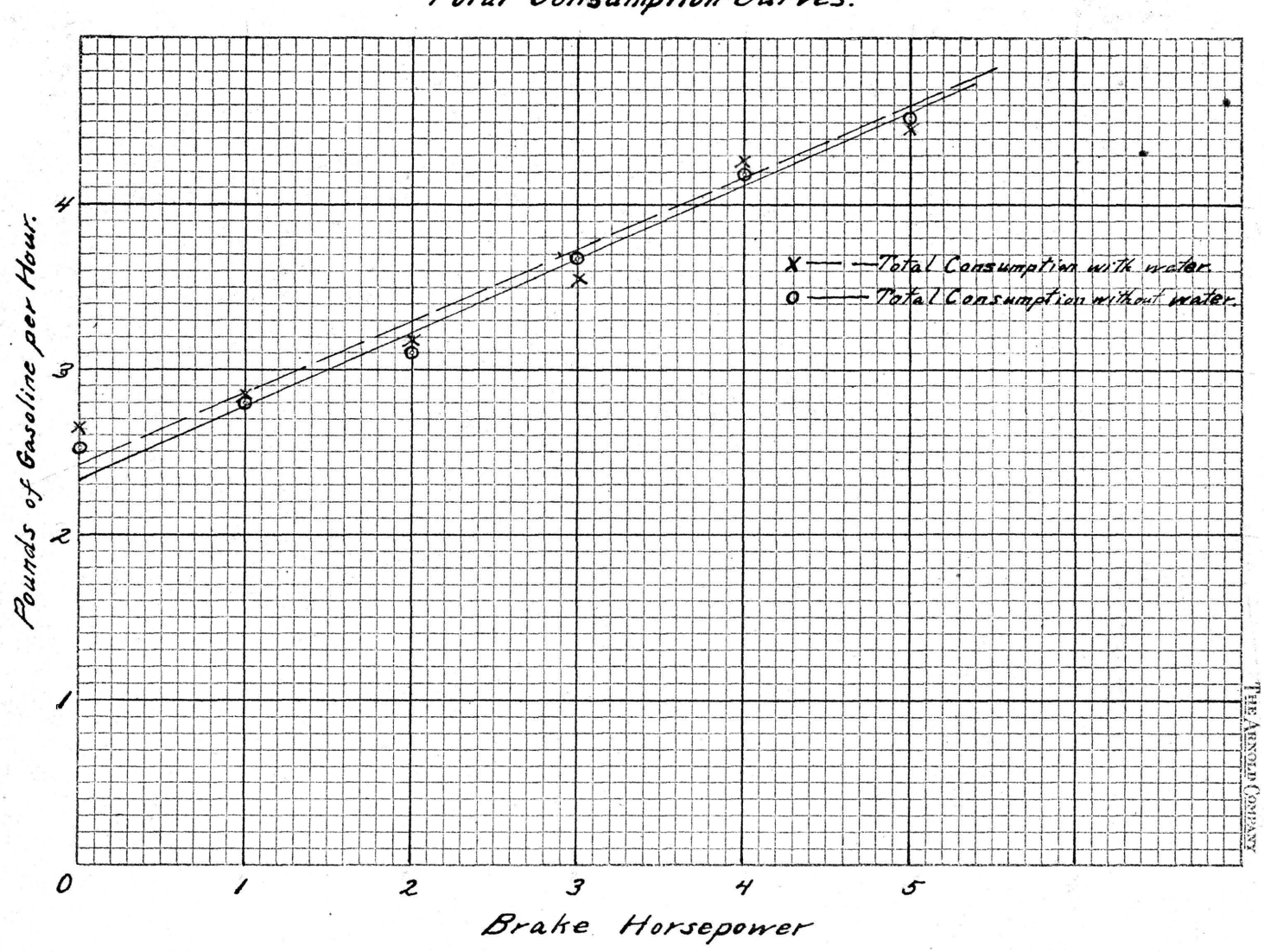
No. of Test.	10	11	12	13
Friction horsepower by friction diagrams	1.795	1.795	1.795	1.795
Percentage of indicated horsepower lost in friction.	27.1%	26.6%	17.37%	19.1%
ECONOMY RESULTS.				
Heat units consumed by engine per hour.				
(a) Per indicated horsepower	15800	16150	15500	15000
(b) Per brake horsepower	21700	23000	18750	18550
Pounds of gasoline consumed per hour.				
(a) Per indicated horsepower	.763	.780	.75	.725
(b) Per brake horsepower	1.0475	1.0635	.907	.895
EFFICIENCIES.				
Percent thermal efficiency on the brake.	11.72	11.57	13.52	13.73
Percent mechanical efficiency.	72.8	73.4	82.7	80.9

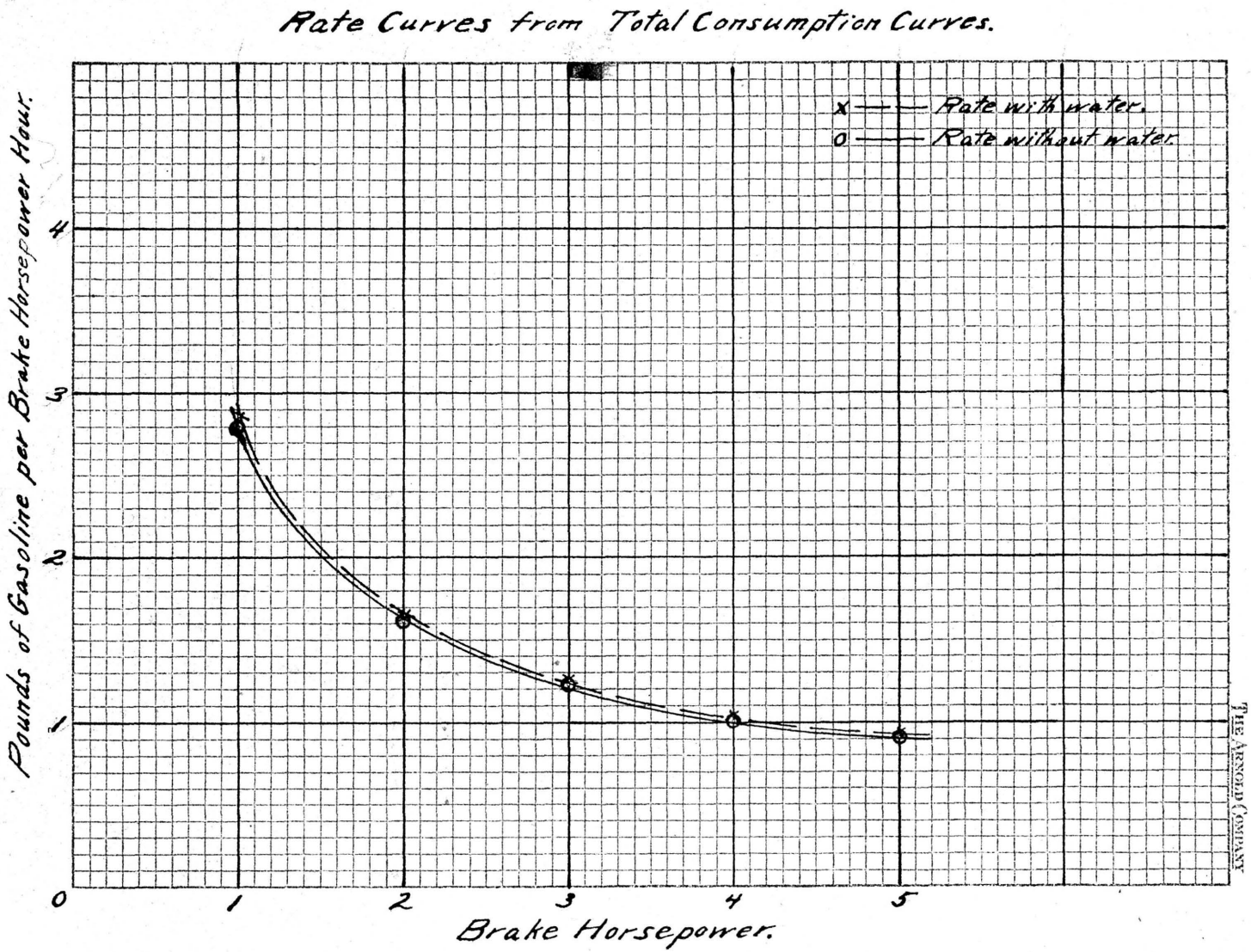
GRAPHICAL PRESENTATION OF RESULTS.

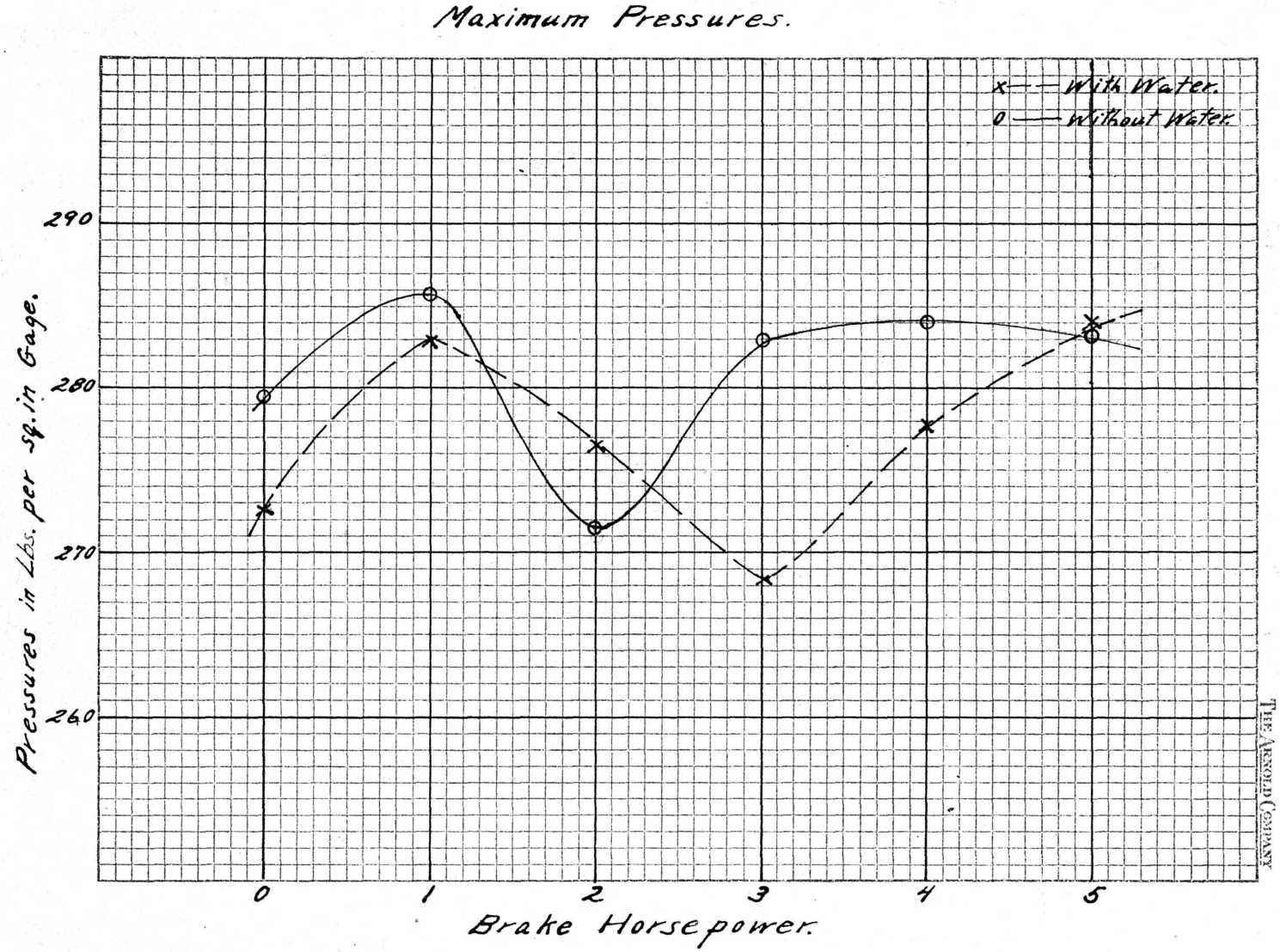
Thermal Efficiencies.

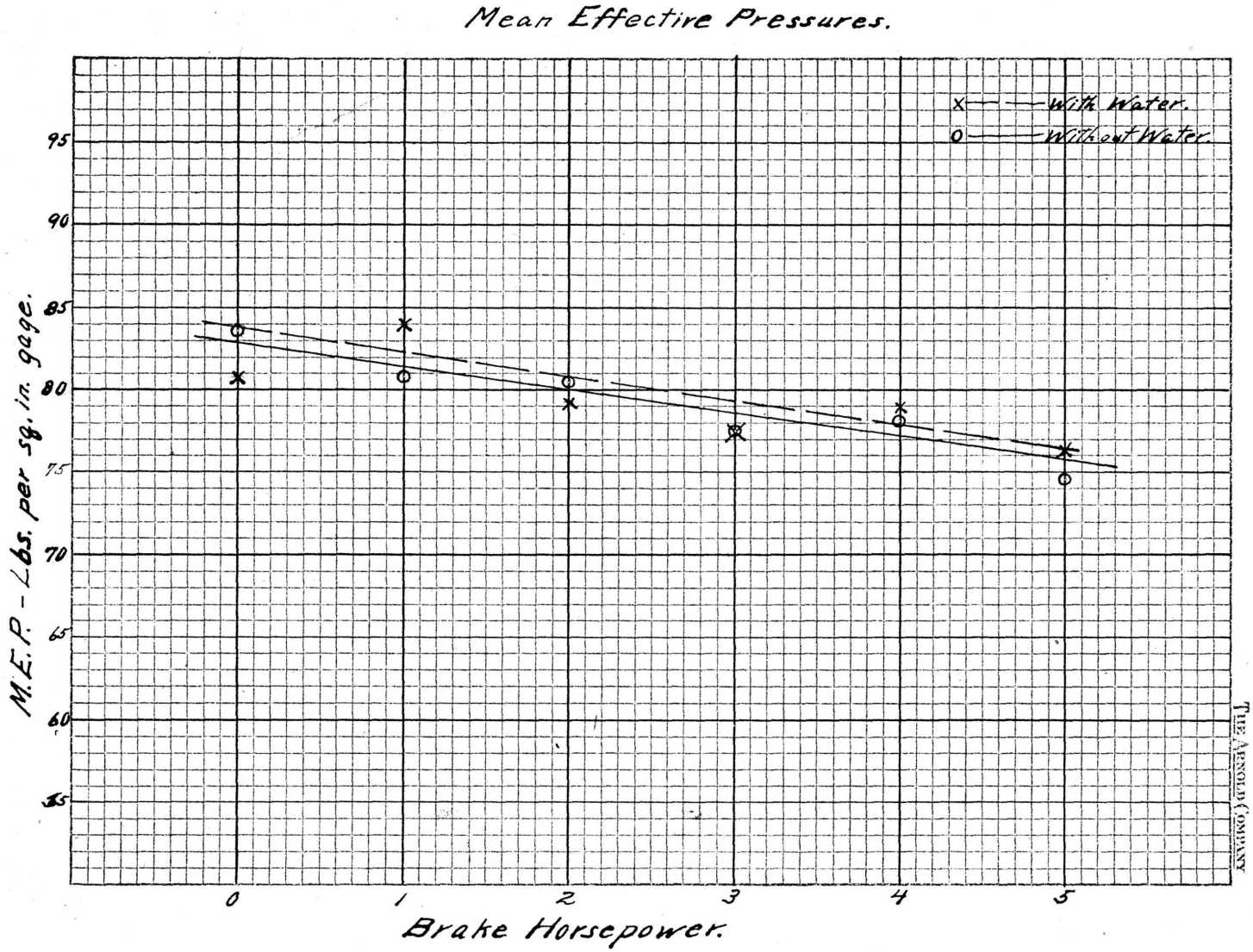


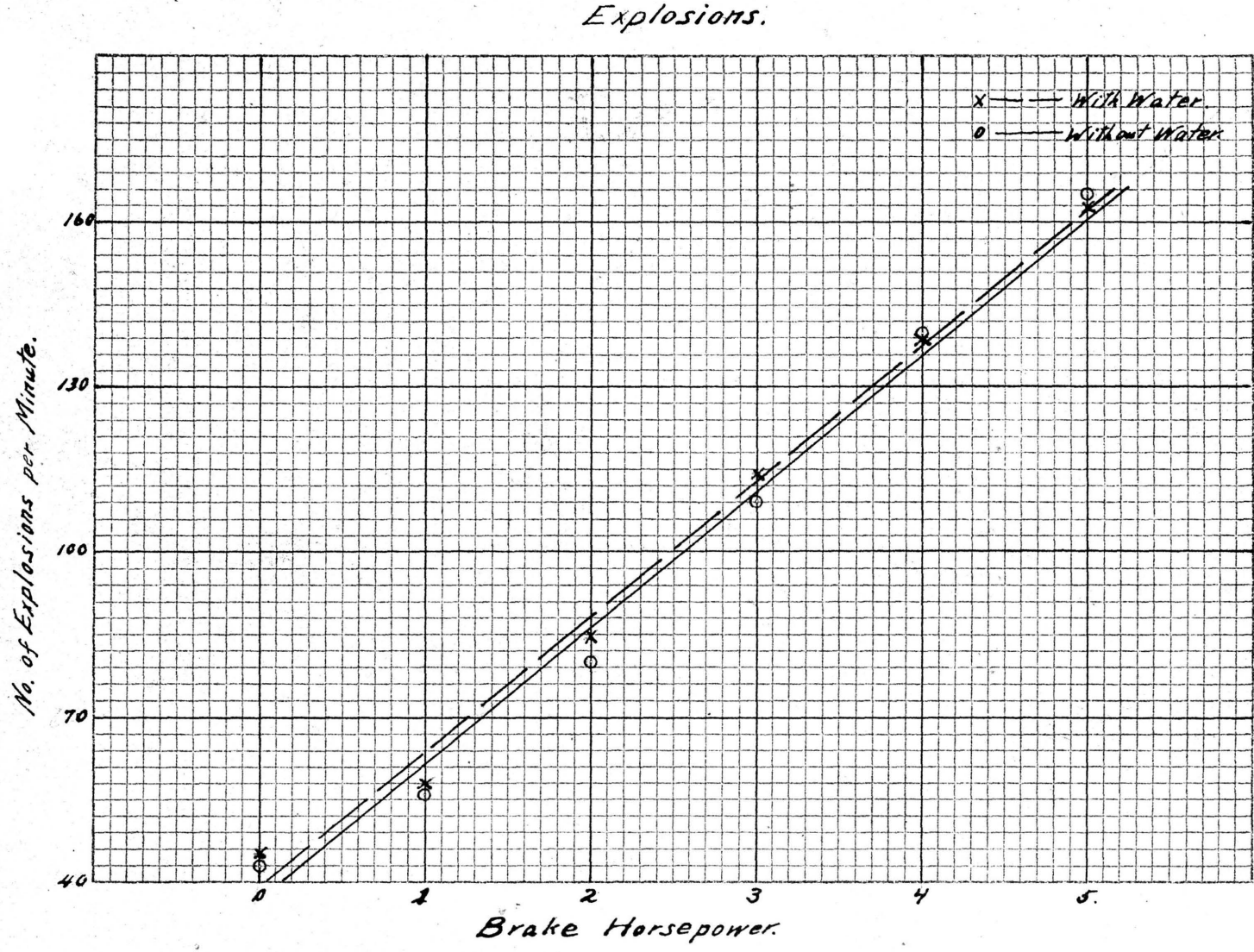

Mechanical Efficiency.
× With Water
○ Without Water.
Percent Mechanical Efficiency.
80
70
60
50
40
0
1
2
3
4
5
Brake Horsepower.


Total Consumption Curves.
Pounds of Gasoline per Hour.
0
1
2
3
4
5
Brake Horsepower
X —— Total Consumption with water.
O —— Total Consumption without water.
THE ARNOLD COMPANY


Rate Curves from Total Consumption Curves.
x —— Rate with water.
o —— Rate without water.
Pounds of Gasoline per Brake Horsepower Hour.
0
1
2
3
4
Brake Horsepower.
1
2
3
4
5
THE ARNOLD COMPANY

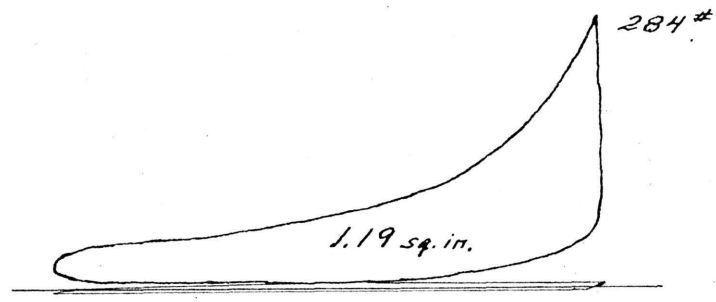

Maximum Pressures.
x—— With Water.
0—— Without Water.
290
280
270
260
Pressures in Lbs. per Sq. in Gage.
0
1
2
3
4
5
Brake Horsepower.
THE ARNOLD COMPANY

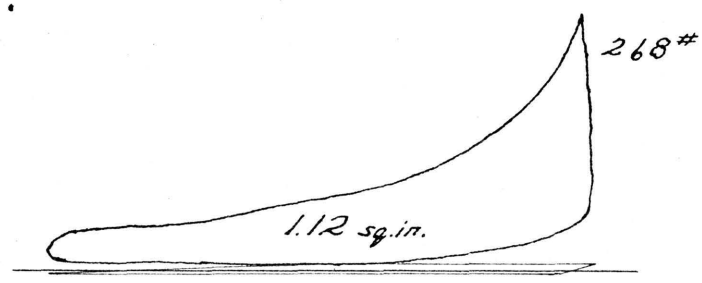

Mean Effective Pressures.
X——With Water.
O——Without Water.
M.E.P. - Lbs. per sq. in. gage.
95
90
85
80
75
70
65
60
55
0
1
2
3
4
5
Brake Horsepower.
THE ARGOLD COMPANY


Explosions.
X —— With Water.
O —— Without Water.
No. of Explosions per Minute.
160
130
100
70
40
0
1
2
3
4
5.
Brake Horsepower.
THE ARNOLD COMPANY

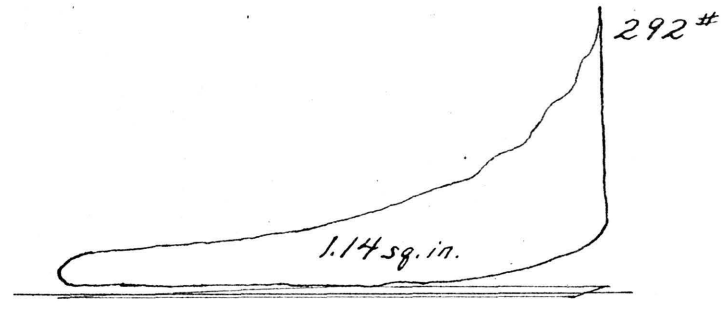
Typical Indicator Diagrams.

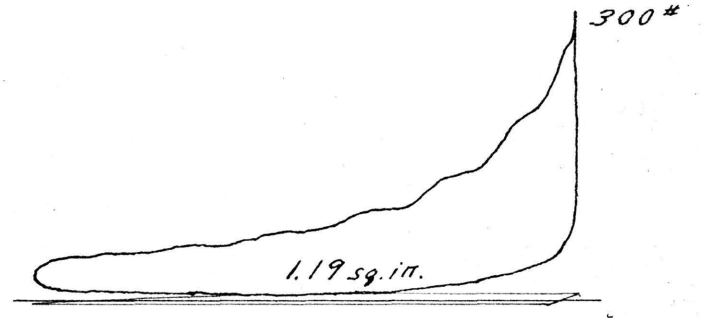
200 Lb. Spring.





With Water.

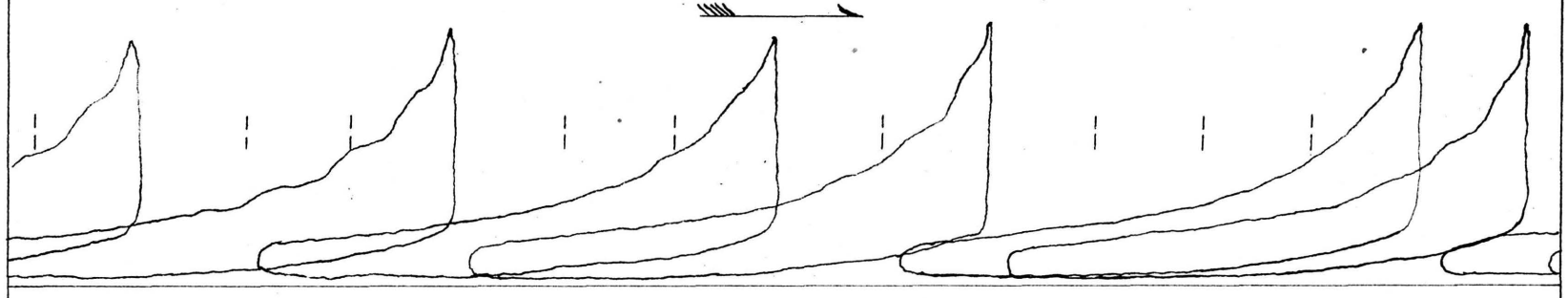




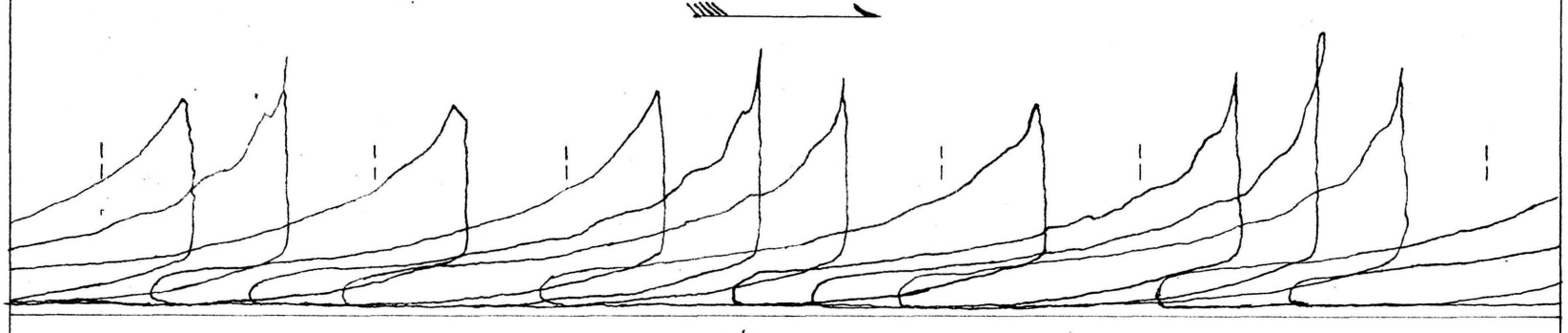
Without Water.

CONTINUOUS INDICATOR DIAGRAMS.

200# spring. 335 r.p.m.



Run No. 14 – 1 b.h.p.



Run No. 6 – 3 b.h.p.

CONCLUSIONS.

As may be seen from the accompanying curves and data sheets, the tests made show the following results:-

1. The thermal efficiency at the various loads is practically identical, with water injection and without.
2. The mechanical efficiency at the various loads does not appear to be greatly affected by water injection.
3. The total consumption and the rate, or fuel used per horsepower hour, is slightly higher with water injection than without.
4. The maximum, or explosion pressures, vary greatly, but in almost all cases they are somewhat lower with water injection than without.
5. The mean effective pressures seem to be slightly higher with water injection than without; thus indicating a slight increase in the area of the diagram. However, this is not borne out by the other results.
6. The number of explosions per minute is slightly greater with water injection than without.

These results which are borne out by the investigations of Prof. J.A.Moyer, Quoted in POWER - Vol. 40 - p. 569, do not justify the use of water injection devices as fuel economizers. However, such devices may, by reducing the maximum, or explosion, pressures, be of value in preventing pounding at heavy loads.

ORIGINAL DATA.

Taken as Tests were made.

Being in the nature of preliminary runs, Tests numbers 1 and 2 are not included in the following.

Test No. 3. April 20,1915.

		TEMPERATURES °F							
No.	Time.	Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	1:15	78	66	68	100	140	272	78	83038
2	1:25	78	66	68	100	144	273	78	83464
3	1:35	79	67	68	102	146	280	78	83892
4	1:45	78	66	68	103	148	286	78	84327
5	1:55	78	66	68	103	150	283	78	84761
6	2:05	80	67	68	103	150	286	78	85195
7	2:15	78	66	68	104	152	283	78	85636
Averages		78.4	66.3	68	102.1	146.5	279	78	

	Cooling water -lbs.			Gasoline -lbs.		
No.	Wt. full.	Wt. empty.	Diff.	Wt. full.	Wt. empty.	Diff.
1		55		8.85	8.43	.42
2	90	55	35	8.43	8.00	.43
3	125	90	35	8.00	7.58	.42
4	161	125	36	7.58	7.15	.43
5	198	161	37	7.15	6.75	.40
6	233	198	35	6.75	6.33	.42
7	270	233	37	6.33		
		Total	215		Total	2.52

Total number of explosions = 85636 -- 83038 = 2598.

No. of exp. per min. = 43.3

Average maximum pressure 279.4 lbs.

Average M.E.P. 83.6 lbs.

Sp. Gr. of gasoline 62° Baume.

Barometer 29.18 ins.

Net weight on brake - 0.0 lbs.

Brake horsepower - 0.

Test No. 4 April 20 1915.

No.	Time.	TEMPERATURES -°F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	3:25	76	65	68	106	150	302	78	88508
2	3:35	76	65	68	107	153	306	79	88948
3	3:45	76	65	68	107	152	300	78	89336
4	3:55	76	65	68	107	153	298	77	89744
5	4:05	75	64	68	108	156	306	79	90011
6	4:15	75	64	68	109	156	307	79	90449
7	4:25	75	64	68	108	154	306	79	90985
Averages		75.6	64.6	68	107.4	153.4	301	78.8	

No.	Cooling water - lbs. Wt. full.	Wt. empty.	Diff.	Gasoline - lbs. Wt. full.	Wt. empty.	Diff.
1		51		9.96	9.50	.46
2	86	51	35	9.50	9.05	.45
3	122	86	36	9.05	8.63	.42
4	159	122	37	8.63	8.19	.44
5	194	159	35	8.19	7.75	.44
6	230	194	36	7.75	7.30	.45
7	266	230	36	7.30		
		Total	215		Total	2.66

Barometer 29.18 ins.

Net weight on brake 0.0 lbs.

Brake horsepower 0.

Explosion counter missed between 3:55 and 4:05.

No.of exp.per min.assumed to be 44.8 from ratio of M.E.P.of No. 3 to M.E.P.of No.4.

Average maximum pressure 272.6lbs

Average M.E.P. 80.8lbs.

Sp.Gr. of gasoline 62° Baume

Water injected per pound of gasoline = .185 lbs.

Test No. 5. April 23 1915.

No.	Time.	TEMPERATURES °F. Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	4:30	77	68	67	103	148	500	78	96801
2	4:40	77	68	67	101	146	496	77	97949
3	4:50	77.5	69.5	67	100	144	492	77	99035
4	5:00	78	69.5	67	100	144	500	77	100095
5	5:10	78	69	67	101	146	506	77	101191
6	5:20	77.5	68	67	101	146	508	77	102258
7	5:30	77	67.5	67	101	146	510	77	103358
Averages		77.4	68.5	67	100.9	145.8	502	77.2	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		56		10	9.39	.61
2	143	56	87	9.39	8.79	.60
3	232	143	89	8.79	8.18	.61
4	322	232	90	8.18	7.55	.63
5	Total 30 min.		266	7.55	6.95	.60
6	Cooling water for			6.95	6.33	.62
7	1 hr. assumed to be 525 lbs.			Total		3.67

Total number of explosions = 103358 -- 96801 = 6557.

No. of exp. per min. = 109.2

Average maximum pressure 283 lbs

Average M.E.P. 77.5 lbs.

Sp. Gr. of Gasoline 61° Baume

Barometer 29.18 ins.

Net weight on brake 27.5 lbs. Brake horsepower 3.

Test No. 6. April 24,1915.

No.	Time.	TEMPERATURES °F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	10:10	70	61	66	97	133	467	75	6170
2	10:20	72	62.5	67	108	153	490	79	7337
3	10:30	72	62.5	67	108	154	490	79	8461
4	10:40	72.5	63	67	108	158	490	79	9588
5	10:50	72.5	63	67	108	158	492	79	10719
6	11:00	72.5	63	67	109	158	494	79	11860
7	11:10	72.5	63	67	110	160	496	79	13025
Averages		72	62.6	67	107	153	488	78.5	

Cooling water - lbs. Gasoline - lbs.

No.	Wt. full.	Wt. empty.	Diff.	Wt. full.	Wt. empty.	Diff.
1		67		10.02	9.42	.60
2	142	67	75	9.42	8.84	.58
3	215	142	73	8.84	8.25	.59
4	290	215	75	8.25	7.63	.62
5	364	290	74	7.63	7.06	.57
6	436	364	72	7.06	6.47	.59
7	509	436	73	6.47		
		Total	442		Total	3.55

Barometer 29.1 ins.

Net weight on brake 27.5 lbs.

Brake horsepower 3.

Total number of explosions = 13025 -- 6170 = 6855

No. of exp. per min. = 114.3

Average maximum pressure 268.31bs.

Average M.E.P. 77.5 lbs.

Sp.Gr. of gasoline used 61° Baume

Water injected per pound of gasoline = .2705 lbs.

Test No. 7. April 24,1915.

		TEMPERATURES °F							
No.	Time.	Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	4:00	71.5	62	66	103	150	426	76	22747
2	4:10	71.5	62	66	104	152	424	77	23651
3	4:20	71	62	66	102	150	414	75	24529
4	4:30	70	61	66	102	150	412	75	25375
5	4:40	70	61	67	102	151	410	75	26239
6	4:50	71	62	67	103	150	410	76	27075
7	5:00	71	62	67	103	151	414	76	27925
Averages		70.9	61.7	66.5	102.7	150.5	415.5	75.6	

	Cooling water -lbs.			Gasoline -lbs.		
No.	Wt. full.	Wt. empty.	Diff.	Wt. full.	Wt. empty.	Diff.
1		107		9.40	8.85	.55
2	167	107	60	8.85	8.35	.50
3	229	167	62	8.35	7.82	.53
4	291	329	62	7.82	7.30	.52
5	348	291	57	7.30	6.80	.50
6	407	348	59	6.80	6.29	.51
7	467	407	60	6.29		
		Total	360		Total	3.11

Total number of explosions = 27925 — 22747 = 5178.

No. of exp. per min. = 86.3

Average maximum pressure 271.4 lbs.

Average M.E.P. 80.4 lbs.

Sp.Gr. of gasoline 61° Baume.

Barometer 29.16 ins.

Net weight on brake 18.3 lbs.

Brake horsepower 2.

Test No. 8. April 27, 1915.

		TEMPERATURES °F							
No.	Time.	Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from engine.	Explosion counter.
1	12:40	79	73	67	104	146	407	79	33032
2	12:50	81.5	73	66	104	147	412	79	33864
3	1:00	82	73	66	104	148	410	79	34705
4	1:10	80	71	66	104	150	402	79	35549
5	1:20	80	71	67	105	150	406	79.5	36401
6	1:30	79	67.5	67	105	150	404	79.5	37259
7	1:40	79	67	67	105	150	400	79.5	38104
Averages		80.7	70.64	66.57	104.4	148.7	407.3	79.2	

	Cooling water -lbs.			Gasoline -lbs.		
No.	Wt. full.	Wt. empty.	Diff.	Wt. full.	Wt. empty.	Diff.
1		70		9.50	8.98	.52
2	131	70	61	8.98	8.45	.53
3	192	131	61	8.45	7.90	.55
4	253	192	61	7.90	7.39	.51
5	310	253	57	7.39	6.85	.54
6	370	310	60	6.85	6.31	.54
7	430	370	60	6.31		
	Total		360		Total	3.19

Barometer 29.23 ins.

Net weight on brake - 18.2 lbs.

Brake horsepower - 2.

Total number of explosions = 38104 -- 33032 = 5082.

No. of exp. per min. = 84.75

Average maximum pressure 876.7 lbs.

Average M.E.P. 79.2 lbs.

Sp.Gr. of gasoline 61° Baume.

Water injected per pound of gasoline = .235 lbs.

Test No. 9. April 27,1915.

No.	Time.	TEMPERATURES °F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from engine.	Explosion counter.
1	2:30	78	68	69	106	160	314	82	39918
2	2:40	78	68	69	115	168	314	83	40445
3	2:50	80.5	69.5	68	110	156	316	81	40991
4	3:00	80.5	69.5	68	108	156	312	80	41527
5	3:10	80	69	68	112	168	360	82	42174
6	3:20	80	69	68	114	168	333	83	42759
7	3:30	79	68	68	115	170	320	83	43300
Averages		79.4	68.75	68.3	111.5	163.8	324.5	82	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		68		9.81	9.33	.48
2	94	68	26	9.33	8.87	.46
3	132	94	38	8.87	8.44	.43
4	168	132	36	8.44	7.95	.49
5	202	168	34	7.95	7.45	.50
6	233	202	31	7.45	7.01	.44
7	261	233	28	7.01		
		Total	193		Total	2.80

Barometer 29.22 ins.

Net weight on brake - 9.15 lbs.

Brake horsepower - 1.

Total number of explosions = 43300 -- 39918 = 3382.

No. of exp. per min. = 56.4

Average maximum pressure 285.7 lbs

Average M.E.P. 80.8 lbs.

Sp.Gr. of gasoline 61° Baume.

Load believed to have increased between 3:00 and 3:10.

Test No. 10. April 29,1915.

No.	Time.	TEMPERATURES °F Dry. bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	9:45	65	60	65	98	140	542	75	53054
2	9:55	65	60	65	98	142	542	75	54444
3	10:05	65	60	65	99	144	536	74	55852
4	10:15	66	61	65	99	144	530	74	57277
5	10:25	66.5	61	65	100	145	530	75	58703
6	10:35	67	62	65	100	145	530	75	60126
7	10:45	68	62	65	100	146	530	75	61548
Averages		66	60.8	65	99.2	143.7	534.3	74.7	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		69		9.81	9.10	.71
2	174	69	105	9.10	8.42	.68
3	282	174	108	8.42	7.70	.72
4	387	282	105	7.70	7.00	.70
5	495	387	108	7.00	6.32	.68
6	600	495	105	6.32	5.62	.70
7	705	600	105	5.62		
		Total	636		Total	4.19

Total number of explosions = 61548 -- 53054 = 8494.

No. of exp. per min. = 141.6

Average maximum pressure 284.1bs.

Average M.E.P. 78.2 lbs.

Sp. Gr. of gasoline 61° Baume.

Barometer 29.1 ins.

Net weight on brake - 36.6 lbs.

Brake horsepower - 4.

Test No.11. April 29,1915.

No.	Time.	TEMPERATURES °F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	11:10	69	62	65	95	150	476	74	64497
2	11:20	69	62	65	102	143	530	76	65871
3	11:30	68.5	61.5	65	102	144	525	76	67348
4	11:40	68.5	62	65	102	144	530	76	68505
5	11:50	68.5	62	65	102	144	535	76	69590
6	12:00	67.5	61.5	65	103	145	530	76	71004
7	12:10	68.5	62	65	103	145	530	76	72413
Averages		68.5	61.8	65	101	145	530.9	75.8	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		74		9.95	9.35	.70
2	176	74	102	9.35	8.62	.73
3	384	176	108	8.62	7.90	.72
4	395	284	111	7.90	7.11	.69
5	496	395	101	7.11	6.41	.70
6	600	496	104	6.41	5.70	.71
7	705	600	105	5.70		
		Total	631		Total	4.35

Barometer 29.1 ins.

Net weight on brake - 36.6 lbs.

Brake horsepower - 4.

Total number of explosions = 72413 -- 64497 = 7916.
Explosion counter readings void between 11:30 and 11:50.

No.of exp. per min.(from ave.) = 139.35

Average maximum pressure 277.7lbs.

Average M.E.P. 78.9 lbs.

Sp.Gr. of gasoline 61° Baume.

Water injected per pound of gasoline = .271 lbs.

Test No. 12. April 30,1915.

		TEMPERATURES °F							
No.	Time.	Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	1:00	74	64	66	101	148	602	78	82635
2	1:10	74	64	66	101	148	600	78	84294
3	1:20	80	70	66	101	148	603	78	85953
4	1:30	82	71	66	102	152	612	78	87622
5	1:40	83	72	66	103	154	610	79	89271
6	1:50	84	73	66	103	154	611	80	90925
7	2:00	85	74	66	104	155	608	80	92570
Averages		80.3	69.8	66	102.1	151.3	606.6	78.7	

	Cooling water -lbs.			Gasoline -lbs.		
No.	Wt. full.	Wt. empty.	Diff.	Wt. full.	Wt. empty.	Diff.
1		66		9.65	8.9	.75
2	184	66	118	8.9	8.14	.76
3	300	184	116	8.14	7.42	.72
4	415	300	115	7.42	6.62	.80
5	530	415	115	6.62	5.85	.77
6	640	530	110	5.85	5.12	.73
7	752	640	112	5.12		
		Total	686		Total	4.53

Total number of explosions = 92570 -- 82635 = 9940

No. of exp. per min. = 165.66

Average maximum pressure 283.3 lbs

Average M.E.P. 74.6 lbs.

Sp. Gr. of gasoline 61° Baume.

Barometer 28.95 ins.

Net weight on brake - 45.8 lbs.

Brake horsepower - 5.

Test No. 13. April 30,1915.

No.	Time.	TEMPERATURES °F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	3:20	77	65	65	102	144	603	79	4668
2	3:30	77	65	65	103	145	608	79	6830
3	3:40	77	65	65	103	146	609	79	7950
4	3:50	76	64	65	103	145	604	79	9576
Averages		76.75	64.75	65	102.75	146	606	79	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		62		9.88	9.13	.75
2	181	62	119	9.13	8.37	.76
3	300	181	119	8.37	7.64	.73
4	420	300	120	7.64		
		Total	358		Total	2.24

Barometer 28.95 ins.

Net weight on brake - 45.8 lbs.

Brake horsepower - 5.

Total number of explosions = 9576 -- 4668 = 4908.

No. of exp. per min. = 163.6

Average maximum pressure 384 lbs.

Average M.E.P. 76.3 lbs.

Sp.Gr. of gasoline 61° Baume.

Water injected per pound of gasoline = .91 lbs.

N.B.:- Impossible to keep load constant during this test. The engine stopped at 3:57;probably due to a slight increase in the load.The same trouble was experienced in trying to make other tests with water injection at this load.

Test No. 14. May 1,1915.

No.	Time.	TEMPERATURES °F Dry bulb.	Wet bulb.	Water in cooler.	Water in jacket.	Water out jacket.	Exhaust from engine.	Exhaust from cooler.	Explosion counter.
1	10:10	62	52.5	62	99	141	325	70	19878
2	10:20	62	53	62	99	142	330	70	20461
3	10:30	62	53	62	100	144	330	70	21069
4	10:40	62.5	54	62	100	143	325	70	21657
5	10:50	63.5	54.5	62	100	144	330	70	22265
6	11:00	62	53.5	62	100	145	328	70	22874
7	11:10	62	53.5	62	100	146	328	70	23477
Averages		63.3	53.43	62	99.71	143.6	326.6	70	

No.	Cooling water -lbs. Wt. full.	Wt. empty.	Diff.	Gasoline -lbs. Wt. full.	Wt. empty.	Diff.
1		83		9.73	9.22	.51
2	125	83	42	9.22	8.77	.45
3	168	125	43	8.77	8.30	.47
4	210	168	42	8.30	7.82	.48
5	252	210	42	7.82	7.35	.47
6	295	252	43	7.35	6.89	.46
7	337	295	42	6.89		
7		Total	254		Total	2.84

Barometer 28.97 ins.

Net weight on brake - 9.15 lbs.

Brake horsepower - 1.

Total number of explosions = 23477 -- 19878 = 3499.

No. of exp.per min. = 58.315

Sp.Gr. of gasoline 61° Baume.

Average maximum pressure 283 lbs.

Average M.E.P. 84 lbs.

Water injected per pound of gasoline = .176 lbs.

INDICATOR DIAGRAMS.

Pressures in pounds per square inch - gage.
Areas in square inches. Average length 2.84 in.

Test No. 3.

No.	Area.	Maximum pressure.
1	1.15	304
2	1.22	280
3	1.19	280
4	1.18	280
5	1.20	272
6	1.20	260
7	1.17	280
Aver.	1.187	279.4

M.E.P. - 83.6

Test No. 4.

No.	Area.	Maximum pressure.
1	1.17	280
2	1.05	272
3	1.14	240
4	1.14	268
5	1.11	264
6	1.17	280
7	1.15	284
Aver.	1.133	272.6

M.E.P. - 80.8

Test No. 5.

No.	Area.	Maximum pressure.
1	1.13	276
2	1.07	280
3	1.09	272
4	1.13	268
5	1.11	264
6	1.09	256
7	1.09	264
Aver.	1.101	283

M.E.P. - 77.5

Test No. 6.

No.	Area.	Maximum pressure.
1	1.14	280
2	1.13	268
3	1.07	260
4	1.10	256
5	1.10	270
6	1.11	272
7	1.06	272
Aver.	1.10	268.3

M.E.P. = 77.5

Test No. 7.

No.	Area.	Maximum pressure.
1	1.13	264
2	1.14	268
3	1.13	280
4	1.16	280
5	1.13	280
6	1.13	260
7	1.15	268
Aver.	1.14	271.4

M.E.P. - 80.4

Test No. 8.

No.	Area.	Maximum pressure.
1	1.14	280
2	1.18	280
3	1.11	272
4	1.13	268
5	1.11	280
6	1.11	268
7	1.09	288
Aver.	1.124	276.6

M.E.P. - 79.2

INDICATOR DIAGRAMS.

Pressures in pounds per square inch - gage.
Areas in square inches. Average length 2.84 in.

Test No. 9.

No.	Area.	Maximum pressure.
1	1.13	288
2	1.16	288
3	1.16	272
4	1.14	288
5	1.15	280
6	1.14	292
7	1.15	292
Aver.	1.147	285.7

M.E.P. - 80.8 lbs.

Test No. 12.

No.	Area.	Maximum pressure.
1	1.00	288
2	1.08	280
3	1.03	280
4	1.03	284
5	1.06	284
6	1.05	284
7	1.07	284
Aver.	1.044	285.5

M.E.P. = 74.6

Test No. 10.

No.	Area.	Maximum pressure.
1	1.14	276
2	1.12	280
3	1.09	288
4	1.10	280
5	1.09	284
6	1.12	292
7	1.10	288
Aver.	1.109	284

M.E.P. - 78.3

Test No. 13.

No.	Area.	Maximum pressure.
1	1.10	280
2	1.08	288
3	1.08	288
4	1.07	280
Aver.	1.083	284

M.E.P. - 76.3

Test No. 11.

No.	Area.	Maximum pressure.
1	1.12	280
2	1.13	280
3	1.12	280
4	1.11	288
5	1.14	280
6	1.13	276
7	1.09	280
Aver.	1.12	277.7

M.E.P. - 78.9

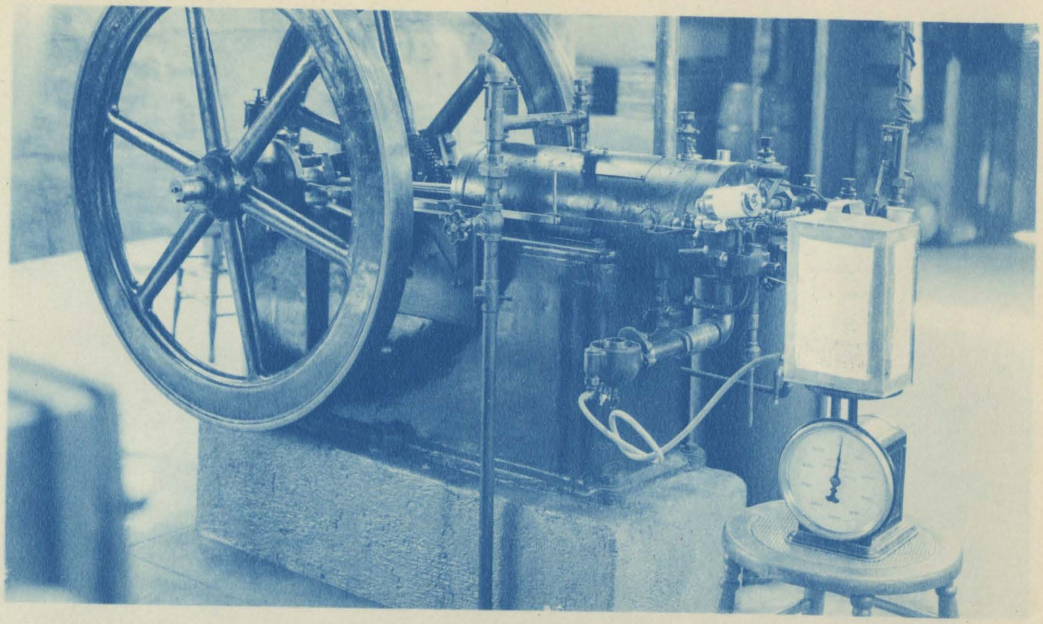
Test No. 14.

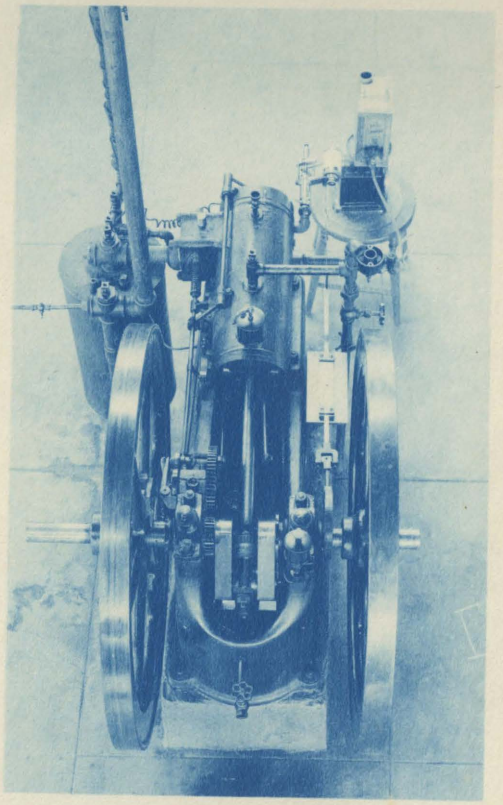
No.	Areas	Maximum Pressure.
1	1.21	292
2	1.18	292
3	1.20	280
4	1.20	272
5	1.18	272
6	1.19	288
7	1.19	284
Aver.	1.193	285

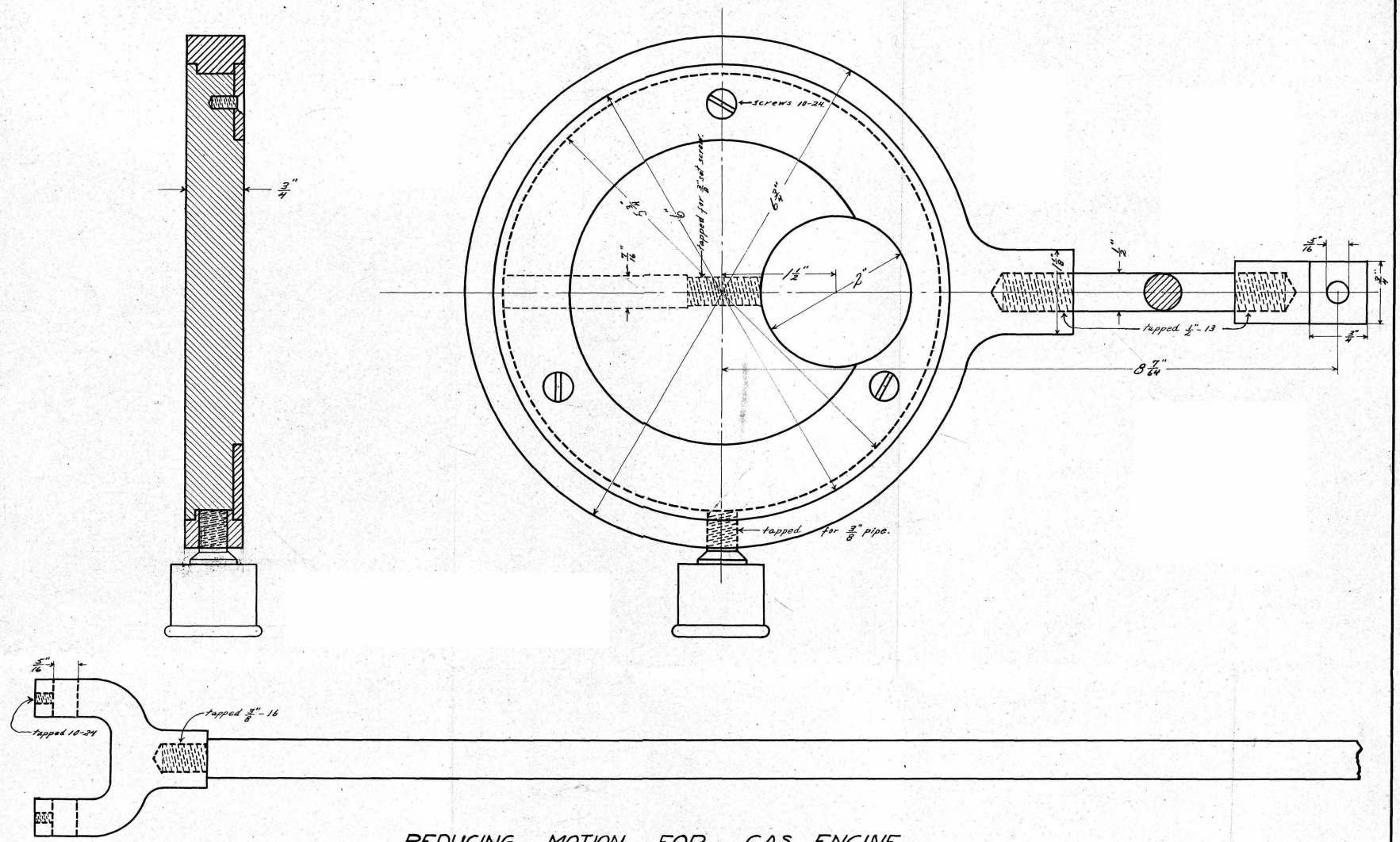
M.E.P. - 84.0

APPENDIX

Photographs and Drawings.

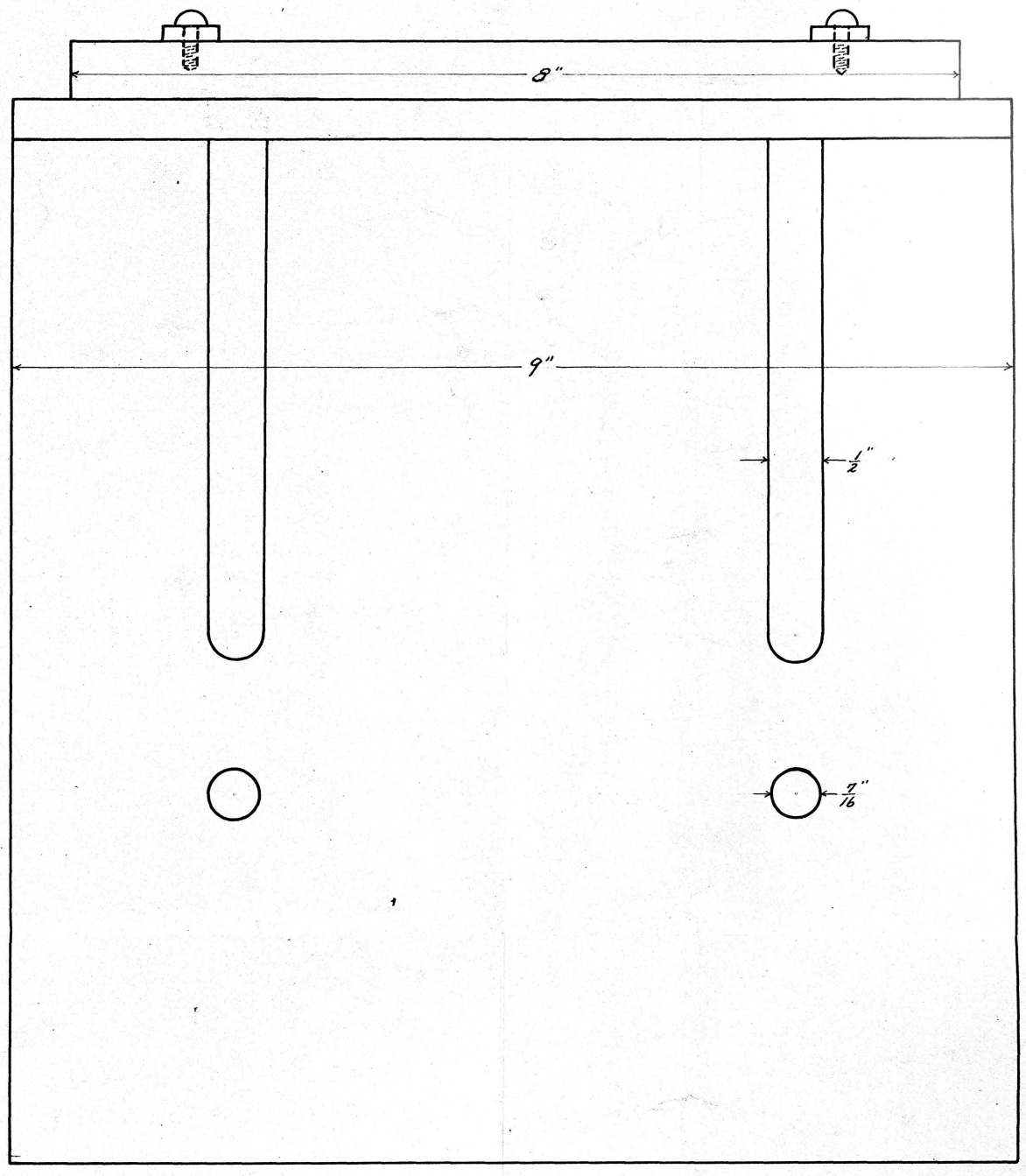


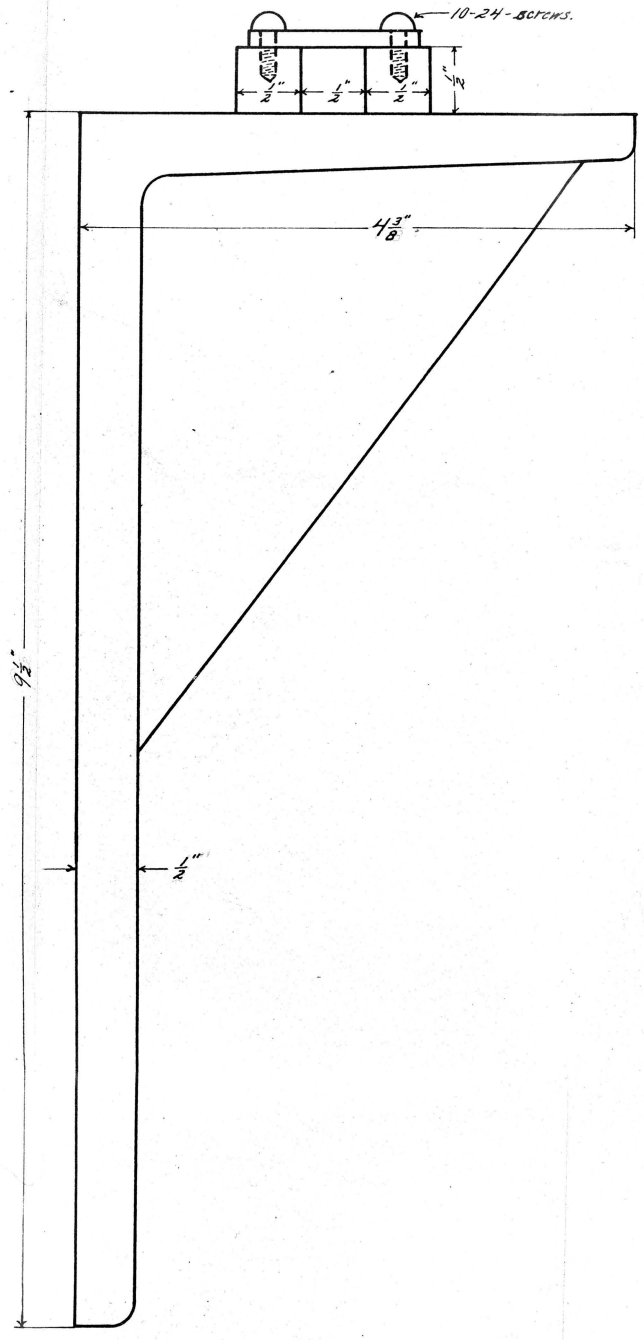




REDUCING MOTION FOR GAS ENGINE

Scale: Full Size.





REDUCING MOTION FOR GAS ENGINE

Scale :; Full Size.