Gasoline Engine Economy as Affected by the Time of Ignition

by George Jay Hopkins

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Submitted to the University of Kansas in partial fulfillment of the requirements for the Degree of Bachelor of Science

GASOLINE ENGINE ECONOMY

as Affected by

the Time of Ignition.

A Thesis

Submitted to the Faculty of the

University of Kansas

by

George Jay Hopkins,

For the Degree of B.S. in Mechanical Engineering.

Lawrence 1907

The author desires to make grateful acknowledgment of the friendly aid and advice of Professor P. F. Walker M.M.E., Professor of Mechanical Engineering at the University of Kansas, to which much of the value of this work is due.

Thanks are also due Mr. William Neville, M.S., who worked with the author during the preparation of their theses.

G. J. Hopkins.

Lawrence, Kansas.
June 1, 1907.

Gasoline Engine Economy as Affected by Time of Ignition.

In the face of the conclusions arrived at by almost every manufacturer of internal combustion engines, the value of such a discussion as this might be questioned by the casual observer. But the vagueness in the practice of adjusting the ignition apparatus, and the divergence of opinions as to the effect of speed and mixture on the time allowed for lead, made it evident that more refinement in this line is not only possible, but in most cases profitable.

Considering the almost infinite variety of uses to which the internal combustion engine is put, it is manifestly impossible to set any one angle of advance, at which the maximum economy will be obtained in all cases. The field of investigation, therefore, is as broad as there is variety of engines, but we have limited this to a certain extent by assuming a definite fuel, and attempting to deal only with gasoline.

That the breadth of the subject is still considerable, is seen from the fact that in 1903, after running under approximately the same conditions-- a series of 346 tests covering a period of six years, Prof. Robertson, lately of Purdue University, withheld data for further consideration, from his article in the Transactions of the American Society of Mechanical Engoneers Vol. 24, Page 1097. (Prof. Robertson used Natural gas instead of gasoline.)

In this article he has considered the following variables;-- speed, load, point of ignition, mixture and jacket temperature. Considering any three of these five fixed, the other two will be inter-dependent. In view of this sensitiveness of one variable to changes of any other, it is fortunately possible to set the load somewhere near the engine's rating, and the jacket temperature between limits found common in practice, without materially narrowing the field of investigation, and at the same time effect a great saving in the labor of collecting data.

In justification of this, it is evident that if a number of values be taken for any variable, the series, to be complete, must be entirely repeated for each value, changing each of the other conditions in order, thus multyplying the work in direct proportion to the number of values taken for any variable.

The point of view during this investigation has been at all times merely a financial one and consequently the curves will be found to relate to the gasoline consumption per unit of power. For the same reason, that is, to make the results commercially useful and comparable to usual practice, the running conditions have been kept as near those ordinarily surrounding actual running engines, and as constant as possible.

The engine used is one installed in the mechanical laboratory of the University of Kansas;-- a seven by ten "Olds", rated at eight H.P. at a speed of about 300 R.P.M.

It's equipment is the same as that supplied commercially and of which the description follows, except that three heads were supplied for the cylinder to give 60, 80, and 100 pounds compression respectively. However, it was found impossible to use any but the lowest for gasoline without serious pre ignition backfiring, though the engine ran well at 100 pounds on natural gas. (Almost pure CH_4 in this region.)

The valve mechanism, to which the explosion counter is attached, is controlled by the governor which holds open the exhaust valve and closes the intake during miss shots. The effect of this will be noticed on some of the cards. The cylinder being better scavenged the mixture was cooler and perhaps somewhat leaner,--due in part to the lag of the fuel valve after being allowed to seat,- and consequently slower burning and less powerful, giving both an inclined explosion line and reduced area.

The exhaust temperature was taken in the line from an auxiliary exhaust port consisting of four 3/8" holes situated near the end of stroke and communicating with the muffler through a pad connection screwed to the side of the cylinder.

Both intake and exhaust valves are of the "mushroom" type, the intake being automatic. The gasoline valve is of the plain needle variety, having on the same stem, a light screen which is acted upon by the inrushing air to lift the valve from its seat. It's lift is adjust able by a threaded sleeve and lock nut. The position of which was indicated by numbers stamped on the faces of the nut.

The ignition is accomplished by a mechanically operated break spark device, the points of which are pushed together and released, when they immediately fly apart under the action of a strong coil spring.

The ignition apparatus is situated in the top of the valve chamber, which is bolted to the side of the cylinder opposite the auxiliary exhaust. Current was supplied through a spark coil by a set of six dry batteries, which being used but once a week, gave an almost constant current of six amperes and nine volts.

The load was applied by an interchangable rope prony brake fitted to either one of the fly wheels, and read by a platform scale. A constant pressure of 70 pounds was maintained, resulting, at an arm of 1.83 feet in a load of about three fourths rating except in the case of varying speed when it became necessary to change the load to keep the power constant.

The indicated power was recorded by a Crosby Indicator using a 300 pound spring and actuated by a light wooden reciprocating device connected to a small crank on the end of the shaft. The speed was taken with a revolution counter.

The inclosed diagramatic sketch will give an idea of the arrangement of apparatus and manner of carrying out tests.

A small high speed steam engine connected to a three foot fan blower was used to drive air into the large tanks to the right, through the valve system shown. They have a capacity of something more than 100 cubic feet each, and are controlled by a set of valves arranged to allow the contents of one to be used while the other is being filled. (In the sketch the tank X is rising while Y is supplying the engine; the crossed valves being closed.)

They were both weighted to a pressure of 3 inches of water and the air used by the engine was measured by taking the difference of the readings of the pointer P before and after emptying. The cord being connected in the center of the tank reads accurately, regardless of tilting.

The regulator illustrated, was interposed to approximate the condition of constant air supply. Its action is as follows: the part A, floating up under the influence of the air from the large tank, raises the lever L which closes the cock C, shutting off the inflow, thus regulating the pressure with reasonable accuracy since A has a content of about five cubic feet and the cylinder much less than one.

The thermometer, T_1 gave the temperature of the incoming air while the exhaust temperature was taken after it has expanded to atmospheric pressure in a chamber of brick laid up loosely.

The temperature of the discharged jacket water was read at T. (much difficulty was experienced in keeping this constant, but an attempt was made to average about 150). Another thermometer was used to measure its incoming temperature, and the discharge was caught in a calibrated tank and its weight read.

The calibrated glass jar, G, contains the gasoline, which is automatically pumped up and returned through an overflow; evaporation being prevented by a tight stopper, perforated to receive the pipes.

All readings, including indicator cards, but excepting jacket water were taken at 5 minutes intervals. Most of the runs were of 20 minutes duration. Care was taken, however, to get all running conditions constant before starting any test, and since facilities were at hand for doing this as perfectly as possible under any conditions, the short tests have been given the same value as longer ones. Indeed, long duplicates of short tests have given quite uniform results.

Three persons were necessary to run a test, since one man's time was almost wholly occupied with the tanks and steam engine.

The observations made were:

1 Speed

2 Load

3 Explosions per min.

4 Gasoline valve setting

5 Angle of ignition advance

6 Amount of air (cu.ft.)

7 Amount of Fuel (pts)

8 Temp. entering jacket water

9 Temp. leaving jacket water

10 Weight jacket water

11 Indicator cards and

12 Barometer.

From this data it is possible to make a complete mechanical and thermal analysis of the engine's performance.

In this paper, however, only the following quantities have been calculated:

1 Gasoline per B.H.P. per hour

2 Gasoline per I.H.P. per hour and

3 Ratio of Air to fuel, by weight, in the mixture

Curves have been plotted showing:

I. Variation of fuel consumption per I.H.P. per hour with various angles of advance:-- at two constant sp speeds.

II. Same per B.H.P.

III. Variation of fuel consumption with varying mixture, the angle of advance being held constant:- for 3 angles. The constants and formulae used in calculating these are as follows,

I.H.P. = .000918 X M.E.P. X Explosions P.M.

B.H.P. = .02238 X R.P.M. (at 70 pounds brake load)

B.H.P. = .01753 X R.P.M. (at 55 pounds brake load)

One pint of gasoline weighs .77067 pounds.

For the weight of one cubic foot of air the following formulae from Kent's hand book was used; $W = \frac{1.3253 \text{ X Barometer}}{459.2 + \text{Temperature}}$; but since the barometer varied so slightly, its average, 28.8" was taken for all cases.

The average of the shots in a Parr Calorimeter gave a heat value of 19,300 British Thermal Units per pound of the gasoline used. The samples were taken at various times during the time occupied by the tests and the quality ran very constant.

Conclusions.

Series A, being first and containing a large number of tests, occupied more time than all the other series attempted. This would not have been true, but for the fact that in repeating some of the runs that looked doubtful when plotted, it was noticed that the points were coming quite regularly higher, which necessitated an entire repetition of the series. Both curves are given, as there appeared no way of deciding that either one was better than the other. The logical conclusion seems to be that the conditions of the engine changed between the first running of the test and its repetition, so as to require a greater consumption of gasoline.

Although a slight difference seems to exist between the shape of the B.H.P. and I.H.P. curves both show a minimum of consumption between 11° and 13° for 305 R.P.M.

Series B.C. and D. were run under the belief that the mixture might be made so lean that the increased number of shots resulting would result in an actual increase of fuel consumption, or in other words that the mixture curves would rise. But during this series this condition was not attained, and it seems that in this engine the leanest mixture that will run well, is the most economical.

Series F.- A consideration of the data of these runs shows only what every engineer knows: that the efficiency of a gas engine varies with the compression. Since the engine would not run at 100# compression, only two points were possible and it was not thought worth while to plot these.

Series G. corresponds to Series A except in speed, which was 350 R.P.M. The curves have about the same shape but the minimum point comes a little above 17°. More points would have made this curve more complete but lack of time prevented.

Series A.

Compression 60# except where noted, in all following-

1	No. of Test	1	1 a	1 b	1 c	1 d	2	3 a
2	Duration-Min.	10	20	20	20	20	15	30
3	Ignition Angle of Advance	14.8	14.8	14.8	14.8	14.8	14.8	17.3
4	Jacket Water pds.	245	129	133	137	135	120	196
5	Temper-atures Air	81	81	82	82	86.5	82	90
6	Temper-atures Exhaust	—	—	180(?)	183	172	181	258
7	Temper-atures Jacket Water In	53	57	57	54	58	53	56
8	Temper-atures Jacket Water Out	147.3	154.6	146	149.6	145	151.2	152
9	Total Explosions	1138	2302	2311	2169	2255	1580	3421
10	Explosions per minute	113.8	115.1	115.56	108.45	112.75	106	114
11	M.E.P.	83.3	82	83.4	87.2	75.6	82.9	79.51
12	I.H.P.	9.1	8.53	9.27	9.1	8.25	8.454	8.719
13	R.P.M.	306.5	306.5	304.75	295.25	307	304	304.3
14	B.H.P.	6.86	6.86	6.82	6.6	6.87	6.8	6.80
15	Total Air Cubic Ft.	—	381	381	—	393	355	557
16	Total Gasoline pts.	1.00	3.61	3.64	3.53	3.44	2.15	5.10
17	Mixture Ratio (Air/Fuel)	—	9.67	9.57	—	9.7	14.8	8.45
18	Pts. per I.H.P. per Hr.	.66	1.27	1.178	1.163	1.253	1.02	1.17
19	Pts. per B.H.P. per Hr.	.87	1.58	1.60	1.605	1.503	1.265	1.503
20	Pts. per Explosion	.000878	.00157	.00157	.00163	.001525	.00135	.00149
21	Setting of Fuel Valve							

Brak-load 70# Gasoline Valve 7

1	3 b	3 c	3 d	4	4 a	4 b
2	25	20	20	15	20	20
3	17.3	17.3	17.3	20.2	20.2	202
4	160	155	125	90	137	135
5	81	86	87	81	80	86.3
6	185	158	191	205	150 (?)	174.7
7	60	58	57	53	57	58.3
8	150.5	141.4	157.6	147.5	145.8	146.4
9	2711	2275	2305	1609	2279	2286
10	108.4	113.75	115.2	107.3	114	114.3
11	79.5	77.8	72	79.5	81.25	77.8
12	8.3	8.52	8.07	8.206	8.37	8.56
13	299	305	307	256	307.25	307
14	6.69	6.83	6.87	5.73	6.87	6.87
15	438	391	377	233	397	411
16	4.18	3.45	3.73	2.35	3.52	3.49
17	8.05	8.58	7.65	9.2	10.38	10.7
18	1.206	1.216	1.386	1.16	1.26	1.222
19	1.478	1.517	1.63	1.64	1.54	1.524
20	.00149	.00152	.00162	.00146	.00155	.001526

Series A.

1	4 c	5	5 a	5 b	6	6 a
2	20	15	15	20	25	30
3	20.2	13	13	13	10.3	10.3
4	150	88	123	128	153	214
5	85.5	87	76	85.5	81.6	84.3
6	190	215	262	166 (?)	223	219.7
7	57	60	54	62	56	59.5
8	150	160	136.2	152	151	145
9	2349	1640	1671	2277	2874	3407
10	112.45	109.3	111.4	114	115	113.6
11	72.8	81	82.7	74.8	78.83	79
12	8.23	8.5	8.86	8.2	8.71	8.41
13	307	2977	301.3	306.6	298	304.3
14	6.87	6.66	6.74	6.86	6.67	6.80
15	383	—	251	385	—	562
16	3.77	2.45	2.53	3.58	4.4	5.1
17	9.00	—	9.2	9.76	—	10
18	1.374	1.15	1.43	1.3	1.21	1.2
19	1.646	1.47	1.5	1.55	1.58	1.503
20	.001605	.001495	.00157	.00157	.00153	.0015

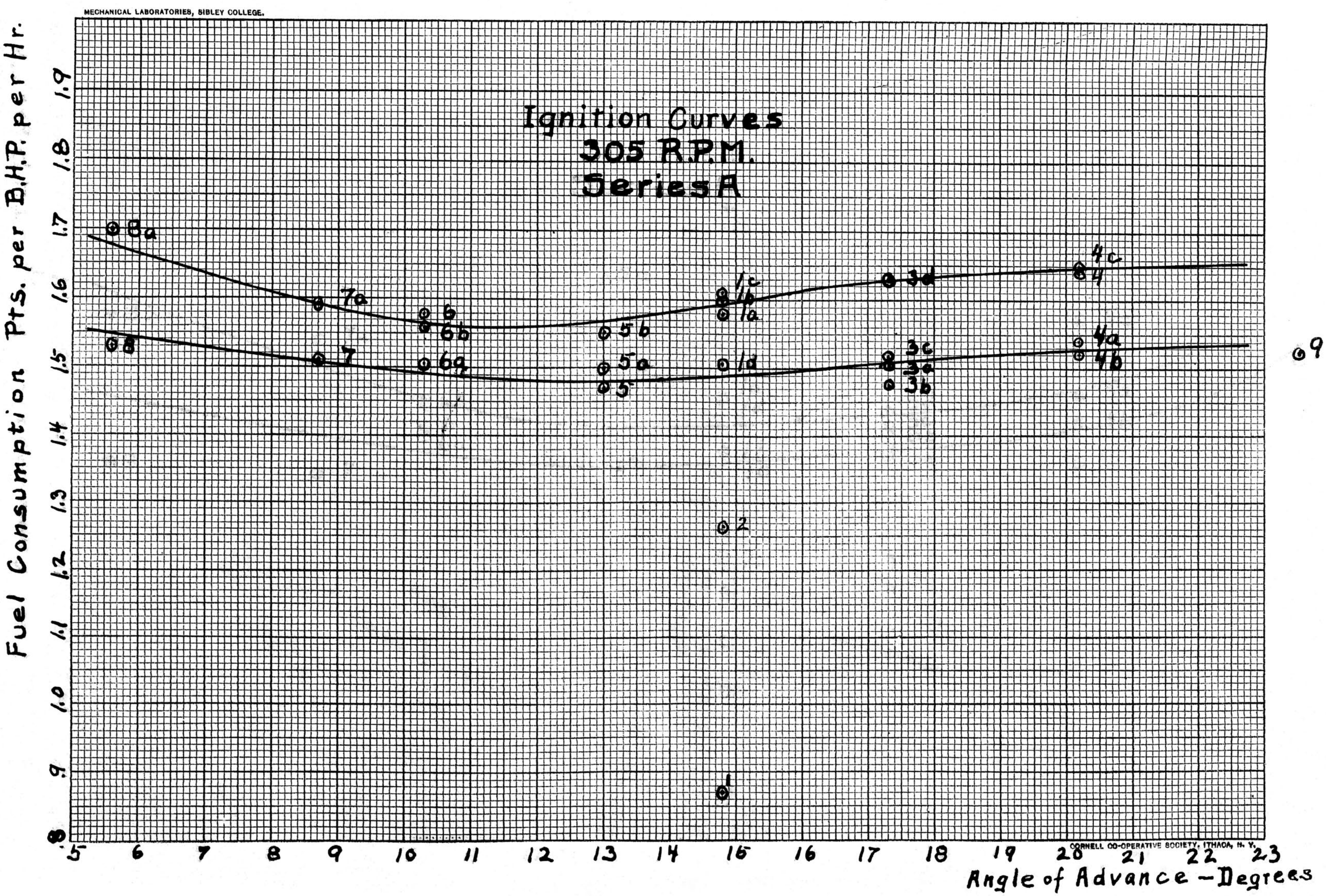
1	6 b	7	7 a	8	8 a	9
2	20	30	20	20	20	20
3	10.3	8.7	8.7	5.6	5.6	23.8
4	140	320	122	145	135	160
5	86	75	85.3	76	88	87
6	190	260	194	269	198	195
7	59.5	54	58.5	56	57	57
8	142.6	136.1	149.8	149.5	148.4	147.8
9	2291	3409	2329	2308	2369	2269
10	114.5	113.6	116.4	115.4	118.4	113.5
11	78.6	82.1	73	80.8	74.6	73.2
12	86.05	8.97	8.18	8.97	8.5	8
13	307.75	304	307	304.5	307.5	307.75
14	6.88	6.8	6.87	6.81	6.88	6.88
15	408	553	393	—	398	—
16	5.59	5.14	3.66	3.47	3.9	3.5
17	6.65	9.95	9.75	—	9.43	—
18	1.244	1.145	1.34	1.16	1.376	1.313
19	1.56	1.51	1.596	1.53	1.70	1.525
20	.00175	.00151	.00157	.001605	.00164	.00154

	Series B				Series C	
1	1	2	3	4	1	2
2	20	20	15	20	20	20
3	13	13	13	13	14.8	14.8
4	143	133	128	128	130	134
5	76	78.5	72.6	85.5	78.3	81
6	190	211	208	166 (?)	212	223
7	55	55	66.5	62	55	55
8	151.8	154.2	151.5	152	152.2	153
9	2305	2348	1929	2277	2320	2374
10	115,2	117.4	128.6	114	116	118.7
11	75.2	78	76.75	74.8	76.4	77.4
12	8.32	8.82	9.495	8.2	8.63	8.84
13	308.25	308.75	307.6	306.6	309.25	308.75
14	6.91	6.92	6.88	6.86	6.92	6.92
15	367	388	299	385	390	384
16	3.2	2.84	2.02	3.58	2.78	2.71
17	10.6	12.6	13.7	9.76	12.6	13.1
18	1.153	.96	.852	1.3	.978	.92
19	1.39	1.23	1.175	1.55	1.205	1.175
20	.00139	.00121	.00105	.00157	.00120	.00114
21	6	5.75	5		5.75	5.33

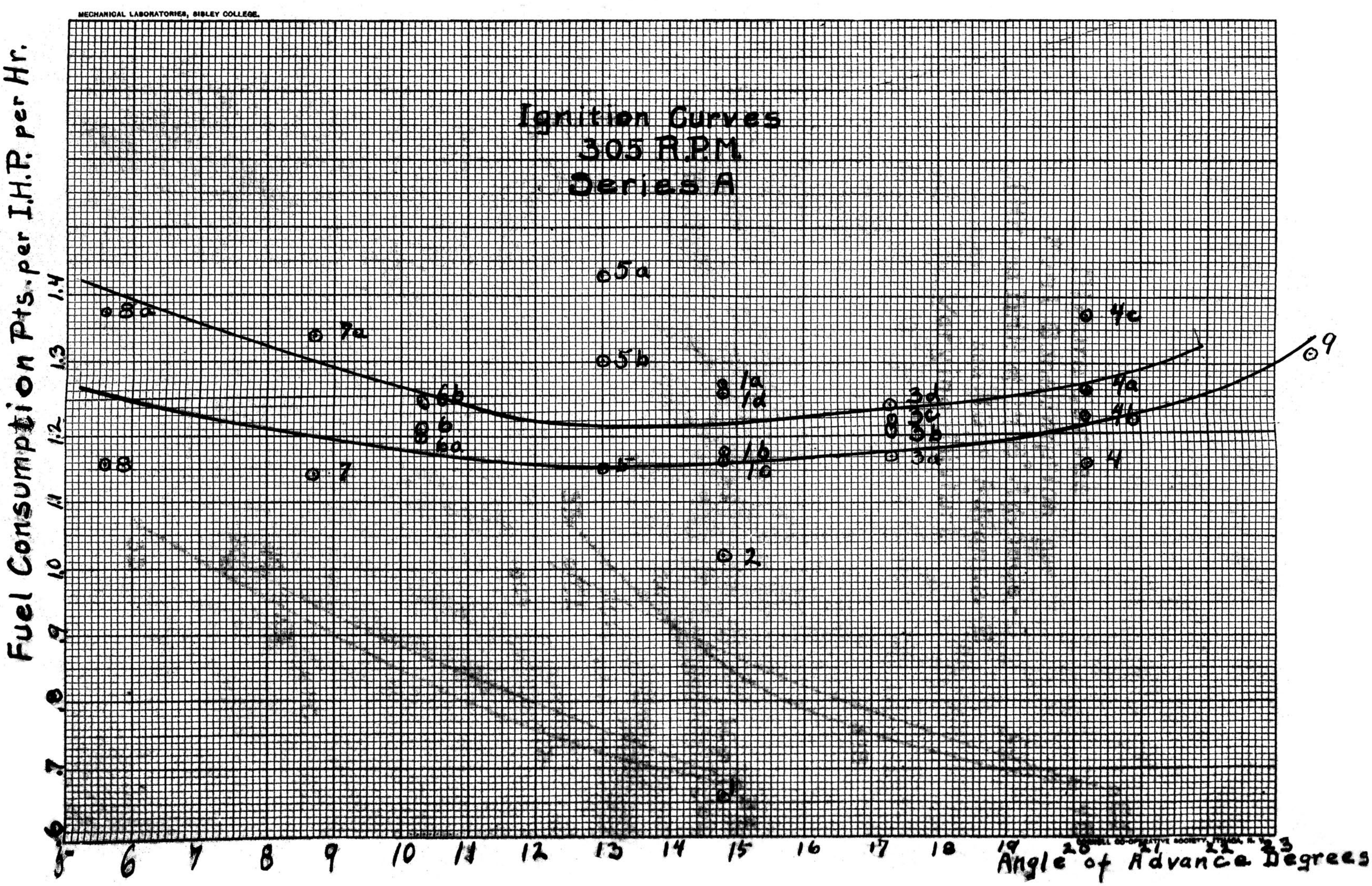
Varying Mixture Series D.

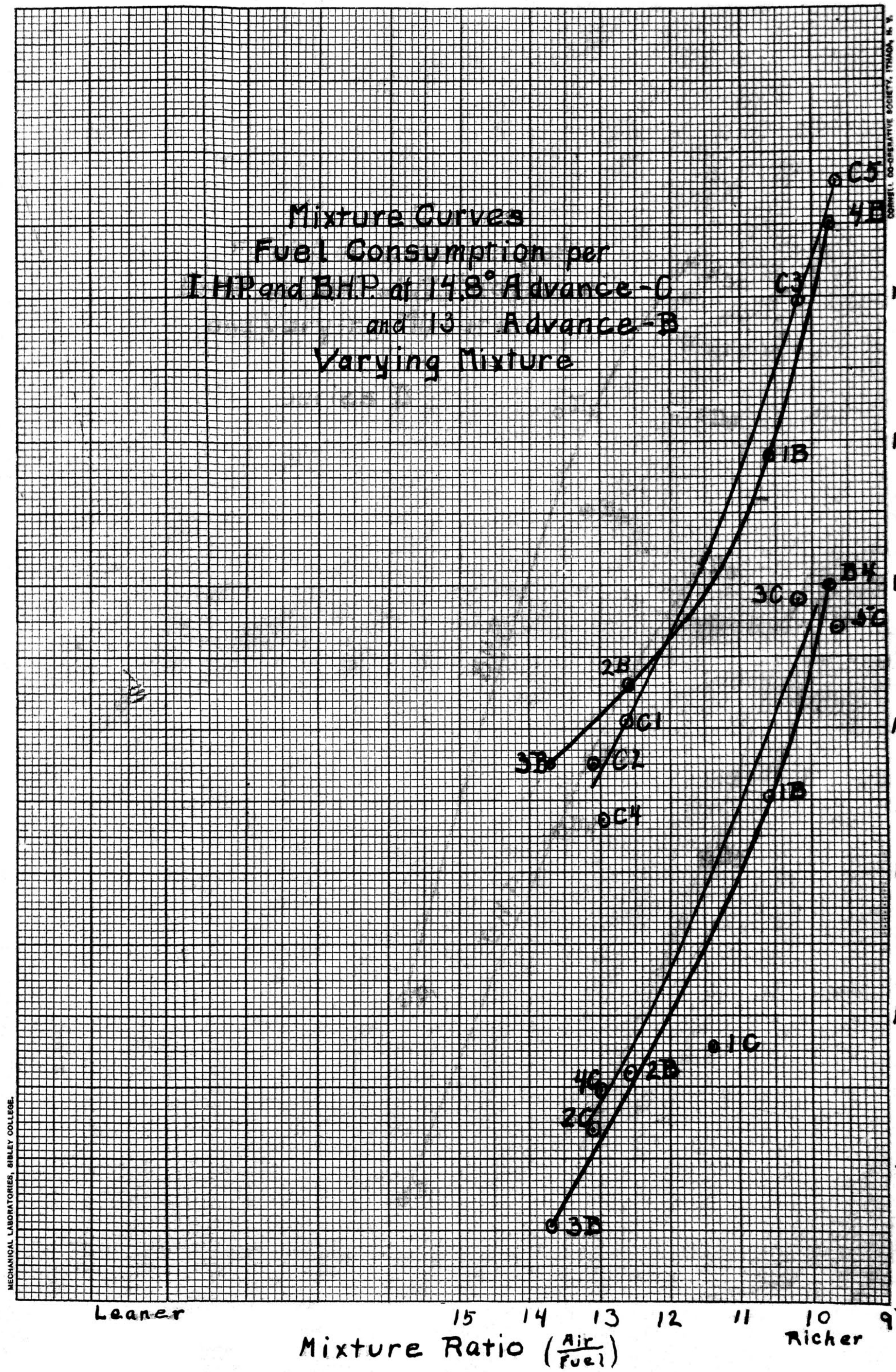
1	3	4	5	1	2	3	4
2	20	20	20	20	20	20	10
3	14.8	14.8	14.8	17.3	17.3	17.3	17.3
4	140	142	129	135	139	126	—
5	98	101.5	81	101.7	101	100	73.3
6	197	227	—	227.7	226.2	225	204
7	69	69.3	57	70	70	69.7	61.6
8	158.2	162.2	154.6	166	160	162.2	144
9	2348	2427	2302	2339	2352	2381	1143
10	117.4	121.3	115.1	117	117.6	119	114.3
11	71	71	82	71	69.8	70.8	77.33
12	8.03	8.29	8.53	8.88	7.88	8.1	8.61
13	308.8	308.75	306.5	309.75	309.3	310	310.6
14	6.92	6.92	6.86	6.93	6.92	6.95	6.95
15	387	387	381	376	387	372	201
16	3.38	2.62	3.61	2.59	3.35	3.81	1.76
17	10.2	13.12	9.67	12.8	10.2	8.65	10.6
18	1.29	.948	1.27	.972	1.277	1.41	1.225
19	1.495	1.137	1.58	1.12	1.452	1.65	1.52
20	.00144	.00108	.00157	.00111	.00406	.0016	.00154
21	6.25	5.75	—	—	6	6.75	6.33

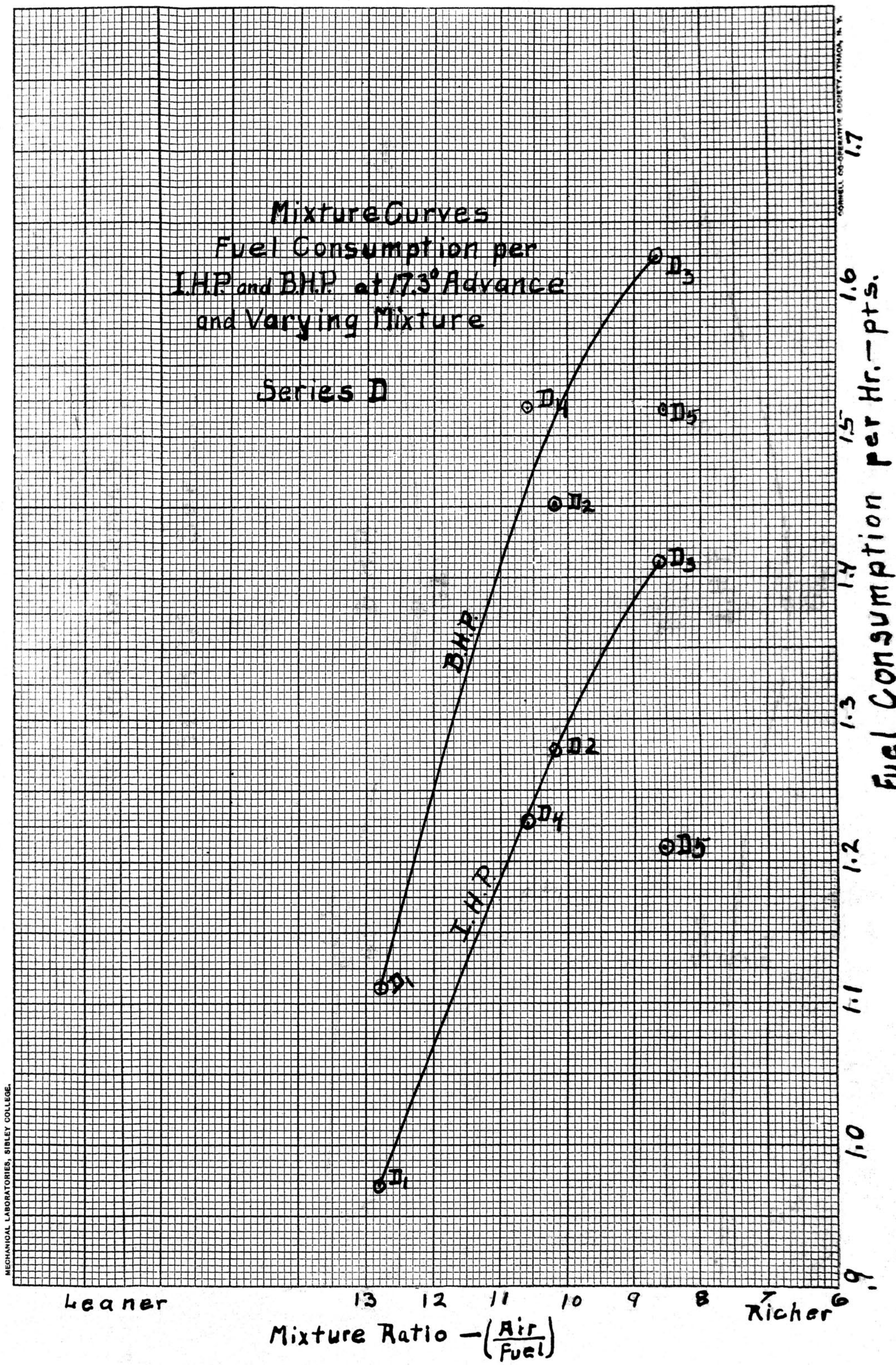
	Series D	Series F 80# compression		Series G Gasoline valve 5.5 Brake load 55# Comp. 60#				
1	5	1	2	1	2	3	3a	4
2	20	20	20	20	20	15	15	15
3	17.3	14.8	14.8	13	17.3	14.8	14.8	2.02
4	155	130	142	166	132	108	100	105
5	86	77	1015	73.2	84	83	83	83
6	158	223	227	221	211	213	224	229
7	58	71	69.3	61	62.5	60	60	60
8	141.4	156.8	162.2	146.8	151.6	147	146.7	147.7
9	2275	2541	2427	2569	2470	1884	1882	1856
10	113.75	127	121.3	128.4	123.5	126.2	126.1	123.7
11	77.8	70.6	71	75.2	75	73	71	69.7
12	8.52	8.48	8.29	9.29	8.91	8.86	8.61	8.29
13	305	307	308.75	343.2	344.2	342.6	344	246.3
14	6.83	6.82	6.92	6.02	6.05	6.01	6.04	6.08
15	391	420	388	310	360	266	271	263
16	3.45	2.38	2.62	3.68	3.47	2.75	2.72	27
17	8.58	16.3	13	7.85	9.44	9.74	9.1	8.9
18	1.216	.842	.948	1.19	1.17	1.24	1.265	1.303
19	1.517	1.04	1.137	1.835	1.725	1.83	1.84	1.78
20	.00152	.000937	.00108	.00143	.001405	.00146	.001445	.001456
21		4.33	5.75					



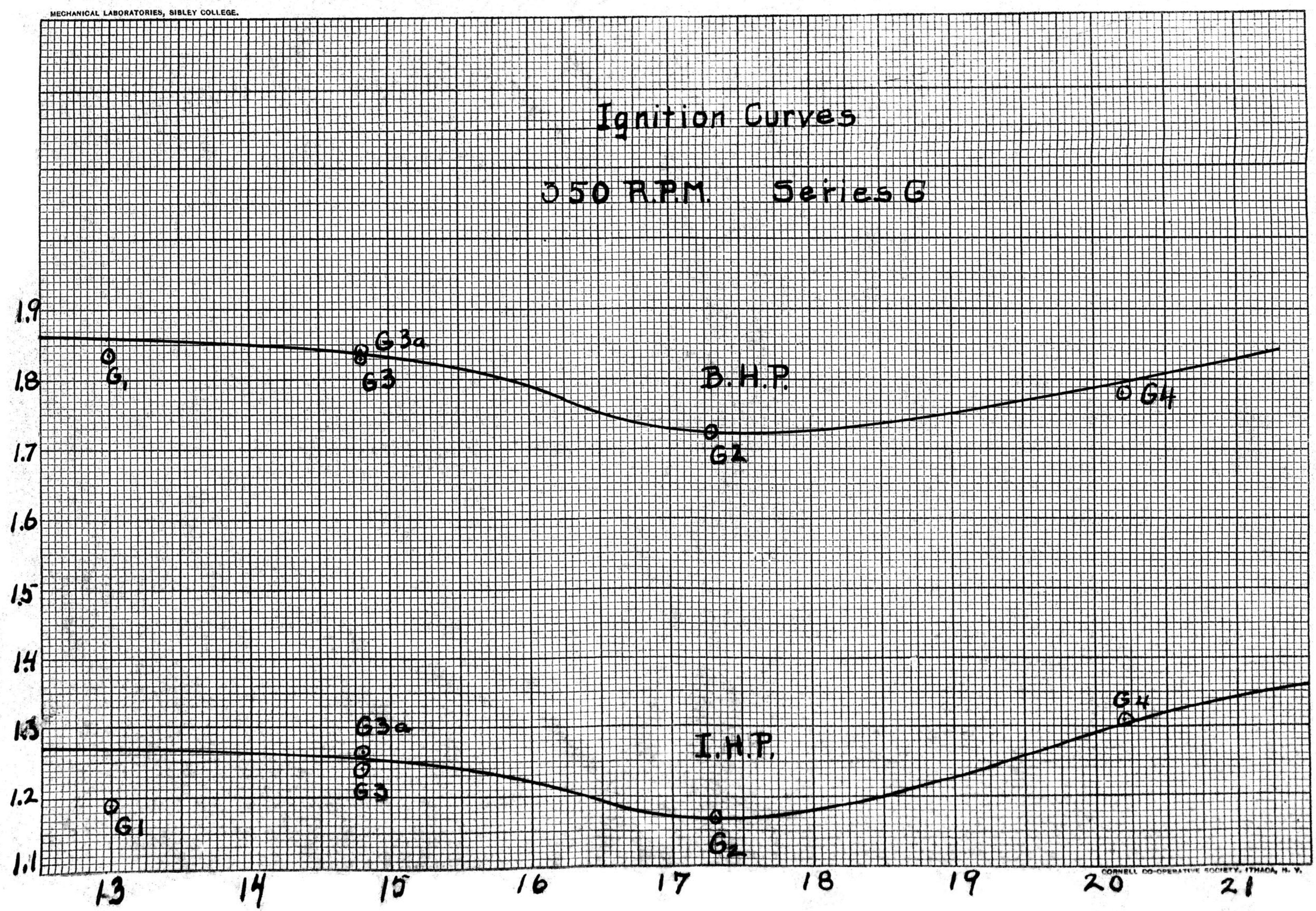
MECHANICAL LABORATORIES, SIBLEY COLLEGE.
Ignition Curves
305 R.P.M.
Series A
Fuel Consumption Pts. per B.H.P. per Hr.
Angle of Advance — Degrees
CORNELL CO-OPERATIVE SOCIETY, ITHACA, N. Y.

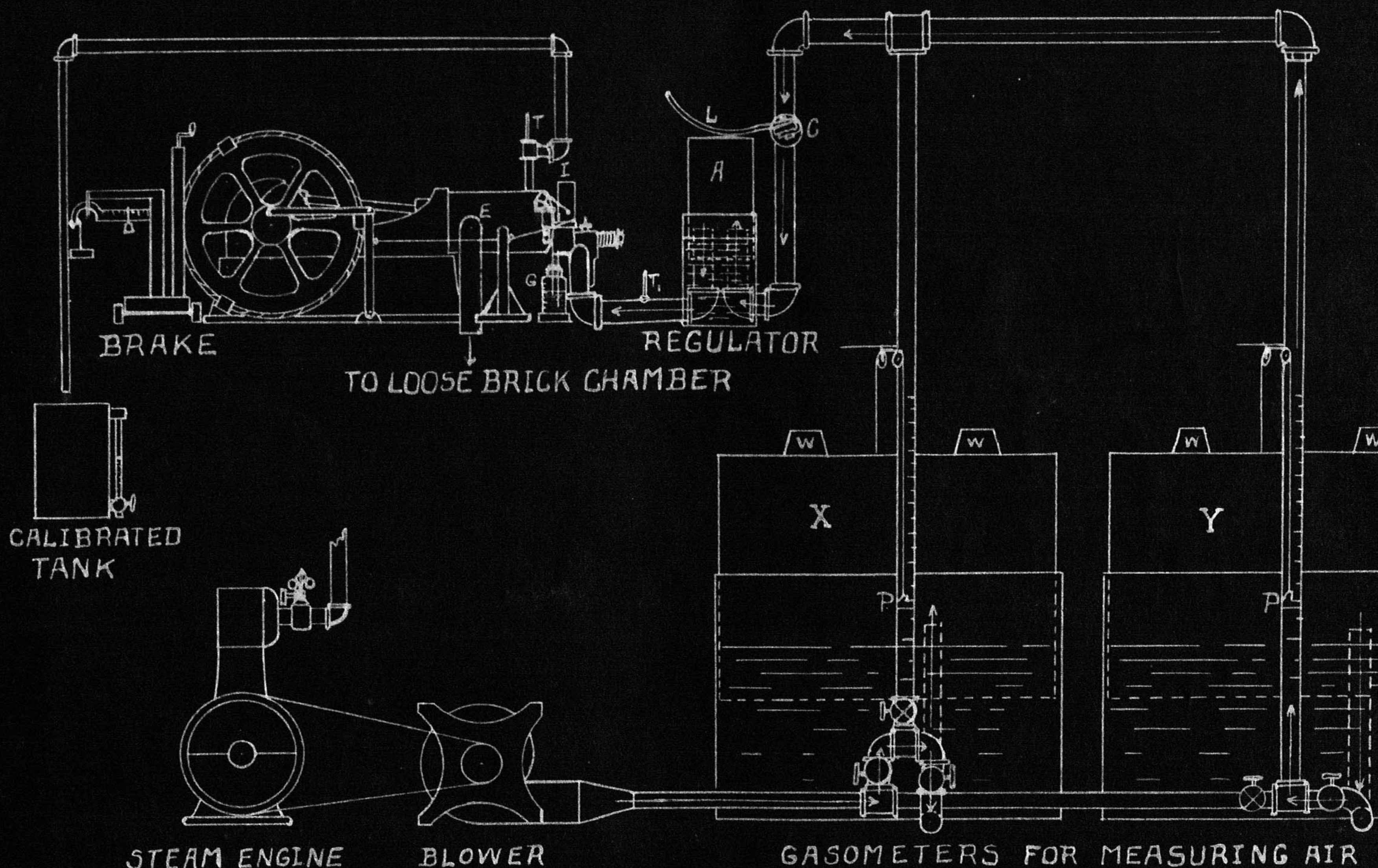

MECHANICAL LABORATORIES, SIBLEY COLLEGE.
Ignition Curves
305 R.P.M.
Series A
Fuel Consumption Pts. per I.H.P. per Hr.
Angle of Advance Degrees
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
8a
7a
5a
5b
6b
6a
7
8
5
2
4c
4a
4b
4
9
3a
3b
3c
3d
1a
1b
1c
1d


Mixture Curves
Fuel Consumption per
I.H.P. and B.H.P. at 14.8° Advance - C
and 13 Advance - B
Varying Mixture
Fuel consumption per Hr. - pts.
Mixture Ratio (Air/Fuel)
Leaner
Richer
15
14
13
12
11
10
9
1.5
1.4
1.3
1.2
1.1
1.0
.9
B
C5
4B
C3
1B
B4
3C
4C
2B
C1
3B
C2
C4
1C
4C
2C
3B
MECHANICAL LABORATORIES, SIBLEY COLLEGE.
CORNELL CO-OPERATIVE SOCIETY, ITHACA, N. Y.



Mixture Curves
Fuel Consumption per
I.H.P. and B.H.P. at 17.3° Advance
and Varying Mixture
Series D
B.H.P.
I.H.P.
D1
D2
D3
D4
D5
Fuel Consumption per Hr. – pts.
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
Leaner
13
12
11
10
9
8
7
6
Richer
Mixture Ratio – (Air/Fuel)
MECHANICAL LABORATORIES, SIBLEY COLLEGE.
CORNELL CO-OPERATIVE SOCIETY, ITHACA, N. Y.


MECHANICAL LABORATORIES, SIBLEY COLLEGE.
Ignition Curves
350 R.P.M. Series G
B.H.P.
I.H.P.
G1
G3a
G3
G2
G4
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
13
14
15
16
17
18
19
20
21
CORNELL CO-OPERATIVE SOCIETY, ITHACA, N. Y.



APPARATUS for TESTING INTERNAL COMBUSTION ENGINE

HOPKINS' and NEVILLE'S THESES

UNIVERSITY of KANSAS - 1907

Sample Cards

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2 ... REVS. PER MIN. ...

Taken ... SCALE ... 3 [illegible]

By ... Piston Diameter ...

At 3:37 ... Piston Stroke ...

Which Engine ... Piston Speed ...

Which Cylinder ... Piston Area ...

Which End ... Engine Constant ...

BOILER PRES ... lbs. gage Diagram Area ...

Pres. in Receiver ... M. E. P. 83

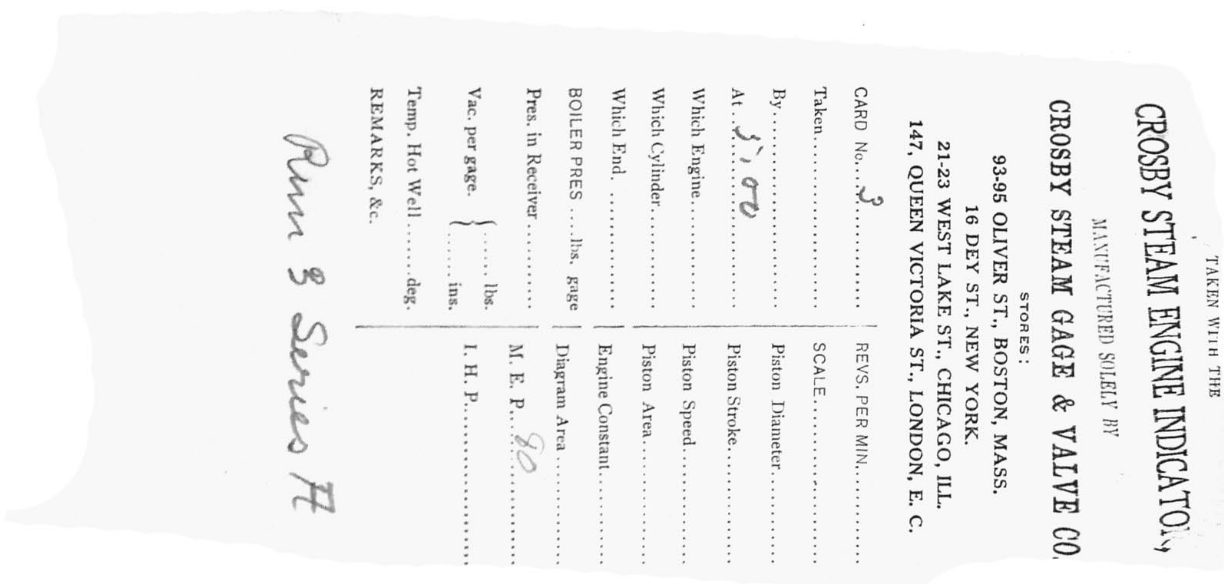
Vac. per gage. { ... lbs. / ... ins. } I. H. P. ...

Temp. Hot Well ... deg.

REMARKS, &c.

2nd chuff #1

Run #1 Series A



TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3 ... REVS. PER MIN. ...

Taken ... SCALE ...

By ... Piston Diameter ...

At 3:00 ... Piston Stroke ...

Which Engine ... Piston Speed ...

Which Cylinder ... Piston Area ...

Which End ... Engine Constant ...

BOILER PRES ... lbs. gage Diagram Area ...

Pres. in Receiver ... M. E. P. 80

Vac. per gage. { ... lbs. / ... ins. } I. H. P. ...

Temp. Hot Well ... deg.

REMARKS, &c.

Run 3 Series A

Run #3 Series A

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 2-27	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 82
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Dupl #4 S-A

Run #4 Series A

F 374: L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 12.05½	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 78
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Dupl #5 S-A

Run #5 Series A

F 374: L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 1	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 3 - 2	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 78
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

#6 A

Run #6 Series A

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 10, 23	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P.
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

#7 Series A

Run #7 Series A

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 11:13 –	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 81.6
Vac. per gage. { ....lbs. / ....ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

#8 Series A

Run #8 Series A

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 9	REVS. PER MIN.
Taken	SCALE
By	Piston Diameter
At 6:02	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 49.75
Vac. per gage. { ....lbs. / ....ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run #9 Series A'

Run #9 Series A

Run #1 Series B

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 1	REVS. PER MIN.
Taken	SCALE 3[illegible]
By	Piston Diameter
At 2'28	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 7873
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run #2 Series B

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2	REVS. PER MIN. 309
Taken	SCALE
By	Piston Diameter
At 3'08	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 80#
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P. 48
Temp. Hot Well ....deg.	
REMARKS, &c.	

#2 Series B

Run #1 Series C

F 374: L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 4.33	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 81.76
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 1
Series C

Run #3 Series B

F 374: L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 9.38	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 75-
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 3
Ser B

Run#3 Series C

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 4	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 1.1.17	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 72
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 3
Series C

Run#2 Series C

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 5.1.11	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. ~~82~~ 77
Vac. per gage. { ...... lbs. / ...... ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run - 2
Series C

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 4	REVS. PER MIN.
Taken	SCALE 3.0
By	Piston Diameter
At 1.150	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 71
Vac. per gage. ......lbs. ......ins.	I. H. P.
Temp. Hot Well ......deg.	
REMARKS, &c.	

Run 4
Seri C

Run #4 Series C

F 374: L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.

16 DEY ST., NEW YORK.

21-23 WEST LAKE ST., CHICAGO, ILL.

147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 4	REVS. PER MIN.
Taken	SCALE 30
By	Piston Diameter
At 21.35	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 70
Vac. per gage. ......lbs. ......ins.	I. H. P.
Temp. Hot Well ......deg.	
REMARKS, &c.	

Run 1
Series D

Run #1 Series D

Run #3 Series D

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 4	REVS. PER MIN.
Taken	SCALE 302
By	Piston Diameter
At 1.04	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 70
Vac. per gage. { ...... lbs. / ...... ins. }	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run D 3

Run #2 Series D

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2 –	REVS. PER MIN.
Taken	SCALE 302
By	Piston Diameter
At 3.03	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 70
Vac. per gage. { ...... lbs. / ...... ins. }	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 2
Series D

Run #1 Series F

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 4	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 2.20	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 72
Vac. per gage. { ......lbs. / ......ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 1
Ser. ~~D~~ F

Run #4 Series D

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 300
By	Piston Diameter
At 2.34	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 77
Vac. per gage. { ......lbs. / ......ins.	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 4
Ser. D

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 3.00
By	Piston Diameter
At 9.2.1	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ... lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 77#
Vac. per gage. { ... lbs. ... ins. }	I. H. P.
Temp. Hot Well ... deg.	
REMARKS, &c.	

Run 1
Ser G

Run #1 Series G

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 3.00
By	Piston Diameter
At 9.5.3	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ... lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 75#
Vac. per gage { ... lbs. ... ins. }	I. H. P.
Temp. Hot Well ... deg.	
REMARKS, &c.	

Run 2
Ser G

Run #2 Series G

Run #3a Series G

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 3 02
By	Piston Diameter
At 5.45	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 70
Vac. per gage. { ...... lbs. / ...... ins. }	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Dup. - Run 3
Ser. G

Run #3 Series G

F 374; L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 2	REVS. PER MIN.
Taken	SCALE 3 02
By	Piston Diameter
At 5.16	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ....lbs. gage	Diagram Area
Pres. in Receiver	M. E. P. 72#
Vac. per gage. { ...... lbs. / ...... ins. }	I. H. P.
Temp. Hot Well ....deg.	
REMARKS, &c.	

Run 3
Series G

F 3741 L 5-06

INDICATOR DIAGRAM

TAKEN WITH THE

CROSBY STEAM ENGINE INDICATOR,

MANUFACTURED SOLELY BY

CROSBY STEAM GAGE & VALVE CO.

STORES:

93-95 OLIVER ST., BOSTON, MASS.
16 DEY ST., NEW YORK.
21-23 WEST LAKE ST., CHICAGO, ILL.
147, QUEEN VICTORIA ST., LONDON, E. C.

CARD No. 3	REVS. PER MIN.
Taken	SCALE 9 (?)
By	Piston Diameter
At 6.07	Piston Stroke
Which Engine	Piston Speed
Which Cylinder	Piston Area
Which End	Engine Constant
BOILER PRES ... Ex. gage	Diagram Area
Pres. in Receiver	M. E. P. 68#
Vac. per gage ... lbs. ... ins.	I. H. P.
Temp. Hot Well ... deg.	
REMARKS, &c.	

Run 4
Series G

Run #4 Series G.