THESIS

This thesis was contributed by

Mr. S. L. Hall

under the date indicated by the department stamp, to replace the original which was destroyed in the fire of March 5, 1916.

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THESIS

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EFFICIENCY OF A GAS ENGINE AS DETERMINED

by

FUEL MIXTURE AND COMPRESSION

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by

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MICHIGAN STATE COLLEGE

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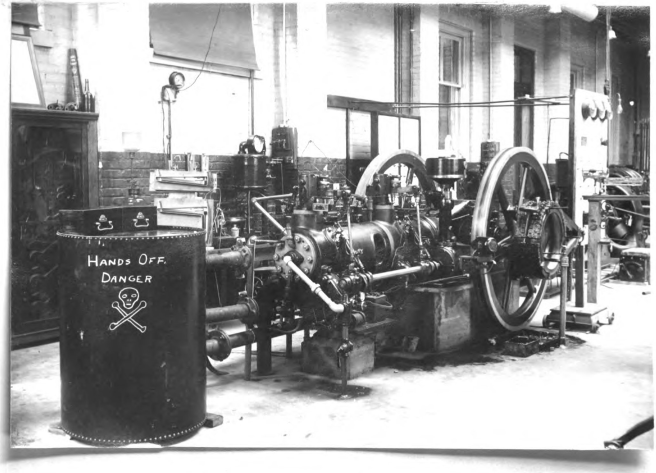

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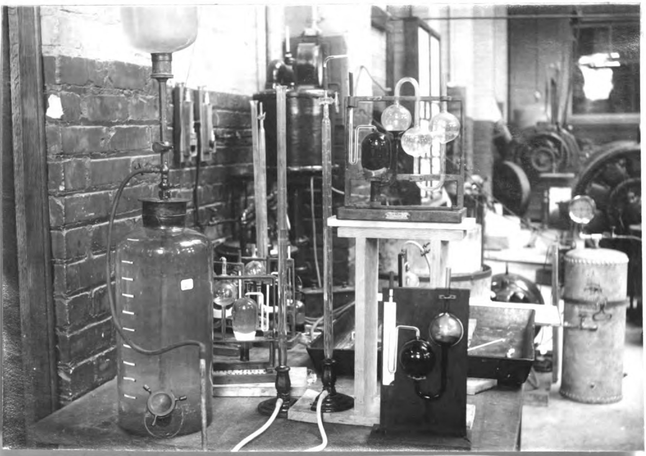

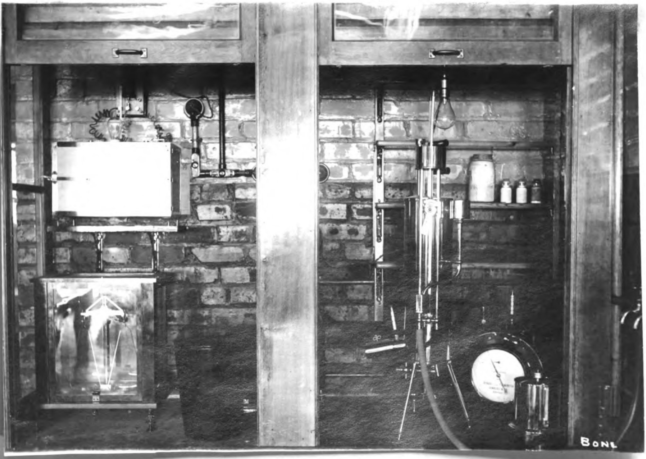
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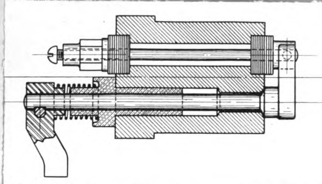

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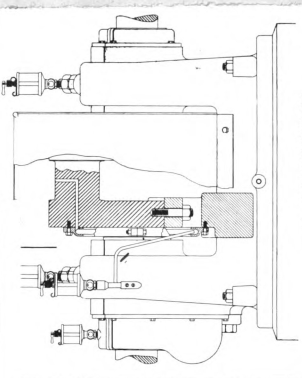
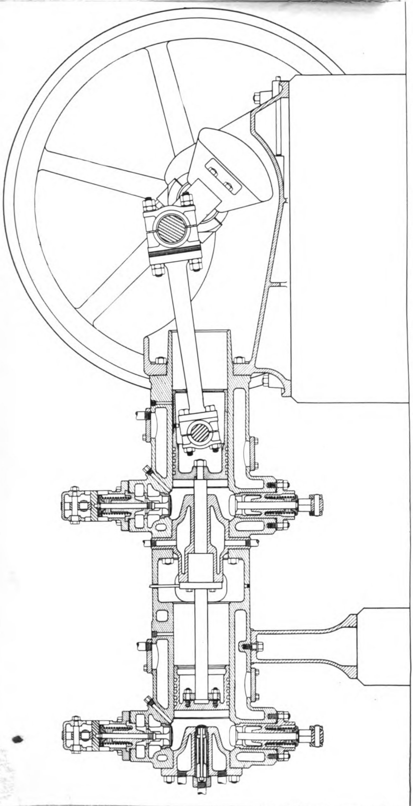
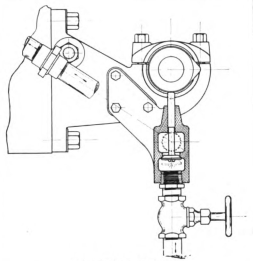
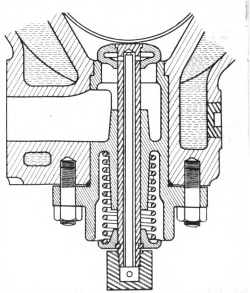




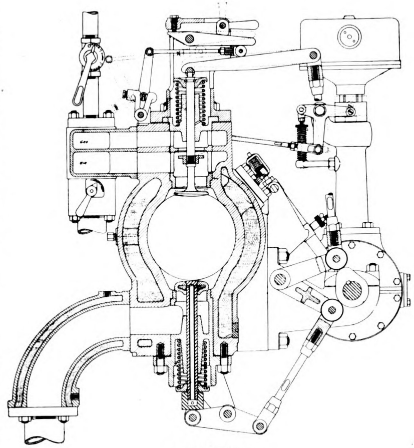
SECTIONAL DRAWING OF NO. 2 ENGINE



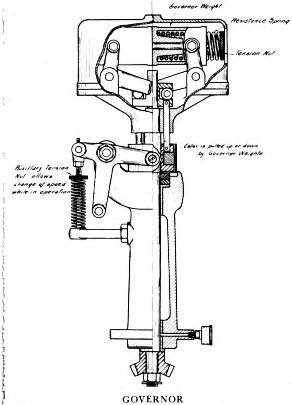
AIR STARTER VALVE



WATER COOLED EXHAUST VALVE SECTION



END SECTION



GOVERNOR

NO. 2 ENGINE EQUIPPED WITH BOTH PRODUCER AND NATURAL GAS

OBJECT

The object of this thesis is to determine the fuel mixture and degree of compression at which the Elyria Gas Engine operates the most economically and efficiently, as determined by Thermal and Mechanical means.

DISCUSSION

Comparatively little has been known of the exact relationship between fuel mixture and degree of compression as affecting the efficiency and economy of the modern gas engine. With the latter coming into prominence as a compact reliable and accessible power unit, the importance of the object of a test of this kind cannot be exaggerated.

Nearly all test reports upon this subject have been to a more or less degree inaccurate due mainly to the difficulty of a suitable means of measuring the amount of air, used for combustion. The apparatus used in this thesis was a system of low pressure orifices, the exact details to be explained later. Th s method is extremely accurate for difference of pressure under 5" of water as is the case in our use of it. A Ventrui Meter was at first intended to be used, but on account of the fact that the pressure ratios change with each load and condition of operation,.and that it would have to be calibrated with a low pressure orifice anyway, this method

was abandoned. The effect of the incurred resistance to the air of the addition of the extra piping was not noticable in the suction cards or in the ability of the engine to carry the loads and therefore not taken into account.

Due to the lack of time to cover sufficient ground, the angle of ignition was not changed during the tests and was set at appproximately the lead for ordinary operation. It was set at 15° lead. No doubt this is not the most efficient angle under all conditions of compression,, but we lacked time to investigate further.

In order to keep down the heat losses as much as possible the cooling water was maintained as near 180° as was permissable by the engines conditions at the beginning of the test, lubricating difficulties kept the cooling water as low as 140°. No attempt was made to determine the heat distribution. As long as the heat losses are kept as low as possible this does not effect the efficiency of the engine and the latter was the factor upon which we based our comparisons of efficiency of mixture and compression.

After the beginning of each test, under its conditions of mixture and compression, the largest load was determined, by experiment that the engine would carry safely. This divided up into five increments to be successively applied, in order to get a sufficient number of points to plot curves The loadwas kept constant thruout the different tests by individual attention.

All tests were run for 30 minutes with 10 minute intervals between tests to obtain average operating conditions. Readings on the gas meter, low pressure orifices, pressure of gas and R. P. M. were taken every five minutes. Indicator cards were taken every 10 minutes with a compression card taken at the end of the test. The latter was taken by cutting out the spark at the time of taking the card, on the cylinder under consideration. This was not done during the test as it would cut out a number of explosions and the fly wheel inertia would be decreased.

Samples of gas were pumped from the meter into a 12" x 30" tank fitted with gauge and needle valve. In order to drive out all air the tank was first filled with water and there displaced with gas. Samples were pumped into the tank from several tests and tested when convenient. The samples were for calorimetry and ultimate analysis of the gas. The analysis was made twice during the test and the calorimeter test run once. The exact details of this test will be given later.

The amount of compression was changed by lengthening out the connecting rod by putting in shims, thus changing the volume of the clearance space. The amount of change made in clearance volume was determined by measuring the projection of the front end piston from the finished end of the cylinder when the engine was on dead center as determined by a tramel bar.

Before running any tests all thermometers used were calibrated with a standard and correction curves plotted for use with each one. Likewise the scales were tested and found to be correct. The tare of the brake was determined by mounting the frame on a pulley balanced and mounted on knife edges and measured by the weight of the free end on a pan of scales.

GAS ANALYSIS

In order to check the amount of air used by the engine as measured by the low pressure orifices it was thought advisable to make chemical analysis of the gas before it entered and after it left the engine. By determining the percentage of combustible constitutents in the gas and the amount of air required for combustion, with the excess of oxygen going thru the engine, as measured in the exhaust gas, we could compute the amount of air used.

The apparatus used was of the Hempel type on account of its simplicity and accuracy in the hands of inexperienced men.. In this process the different constitutents are absorbed by some special reagent. The gases to be determined were CO_2, Olifinis, O, CO, H, and CH_4. The reagents for the same were KOH, $H_2S_2O_7$, Pyrogallic acid and Cu_2Cl_2, respectively. H was taken out by the copper oxide method, while CH_4 was determined by explosion. The method was as follows;

100 cc of the gas was collected in a burette tube. The burette tube was attached to the KOH pipette by means of capillary tube in order to keep the amount of air admitted as small as possible. The gas was passed over the KOH until the reading on the burette was constant, showing that all the CO_2 had been taken out. The diminution in volume read and the process repeated over disulphuric acid. Before using the pyrogallic pipette the fumes of the former acid had to be taken out by means of KOH. After the process had been repeated over the pyrogallic cuprus chloride and the hot copper, 10 cc of the residue was taken and placed in the explosion bulb with 70 cc of air and burned. The following reaction took place:

$$CH_4 + 4O = CO_2 + 2H_2O$$

The diminution in volume due to the $2H_2O$ is so small as to be negligible and we can measure the amount of CH_4 in the 10 cc by measuring the CO_2 by passing over KOH. Now by determining the amount of CH_4 in 100 cc from the proportion in 10 cc we have the exact percentage of the constitutents since we started with 100 cc.

Sample analysis.

Before KOH		100 cc
After "		97.55 cc
	CO_2	2.45 cc
Before $H_2S_2O_7$		97.55 cc
After "		91.1 cc
	Olifinis	6.45 cc

Before Pyrogallic acid	91.1 cc
After " "	88.65 cc
O	2.45 cc
Before cuprus chloride	88.65 cc
After " "	74.15 cc
CO	14.5
Before hot copper	74.15 cc
After " "	42.15 cc
H	32. cc

Amount of CO_2 after explosion of 10 cc residue = 4.3

$100 - (2.45 + 6.45 + 2.45 + 14.5 + 32) = 47.85$

$47.85 \times \frac{4.3}{10} = 21.6$ cc CH_4 present.

In collecting exhaust gas samples a pipe was led from the exhaust to a gasometer where the gas was drawn in by the weight of the water. Analysis of the exhaust gas was made during each test for each different load. The determination of the amount of air from these analysis and also the heating value will be shown in a sample calculation of the thesis data.

The chemical constants of heating value of each gas and its amount of air required for combustion were taken from the Modern Gas Engine and Gas Producer, By A. M. Levin and are given below.

Air required for combustion per cu; ft. gas.

H	2.4 cu. ft.
CH_4	9.61 "
C_2H_4	14.3 "
C_6H_6	36. "
CO	2.4 "

Heating value per cu. ft. gas.

H	275 B. T. U.
CH_4	910 "
C_2H_4	1512 "
C_6H_6	3560 "
CO	324 "

The amount of air required for combustion of 1 cu. ft. of gas is found by multiplying the amount of air necessary to burn one cu. ft. of each constitutent by its percentage in the gas and taking the total.

The heating value is likewise found by multiplying the heating value of one cu. ft. of each constitutent by its percentage in the gas.

All results are worked out for standard conditions of 62^{o} F and 30" of mercury and the heating values are given as the low heating values.

CALORIMETRY

The apparatus used for determining the heating value of the gas was the one most generally used, namely Junkers Calorimeter which is shown in one of the cuts. In connection with the apparatus there is used a gas meter and pressure regulator. The flow of the gas is from the source of supply thru the gas meter, thru the pressure regulator and thru the burner.

The temperature of the cooling water is measured, by thermometers placed in the pockets provided at the inlet and discharge of the apparatus. The amount of cooling water can be regulated by means of graduated valve, thus regulating the existing temperature difference of the cooling water, which should be about 15° to 20° C. A thermometer is placed at the exhaust gas exit and this should be maintained at the room temperature in order not to lose any heat from the apparatus. The condensation which will result from the combustion of H is drained at the bottom into a graduated beaker.

The gas meter is fitted with apparatus to measure existing temperature and pressure in order to be able to reduce the meter reading in liters to standard conditions of 62° F and 30" Hg.

Preliminary to the test the apparatus must be in operation for some time, until the condensation is flowing

at a normal rate, and the temperature difference is constant. The test may now be started by reading the meter and shifting cooling water and condensation to graduated beakers and observing the temperatures. The test can be run for any length of time taking readings frequently in order to get average conditions.

The measuring vessels used with this apparatus are graduated in liters and the thermometers in centigrade. The result; the weight of cooling water in kilograms times the increase in temperature in centigrade will therefore be expressed in calories which are equivalent to 3.965 B. T. U. If V is the volume of gas consumed in cu. ft. reduced to standard conditions at 62° F and 30" Hg.
W the weight of cooling water in kilograms.
t_2 centigrade, the mean discharge temperature of the cooling water, than the calorific power of the gas per cubic foot will be.

$$H = 3.968 \frac{W(t_2 - t_1)}{V}$$ for its high value.

To obtain the low value we have to correct for the condensation in the following manner.

If V is the volume of the gas used as above, C the amount of condensation in cubic centimeters then

$$h = \frac{2.381 \times C}{V}$$

and

$H - h = H'$ low calorific value.

MEASURING THE GAS

The amount of gas passing into the engine was measured by a gas meter accurate within 2%. Pressure and temperature were both measured on the inlet and outlet side of the meter. These readings were necessary in order to obtain the amount of gas used under standard conditions of 62° F and 30" Hg.

if P_1 = Pressure of standard gas (30" Hg.)

V_1 = Volume of standard gas.

T_1 = Absolute temperature of standard gas (521.2° F)

P = Pressure of gas under meter conditions.

V = Volume of gas under meter conditions.

T = Absolute temperature of gas under meter conditions.

Then

$$\frac{P_1V_1}{T_1} = \frac{PV}{T} \qquad V_1 = \frac{PVT_1}{TP_1}$$

$$\frac{T_1}{P_1} = \frac{521.2}{30} = 17.373$$

$$V_1 = 17.373\,\frac{PV}{T}$$

EFFICIENCY AND COMPRESSION

Beside playing an important part in gas engine design with reference to piston speed and weight of reciprocating parts, compression is one of the fundamental factions of efficiency. The equation of the theoretical efficiency of the gas engine cycle is

$$E = 1 - \left(\frac{V_b}{V_a}\right)^{n-1}$$

$$= 1 - \frac{1}{r^{n-1}}$$

Where V_a = total volume of cylinder

V_b = volume of compression space.

r = the ratio of V_a to V_b (ratio of compression)

N = the ratio between the specific heat of the gas at constant pressure and that at constant volume and has the average value in gas engine practice of 1.35.

As shown in the formula the theoretical efficiency increases with the intensity with which the charge is compressed before ignition. However, there is a limit to this efficiency due to the fact of pre-ignition of some fuels, under high compression. Lucke of Columbia University makes a statement that the amount of compression is limited by the amount of hydrogen present in the gas and states that one atmosphere must be deducted from the compression for every 5% of hydrogen present.

Thus the thermal efficiency of the heat transformation is first dependent on the compression that can be allowed, but it is also determined by the amount of heat that passes to the cooling water. Again the thermal efficiency will vary mathematically, dependent upon whether the results were derived from output taken as I. H. P. or B. H. P. and the input derived from high or low heating value of the gas. In working up all our results we used B. H. P. for output and the low heating value as the input.

The use of thermal efficiency in referring to gas engine test is made more distinct by referring to economy. By economy is meant the expenditure in heat units that is necessary in order to get the necessary transformation, under a certain efficiency, to do the work in the cylinder. Thus (1) I. H. P. is equal to 2.545 heat units per hour and if the thermal efficiency of transformation is 24%, $\frac{2545}{.24}$ or 10,600 B. T. U. would need to be expanded to do I. H. P. The latter is the economy, the thermal efficiency being determined from the I. H. P.

MEASUREMENT OF AIR USED FOR COMBUSTION

The apparatus we used to measure the air, consisted of a steel tank, two manometers with tubes to connect, two 2-in orifices with connecting pipes, thermometers and pipe leading to intake valve of engine. (See blue print on page)

The 3" pipe leading from the tank to the engine was made as short as possible to do away with friction of the air passing thru it. This pipe projected into the middle of the tank in order to avoid the eddy currents and so that about the same amount of air would be supplied by each of the two orifices, thus doing away with excessive suction in this case, on either orifice. The suction was always less than 5" of water to facilitate the use of the correct constant.

The tank was cylinderical in shape being 30" in diameter and 40" high, and was used as a receiver for the air to keep the pressure nearly constant. This made it much easier to obtain correct readings on the manometers.

The orifices were two in number and fastened to the ends of two 3" pipes which were screwed into the tank about 12" apart. These pipes were made 16" long to get rid of all eddy currents and yet not long enough to cause undue friction losses in the pipes. These orifices were of standard thickness (.057") being plates with a 2" circular orifice bored straight thru. The edges were not beveled.

It has been found from experiment that with an orifice

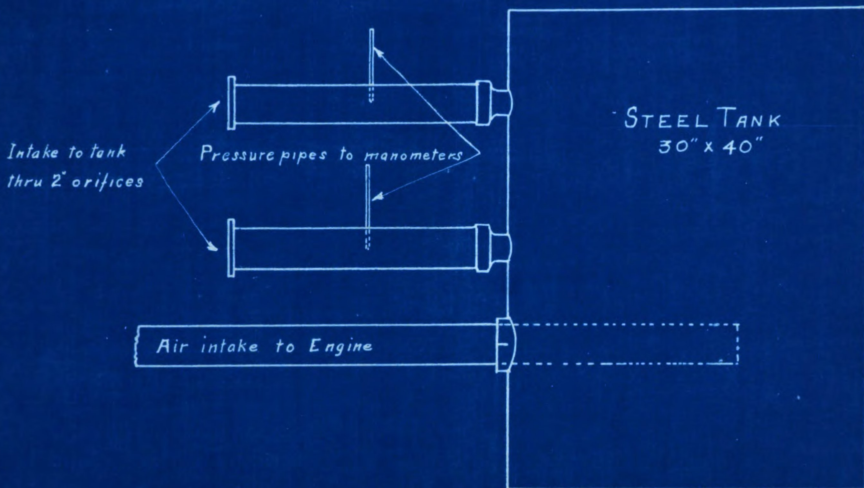
of this size and thickness the coefficient remains practically constant with pressures up to 5" of water and does not change appreciably for temperatures of air between 40° and 100° F, or for the size of receiving tank if the ratio of the area of the tank to the orifice is greater than 20 to 1.

We measured the degree of suction by boring holes in the pipes leading from the orifices to the tank and inserting small brass tubes in holes thru rubber stoppers in these holes. These brass tubes were placed into the pipes far enough to get an average reading on the manometers. Small rubber tubes lead from these brass tubes to the manometers which were of the suction type and read in hundredths of an inch of water.

The temperature of the air was taken by a thermometer hung in front of the two orifices to get an average temperature.

Thus by taking the temperature of the entering air and the pressure in inches of water we may by the formula $W = .6299\ Cd^2 \sqrt{I \div T}$ find the weight of air entering the engine in pounds per second. In this case the constant (C) is .6, d = 2", i = inches of water, T = absolute temperature of entering air.

This method of measuring air was taken from R. J. Durley's discussion in the Transactions of the A. S. M. E. Vol. 27, 1906.


Steel Tank
30" x 40"
Intake to tank
thru 2" orifices
Pressure pipes to manometers
Air intake to Engine

CONCLUSIONS

The test was run under mixtures of 5.9 to 10 cu. ft. of air per 1 cu. ft. of gas and under compression of 105 to 190# per sq. in. The limit was reached under which the largest load that could be carried under a mixture of 11 to 1. No tests were run of light loads as it was not deemed profitable if the largest load could not be carried. The limit of test was also reached at 190# per sq. in. of compression. At this point preignition was established to such an extent as was apt to damage the engine and the test was stopped. However, preignition was never found on the indicator card or on the compression card when the spark was cut out. The only evidence of preignition was the pounding of the engine. This pounding could probably be done away with by giving the spark less angle of advance, however, this was not done.

By using the same loads under the several tests we were able to determine the effect of f ll mixture on B. H. P., I. H. P. and mechanical efficiency under different compressions, as can be seen from the curves plotted; they remain nearly constant. Thus all the change that was made by the testwas thrown into the thermal efficiency and all conclusions were drawn from the latter. The exhaust gas analysis was discarded after the first compression test was run as the two methods of measuring the air checked.

From this fact we feel sure that our method of measuring air was extremely accurate and can be recomended for any such work as it is far less complicated to work up than is the chemical analysis.

From the results of the tests the most noticable changes were made by varying the fuel mixture, all of which would give about the same mechanical efficiency. From the curves on page the mixture that give the maximum thermal efficiency was a proportion of 10.5 volumes of air to 1 volume of gas. The curve would probably drop if continued, on account of the fact that a ratio of 10.5 was the weakest mixture that would maintain the same conditions of load and mechanical efficiency.

These curves also show the effect of changing the compression. This is also shown on page . A compression of about 150# to 160# gave the greatest thermal efficiency and also the greatest economy as shown by the tabulations. The corresponding ratio of compression ran from 6 to 6.5. A higher compression than stated would not be advisable on account of the falling off in economy of [illegible]% from a ratio of 6 to 7.5. This is somewhat contrary to what might be expected from an inspection of the theoretical efficiency curve, but is probably due to the excessive loss of heat given to the cooling water at the time of preignition. From the curves showing the effect of compression and from results of other tests, it would be reasonable to assume that if preignition could be prevented a higher economy could be reached. This preignition could be prevented by the admission of a spray of water in with the incoming charge, which would tend to cool off the cylinder. Regarding the cause of preignition, we cannot say, but from other experiments made by authorities who have layed it to the amount of hydrogen in the gas, we reached a great deal higher compression per volume of hydrogen present than did either C. E. Lucke of Columbia University in his "Gas Engine Design" or H. E. Wimperis in his "Internal Combustion engine". Again it might be caused by carbon particles in the high heat of ignition and compression.

Again a higher efficiency and economy could have been reached by changing the angle of ignition. Cards No. 10, 11 and 12 were taken of the 65# load under the respective tests and show a slow burning mixture that could be remedied by increasing the angle of ignition. For the other tests the angle of ignition was about right.

One peculiar feature was noticed in the experiment and, that was the ratio of air to gas was not constant thruout a certain mixture under different loads. As can be seen from some of the curves the ratio curve is not always a straight line. This probably is due to some defect in the pressure regulator of the gas main.

The conditions under which the engine gave the best results are: ratio of air to gas = 10; compression = 150# per sq. in; cu. ft. of gas per B. H. P. per hour = 21; mechanical efficiency = 80%; thermal efficiency = 23%; load 170# and developes 40 I. H. P.

The exponent (n) as used in the formula for the theoretical efficiency of the Otto gas engine cycle was determined from the compression cards by means of the following formula:

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n$$

P_1 = initial pressure

V_1 = total cylinder volume

P_2 = pressure at any point of curve

V_2 = volume corresponding to pressure P_2.

n = ratio of specific heat of the gas at constant pressure and at constant volume.

From compression No. 1 rear cylinder.

P_1 = 14.7 - 10 = 4.7

P_2 = 14.7 + 38 = 52.7

V_2 = 141 cu. in. = clearance space.

V_1 = 141 + 603.18 = 744.8 = total volume of cylinder.

$$\frac{4.7}{52.7} = \left(\frac{141}{744.8}\right)^n$$

Log 4.7 - log 52.7 = n(log 141 - log 744.18)

$$\begin{array}{r} .672098 \\ -1.721811 \\ \hline .950287-2 \end{array} \qquad \begin{array}{r} 2.149219 \\ 2.871645 \\ \hline .277565-1 \end{array}$$

$$n = \frac{1.049713}{.722435} = 1.45$$

Cards Nos. 1, 3, 4, and 5 give the following value of (n).

No. 1 = 1.45

" 3 = 1.345

" 4 = 1.25

" 5 = 1.49

1.386 = average.

Ratio of Compression R. Cyl 5.28 F Cyl. 4.97

Load	Time in Minutes	R.P.M.	Compression Front Cyl.	Compression Rear Cyl.	Barometer	Gas Pressure	Gas Temp
Test No.1. Comp. No.1. Mix. No.1.							
165	30	312	117	106	29.25	2.84	69.
130		318	107	92		3.15	66.
95		321	97	82		3.49	66.
60		326	80	54		3.86	64.
25		326	49	38	29.24	4.00	7.2
Test No.2. Comp No1. Mix. No.2.							
170	30	308	122	104	28.84	2.44	72
135		314	101	84.5		3.00	73.
100		322	81.5	70		3.40	73.
65		324	70	52		3.6	74.
30		326	55	48	28.84	3.87	75.
Test No.3. Comp. No.1 Mix. No.3.							
170	30	310	108	103	29	2.85	70
135		315	98.5	89.5		3.2	70
100		320	83	67	28.98	3.5	71
65		324	67	52.5		3.75	73
30		325	53.5	39	28.98	3.87	74
Test No. 4. Comp. No.1 Mix No.4.							
170	30	311	119	103	28.94	2.9	65
135		317	99	87		3.19	66
100		321	88.5	71	28.93	3.45	66.
65		323	70	57.5		3.65	67.
30		327	52	44	28.94	3.8	68.
Test No.5. Comp. No.1. Mix No.5.							
170	30	300	126	116	29.04	3.37	58
135		312	108.5	98		3.57	60
100		318	92.5	78	29.04	3.7	61.
65		323	83.25	63.5		3.81	62
30		325	63	51.25	29.04	3.87	63.

Ratio of Compression R. Cyl. 5.28 F. Cyl. 4.97							
	Gas		Air				
Load	Cu. Ft. Metered	Cu. Ft. Std. Gas	Pressure in inches water Orifice No. 1	Pressure in inches water Orifice No. 2	Temp Deg. F.	Cu. Ft. Total	Cu Ft Air/cu Ft of Gas from Chem. Analysis
Test No. 1. Comp. No. 1 Mix No. 1.							
165	406	388	.72	.86	76	2755	6.9
130	350	337	.567	.668	72.3	2470	7.1
95	277	267	.43	.5	79.8	2091	7.6
60	223	213	.315	.37	77.8	1848	8.3
25	169	159	.212	.24	86.4	1450	9.2
Test No. 2. Comp. No. 1 Mix. No. 2.							
170	492	467	.73	.87	82.5	2751	5.74
135	400	383	.57	.684	85.8	2425	6.1
100	315	299	.427	.5	92.4	2080	6.7
65	233	221	.225	.34	92.2	1772	7.86
30	176	166	.2	.23	89.1	1419	8.0
Test No. 3 Comp. No. 1 Mix No. 3.							
170	437	420	.77	.9	85.5	2755	6.1
135	379	364	.594	.7	86.7	2405	6.2
100	300	286	.455	.525	85.1	2144	7.3
65	234	222	.305	.37	85.5	1773	7.8
30	177	163	.205	.24	82.57	1449	8.6
Test No. 4 Comp. No. 1 Mix. No. 4							
170	379	364	.765	.902	75.4	2825	7.3
135	332	320	.618	.728	77.4	2529	7.64
100	277	267	.471	.561	71.57	2228	7.8
65	225	217	.345	.41	71.57	1895	8.16
30	178	171	.225	.232	73	1482	8.35
Test No. 5 Comp. No. 1 Mix. No. 5.							
170	336	330	1.01	1.2	63.14	3284	8.2
135	303	296	.827	.967	67.2	2934	8.3
100	263	257	.6	.711	67.85	2518	8.15
65	215	209	.408	.494	68.7	2090	8.4
30	171	166.5	.269	.339	67.7	1716	8.5

Ratio of Compression R. Cyl. 5.28. F. Cyl. 4.97.

Load	Cu. Ft. Air per Cu. Ft. Gas	Cu. Ft. Gas per B.H.P. per Hour	I.H.P.	B.H.P.	Mechanical Efficiency	Thermal Efficiency	
Test No. 1. Comp. No. 1 Mix. No. 1							
165	7.1	24.4	40.28	31.8	79.0	19.6.	
130	7.3	27.0	35.44	24.88	70.2	17.7	
95	7.6	29.0	26.04	18.38	70.6	16.4	
60	8.3	36.0	20.45	11.81	57.6	13.3	
25	9.2	64.0	14.53	4.968	34.14	7.49	
Test No. 2. Comp. No. 1 Mix. No. 2.							
170	5.9	29.7	38.22	31.41	82.2	16.0	
135	6.35	30.0	32.72	25.4	77.7	15.9	
100	6.9	31.8	25.94	18.72	72.1	14.9	
65	8.0	35.0	19.69	12.64	64.2	13.1	
30	8.1	56.6	14.18	5.87	41.85	6.09	
Test No. 3. Comp. No. 1 Mix. No. 3.							
170	6.55	26.4	39.9	31.7	79.9	18.0	
135	6.6	28.5	33.05	25.5	77.0	16.8	
100	7.5	29.8	26.88	19.2	71.5	16.1	
65	8.0	35.2	21.4	12.6	59.0	12.9	
30	8.9	56.0	14.07	5.85	41.7	8.6	
Test No. 4. Comp. No. 1. Mix. No. 4.							
170	7.75	23.0	39.44	31.7	76.5	20.7	
135	7.9	25.0	33.7	25.7	71.7	19.3	
100	8.35	27.6	26.89	19.3	59.1	17.2	
65	8.74	34.6	21.33	12.6	42.6	13.85	
30	8.7	58.0	13.84	5.9	20.7	8.25	
Test No. 5. Comp. No. 1 Mix. No. 5.							
170	9.9	21.4	42.47	30.8	72.9	22.2	
135	9.9	23.5	34.79	25.2	73.0	20.3	
100	9.8	26.7	28.16	19.2	69.0	17.8	
65	10.0	33.2	20.52	12.6	61.5	14.4	
30	10.3	57.0	12.76	5.84	45.7	8.36	

Ratio of Compressiom R.Cyl. 6.04 F.Cyl 5.65							
Load	Time in Minutes	R.P.M.	Compression Front Cyl.	Compression Rear Cyl.	Barometer	Gas	
						Pressure Inches H_2O	Temp Deg. F.
Test No.6. Comp. No.2 Mix. No.1							
170	30	312	137	116	28.84	2.76	71.1
135		317	115	98		3.07	70.6
100		321	100	85		3.28	72.06
65		324	87	65.5		3.45	73.31
30		326	65	50	28.87	3.62	73.87
Test No.7 Comp. No.2. Mix. No.2.							
170	30	312	132	120	29.08	2.85	69.14
135		317	118	97.5		2.92	70.5
100		322	106	82		3.27	72.6
65		324	86.5	66		3.5	73.1
30		327	62.5	50.5	29.12	3.65	73.2
Test. No.8 Comp. No.2. Mix No.3.							
170	30	313	140	120	28.95	2.65	61.8
135		317	118	103		2.97	62.74
100		321	106	87		3.15	66.81
65		323	87	69		3.27	74.78
30		326	70	50	28.85	3.45	69.7
Test. No.9. Comp. No.2. Mix. No.4.							
170	30	311	138	119	28.71	2.83	62.4
135		316	122	105		3.12	68.5
100		320	104	88		3.32	72.13
65		324	84	70		3.5	74.9
30		326	70.5	51	28.77	3.65	72.7
Test No.10 Comp. No.2. Mix No.5							
135	30	310	144	126	29.13	3.03	57.6
100		317	122	112		3.28	64.2
65		323	98	75		3.45	66.7
35		326	81	65		3.5	68.7

Ratio of Compression R. Cyl. 6.04 F. Cyl. 5.65

Load	Gas		Air					Air Required For Combustion
	Cu. Ft. Metered	Cu. Ft. Std. Gas	Pressure in inches water		Temp Deg. F.	Cu. Ft. Total		
			Orifice No. 1.	Orifice No. 2				
Test No. 6 Comp. No. 2. Mix. No. 1								
170	405	386	.693	.82	78	2685		5.1
135	338	322	.562	.649	88.5	2376		
100	279	265.5	.425	.51	86.85	2093		
65	224	213	.317	.38	87.5	1803		
30	169	160.5	.2	.25	84	1453		
Test No. 7 Comp. No. 2. Mix. No. 2.								
170	446	430	.653	.78	74.28	2618		5.1
135	377	362	.537	.625	75	2367		
100	292	279	.4	.47	78.54	2033		
65	227	217	.28	.344	73.85	1730		
30	168	161	.18	.22	71.1	1387		
Test No. 8. Comp No. 2 Mix. No. 3.								
170	378	366	.678	.82	69.4	2687		5.1
135	334	323	.581	.677	77.18	2432		
100	284	263	.458	.543	85.18	2164		
65	228	216	.35	.4	84.01	1855		
30	173	165	.22	.26	78.14	1401		
Test No. 9 Comp. No. 2 Mix. No. 4.								
170	370	356	.758	.869	89	2755		5.19
135	328	313	.6	.691	96.28	2441		
100	281	266	.47	.547	96.4	2162		
65	227	214	.331	.391	87.85	1838		
30	171	162	.201	.268	62.	1517		
Test No. 10. Comp. No. 3 Mix No. 5								
170								
135	298	294	.984	1.157	84.15	3172		5.19
100	255	248	.67	.8	83.42	2631		
65	210	202	.442	.544	78.4	2166		
35	174	168	.288	.365	79.1	1951		

Ratio of Compression. R. Cyl. 6.04. F. Cyl. 5.65.

Load	Cu. Ft. Air per Cu. Ft. Gas.	Cu. Ft. Gas per B.H.P. per Hour	I. H. P.	B. H. P.	Mechanical Efficiency	Thermal Efficiency
Test No. 6. Comp. No. 2. Mix. No. 1.						
170	6.95	24.25	41.8	31.8	76.1	20.6
135	7.37	25.0	36.9	25.1	69.6	18.8
100	7.9	27.6	29.2	19.25	66.0	17.25
65	8.4	33.8	20.3	12.6	62.0	14.09
30	9.05	54.7	14.3	5.86	41.0	8.7
Test No. 7. Comp. No. 2. Mix. No. 2.						
170	6.1	27.02	41.4	31.8	76.9	17.5
135	6.54	28.02	35.79	25.7	71.9	16.8
100	7.3	29.9	27.66	19.3	69.8	16.4
65	8.0	34.3	20.51	12.65	61.75	13.8
30	8.3	54.6	13.28	5.9	44.4	8.75
Test No. 8. Comp. No. 2. Mix. No. 3.						
170	7.34	22.95	39.05	31.92	81.75	20.7
135	7.62	25.15	33.3	25.68	77.1	18.7
100	8.56	27.3	27.58	19.26	69.9	17.3
65	8.59	34.3	20.86	12.6	60.5	13.8
30	8.5	56.4	14.68	5.86	40.0	8.55
Test No. 9. Comp. No. 2. Mix. No. 4.						
170	7.8	22.21	39.41	31.75	80.5	21.2
135	7.8	24.5	32.12	25.6	79.7	19.4
100	8.13	27.7	26.65	19.2	72.0	17.2
65	8.6	33.9	20.53	12.63	61.6	14.0
30	9.35	55.2	14.38	5.87	40.8	8.75
Test No. 10. Comp. No. 2. Mix. No. 5.						
170						
135	10.8	23.7	32.67	25.12	76.9	20.3
100	10.6	26.1	25.23	19.03	75.5	17.95
65	10.7	32.0	20.54	12.6	61.4	14.85
35	11.6	49.0	14.77	6.85	46.4	9.7

Ratio of Compression R Cyl. 7.4 F. Cyl 7.115

Load	Time in Minutes	R.P.M.	Compression Front Cyl.	Compression Rear Cyl.	Barometer	Gas Pressure inches H_2O	Gas Temp. Deg. F.
Test No. 11 Comp No. 3 Mix. No. 1.							
170	30	313	190.5	166	29.16	2.55	58.75
135		317	168	146		2.8	60.3
100		322	129	116		3.1	62.1
65		325	122	87		3.3	62.86
30		327	94	70		3.45	64.28
Test No. 12. Comp. No. 3 Mix. No. 2.							
170	30	312	182	160	29.2	2.01	67.5
135		317	164	140		2.34	68.2
100		322	136	109		2.6	68.5
65		325	110	87		2.73	68.6
30		329	88	66		2.87	67.7

Ratio of Compression R Cyl. 7.4 F Cyl. 7.115

Load	Gas		Air				Air Required for Combustion
	Cu Ft Metered	Cu Ft Std. Gas	Pressure in inches water: Orifice No. 1.	Pressure in inches water: Orifice No. 2.	Temp Deg. F	Cu. Ft. Total	
Test No. 11. Comp No. 3. Mix. No. 1.							
170	416	409	.715	.84	75.14	2723	5.1
135	371	364	.604	.704	78.71	2490	
100	290	284	.43	.514	77.28	2124	
65	230	225	.317	.39	75.28	1838	
30	175	171	.213	.263	74.4	1505	
Test No. 12. Comp No. 3. Mix. No. 2.							
170	452	436	.667	.817	81.1	2650	5.1
135	379	366	.522	.654	78.85	2375	
100	297	287	.385	.488	73.7	2041	
65	233	226	.258	.354	69.48	1712	
30	178	173	.165	.233	72.1	1376	

Ratio of Compression. R. Cyl. 7.4 F. Cyl. 7.115

Load	Cu. ft. air per Cu. Ft. Gas.	Cu. Ft. Gas per B.H.P. per Hour.	I. H. P.	B. H. P.	Mechanical Efficiency.	Thermal Efficiency.
Test No. 11. Comp. No. 3. Mix. No. 1.						
170	6.67	25.6	40.0	31.9	79.8	18.7
135	6.85	28.7	34.76	25.68	73.9	16.8
100	7.5	29.4	28.9	19.33	66.9	16.3
65	8.17	35.5	21.11	12.68	60.1	13.3
30	8.83	57.8	15.1	5.9	39.0	8.2
Test No. 12. Comp. No. 3. Mix. No. 2.						
170	5.73	27.4	43.31	31.8	73.5	17.4
135	6.48	28.4	33.28	25.7	77.2	16.6
100	7.06	29.7	28.31	19.32	68.3	16.05
65	7.56	35.6	21.07	12.7	60.25	13.4
30	7.95	58.5	14.46	5.92	41.0	8.12

Chemical Analysis.

COMPRESSION NUMBER.	CO_2	C_2H_4	C_6H_6	O	CO	H	CH_4	HEATING VALUE IN B.T.U.	AIR REQUIRED FOR COMBUSTION.	B.T.U. FROM CALORIMETER.
1	2.45	1.45	5.0	2.45	14.5	32.0	21.0	531	5.2	533
2	2.15	1.5	4.5	2.85	12.5	36.5	25.0	552	5.8	536
3	3.2	1.0	5.0	4.0	13.0	33.0	21.0	529	5.1	534

Exhaust Gas Analysis

CO_2	O.	CO	CO_2	O	CO	CO_2	O	CO
Mix. 3. Comp. 1.			Mix. 4. Comp. 1.			Mix. 5. Comp. 1.		
13.2	.8	0	8.2	5.6	0	9.2	3.15	1.0
13.0	1.0	0	8.4	5.4	0	9.6	2.9	.2
12.2	2.1	0	8.4	5.0	0	7.8	8.8	0
11.8	3.6	0	8.4	5.2	0	10.4	8.85	0
10.4	5.0	0	9.6	6.4	0	9.6	9.4	0

NORMAL EFFICIENCY AND ECONOMY FOR VARYING COMPRESSIONS_IN GAS ENGINE.

COMP. RATIO R. CYL.	COMP. RATIO F. CYL.	THERMAL EFFICIENCY	THEORETICAL EFFICIENCY F. CYL.	THEORETICAL EFFICIENCY R. CYL.	AV. THEO. EFFICIENCY.	ECONOMY.	COMPRESSION R. CYL.	COMPRESSION F. CYL.
5.28	4.97	19.6	42.7	44.1	43.4	12,900	106	117
6.04	5.65	20.6	45.5	47.9	46.7	12,350	116	137
7.4	7.11	18.7	49.6	50.3	49.9	13,600	166	190.5

Curves showing the relationship of I. H. P., mechanical efficiency, thermal efficiency, ratio of air to gas and Cu. ft. of gas used per B. H. P. with B. H. P.

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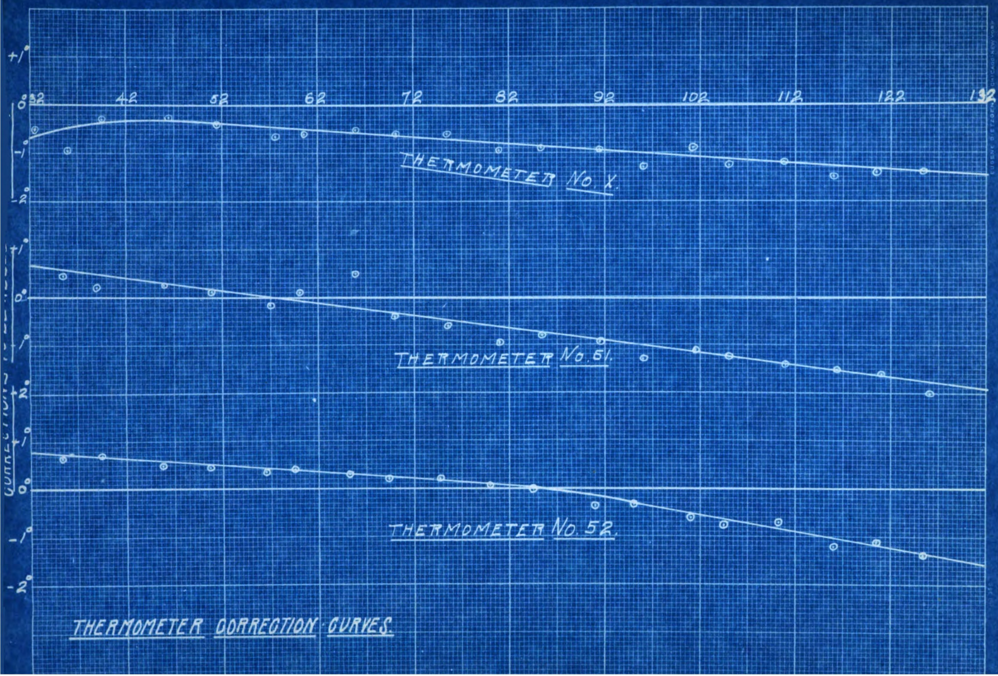
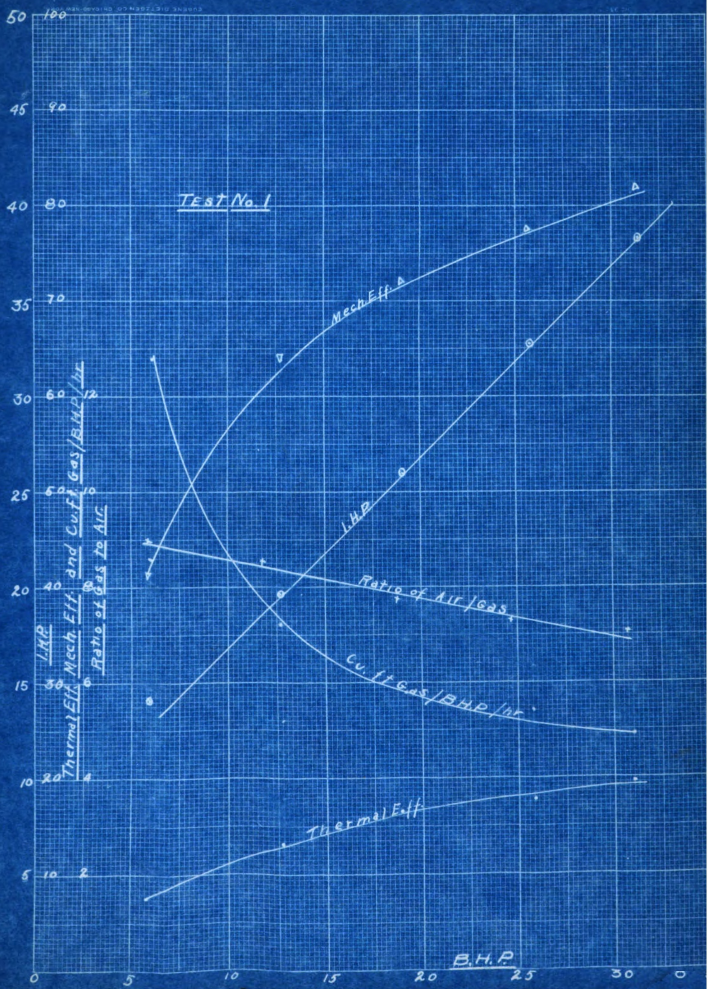
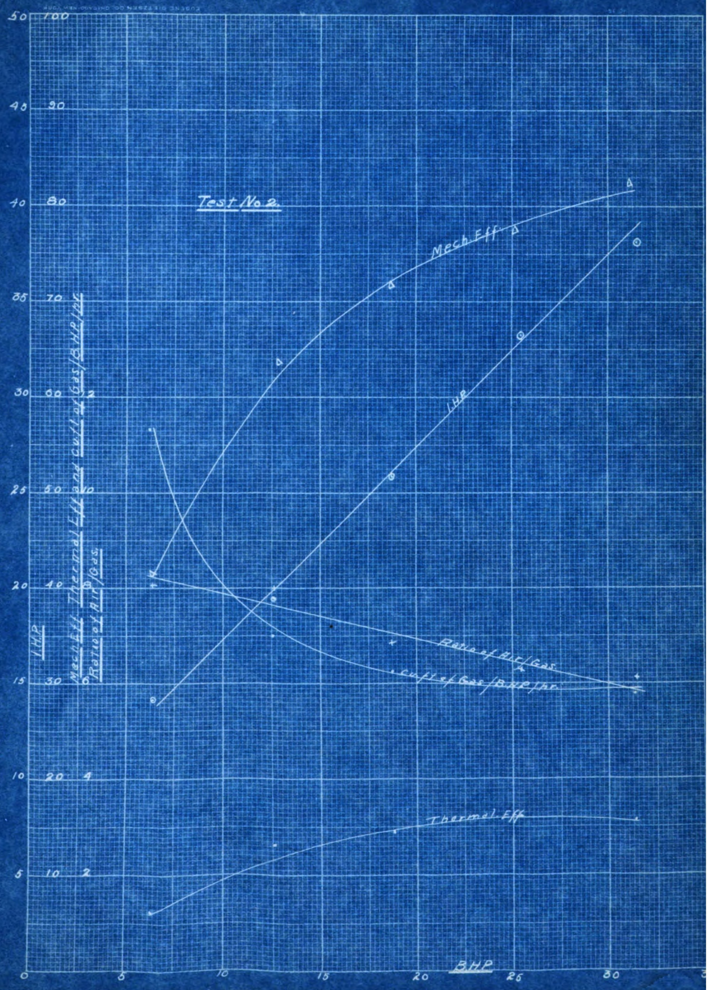
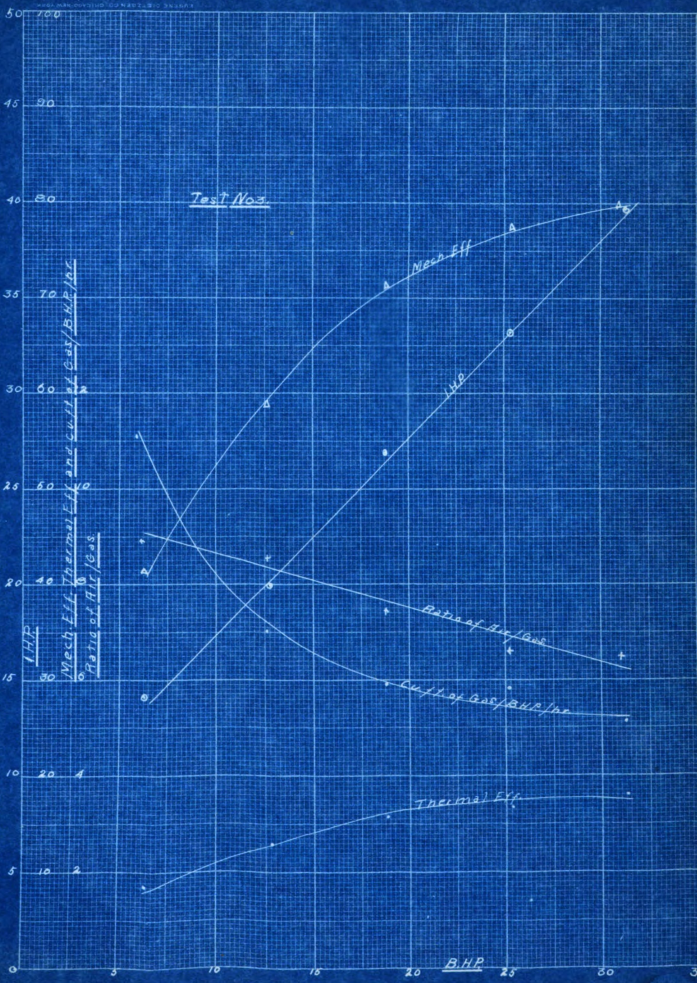

THERMOMETER CORRECTION CURVES.
THERMOMETER No. X.
THERMOMETER No. 51.
THERMOMETER No. 52.
32
42
52
62
72
82
92
102
112
122
132
+1°
0°
-1°
-2°
+1°
0°
-1°
-2°
+1°
0°
-1°
-2°



Test No. 1
Mech. Eff.
I.H.P.
Ratio of Air/Gas
Cu. ft Gas/B.H.P./hr
Thermal Eff.
B.H.P.
I.H.P.
Thermal Eff. Mech. Eff. and Cu. ft. Gas/B.H.P./hr
Ratio of Gas to Air
0
5
10
15
20
25
30
35
40
45
50
100
90
80
70
60
50
40
30
20
10
12
8
6
4
2



Test No 2.
Mech. Eff.
I.H.P.
Ratio of Air/Gas.
cu ft of Gas/B.H.P./hr.
Thermal Eff.
I.H.P.
Mech Eff. Thermal Eff and cu ft of Gas/B.H.P./hr.
Ratio of Air/Gas.
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12



Test No3.
Mech Eff
I.H.P
Ratio of Air/Gas
Cu ft of Gas/B.H.P./hr
Thermal Eff.
I.H.P.
Mech Eff. Thermal Eff. and cu ft of Gas/B.H.P./hr
Ratio of Air/Gas
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
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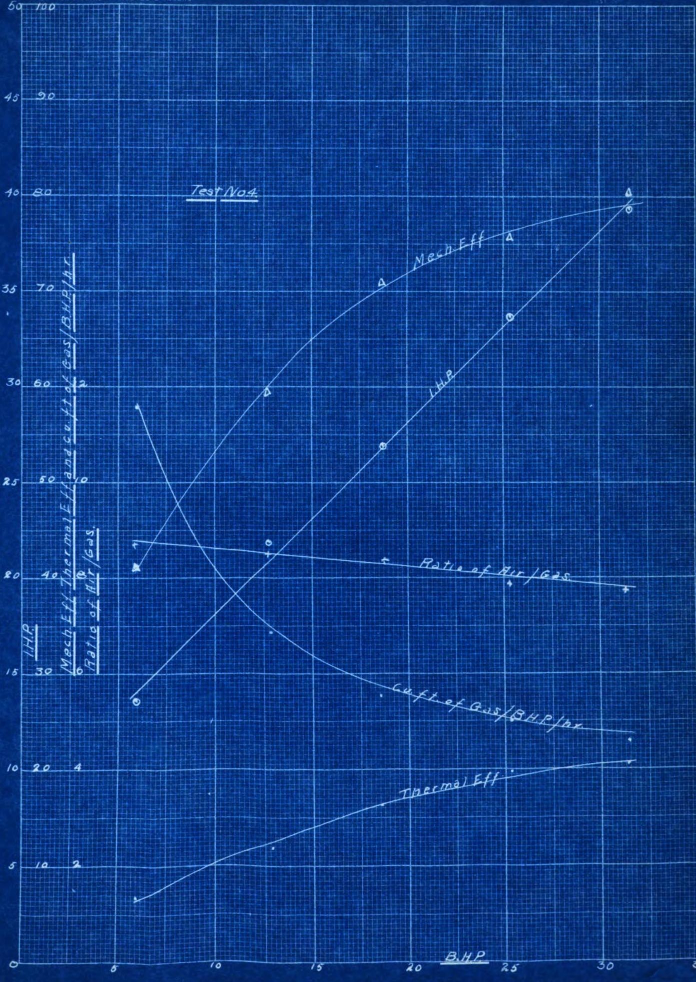
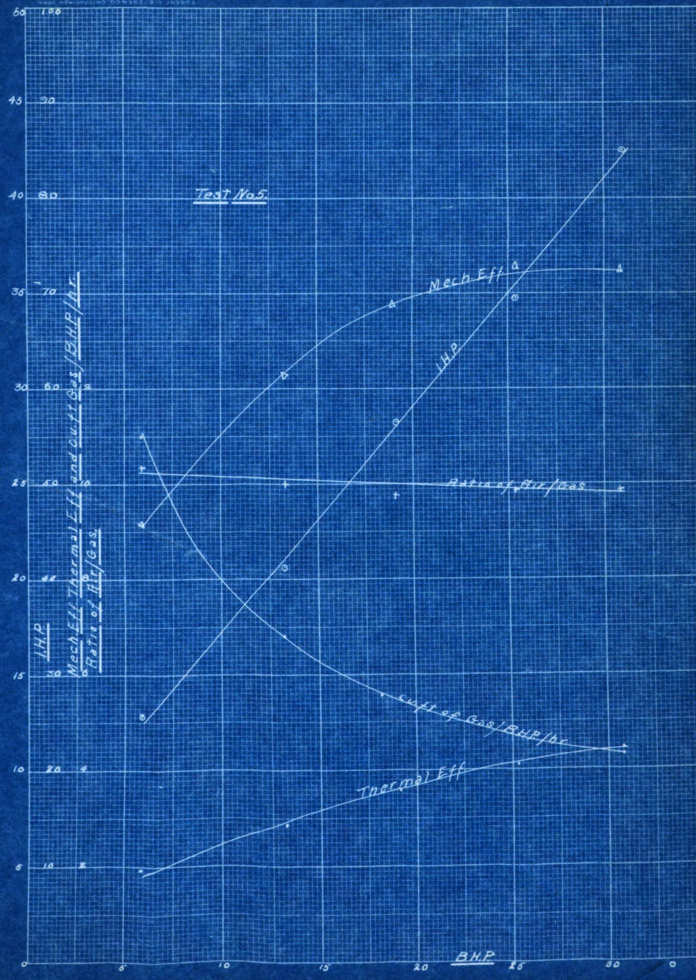
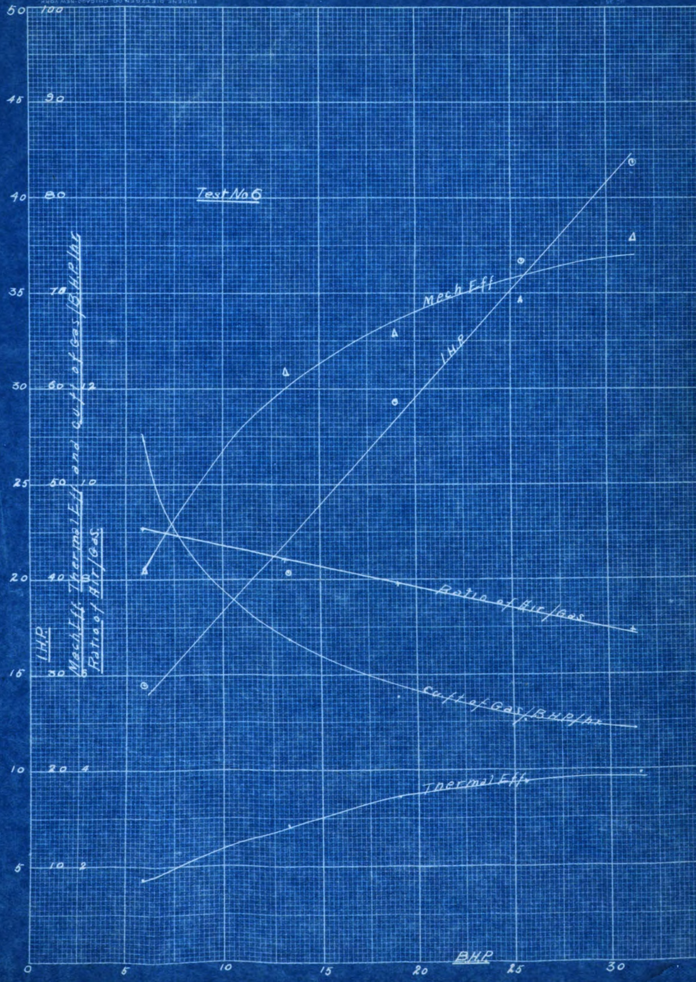
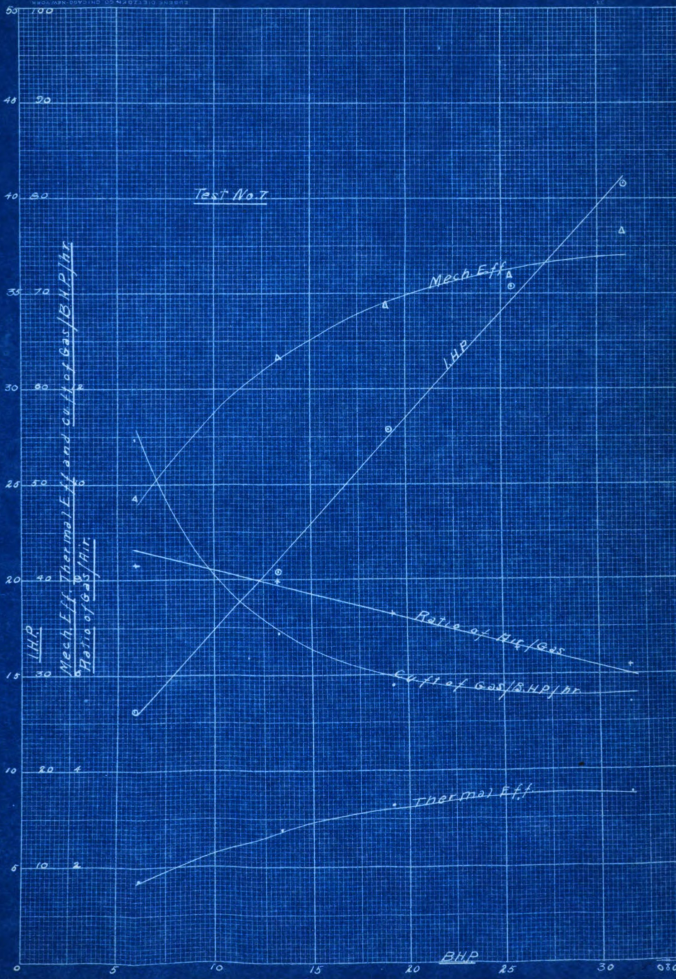
10
15
20
25
30

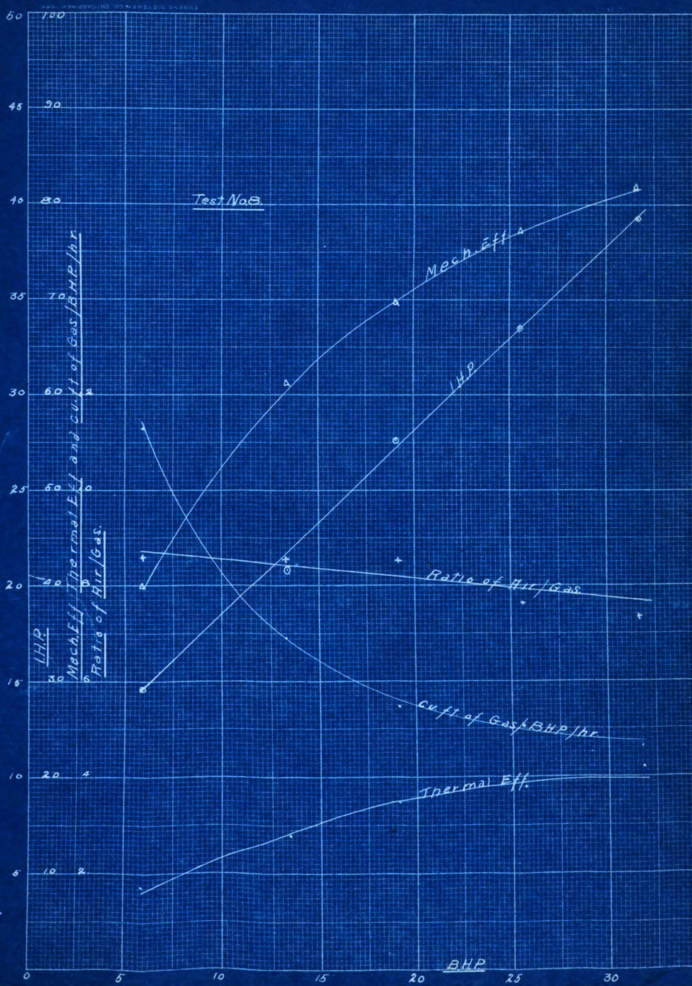

Test No 4
Mech Eff
I.H.P.
Ratio of Air/Gas.
Cu.ft. of Gas/B.H.P./hr.
Thermal Eff
I.H.P.
Mech Eff, Thermal Eff and cu.ft. of Gas/B.H.P./hr.
Ratio of Air/Gas.
B.H.P.



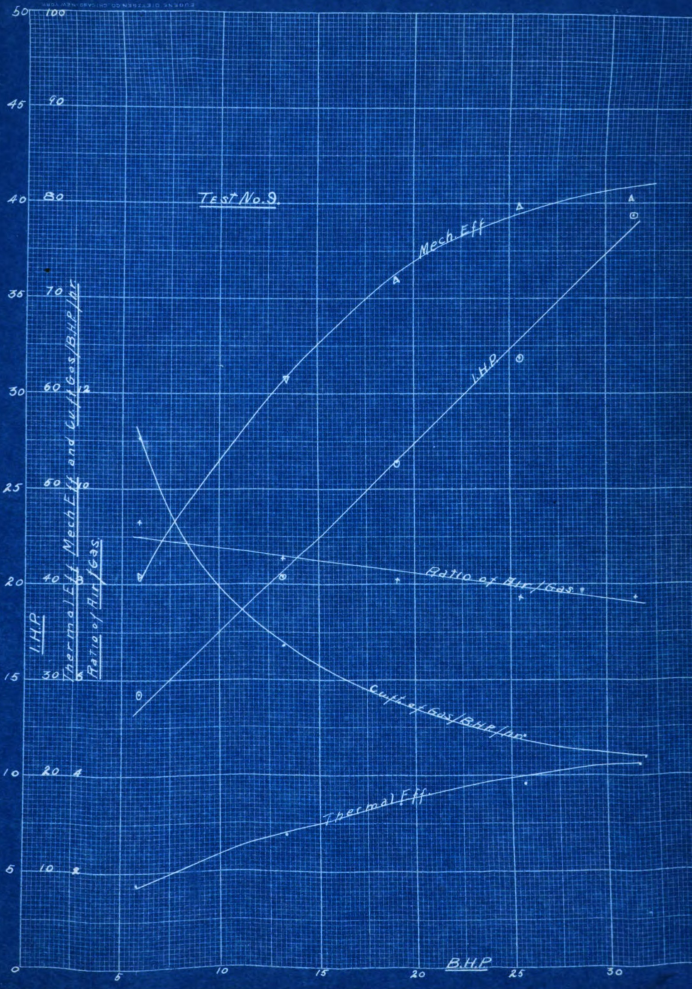
Test No.5.
Mech Eff
I.H.P.
Ratio of Air/Gas
Cu ft of Gas/B.H.P/hr
Thermal Eff
I.H.P.
Mech Eff Thermal Eff and Cu ft Gas/B.H.P/hr
Ratio of Air/Gas
B.H.P


Test No 6
Mech Eff
I.H.P.
Ratio of Air/Gas
Cu ft of Gas/B.H.P/hr
Thermal Eff
I.H.P.
Mech Eff. Thermal Eff. and Cu ft of Gas/B.H.P./hr
Ratio of Air/Gas
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
100
90
80
70
60
50
40
30
20
10
12
10
8
6
4
2

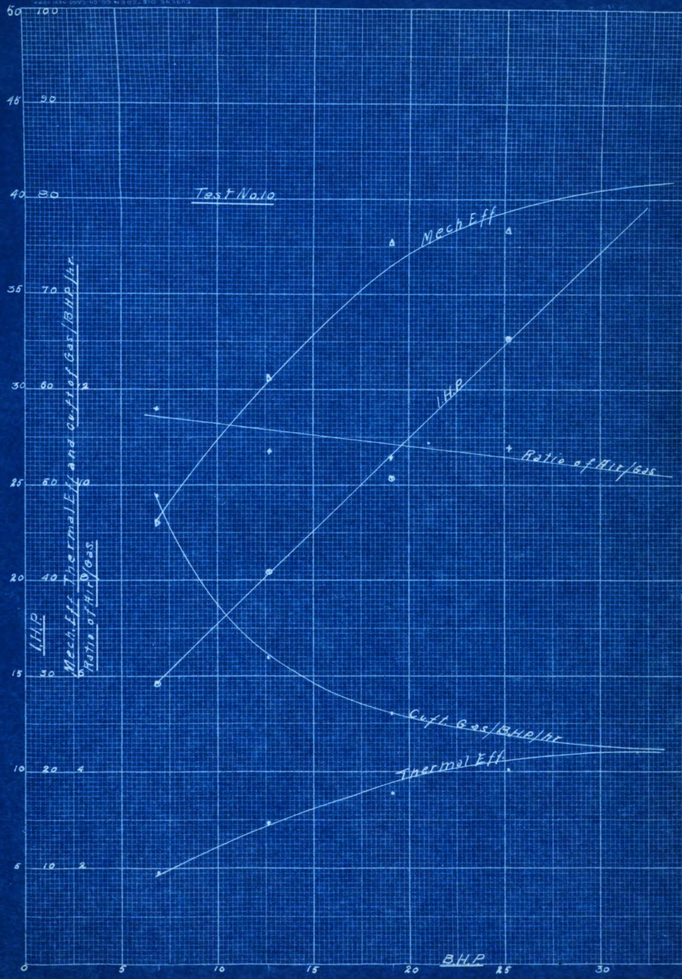

Test No. 7
Mech. Eff.
I.H.P.
Ratio of Air/Gas
Cu ft of Gas/B.H.P./hr
Thermal Eff.
I.H.P.
Mech. Eff. Thermal Eff and Cu ft of Gas/B.H.P./hr
Ratio of Gas/Air
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
100
90
80
70
60
50
40
30
20
10
12
10
8
6
4
2



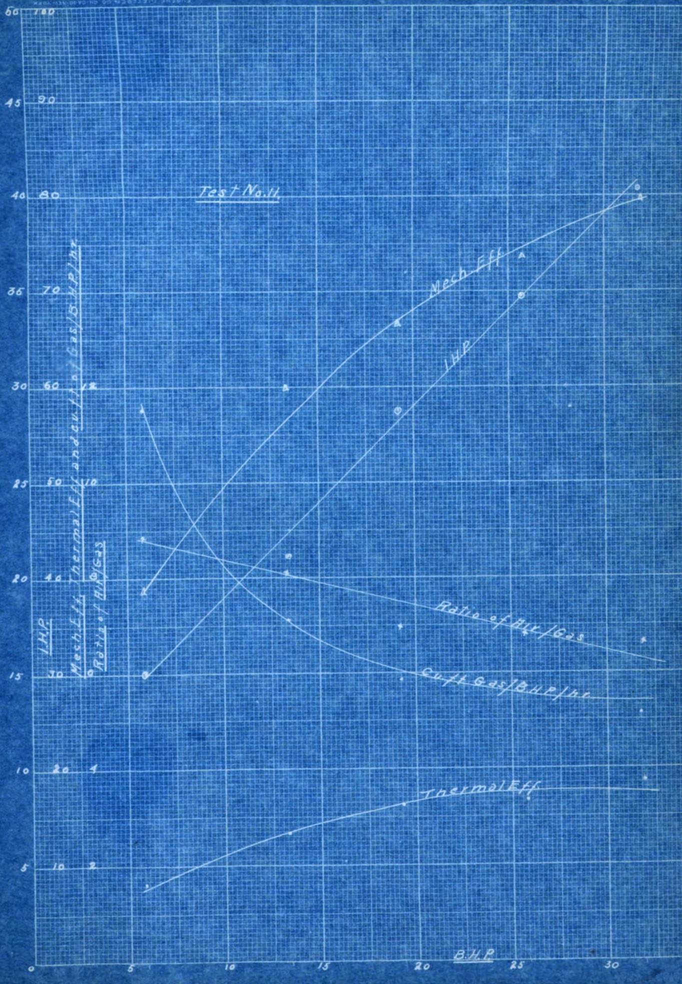
Test No.8.
Mech. Eff.
I.H.P.
Ratio of Air/Gas.
Cu.ft. of Gas/BHP/hr.
Thermal Eff.
I.H.P.
Mech. Eff. Thermal Eff. and Cu.ft. of Gas/B.H.P./hr.
Ratio of Air/Gas.
B.H.P.
0
5
10
15
20
25
30
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12



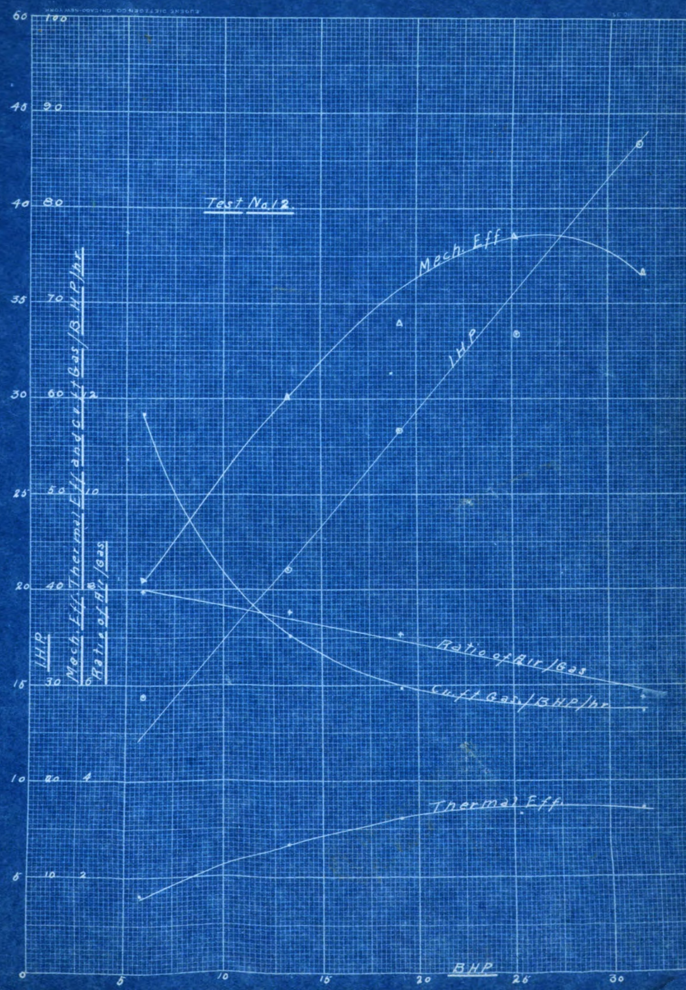
Test No. 9.
Mech. Eff
I.H.P.
Ratio of Air/Gas
Cu ft of Gas/B.H.P./hr
Thermal Eff.
I.H.P.
Thermal Eff Mech Eff and Cu ft Gas/B.H.P./hr
Ratio of Air/Gas
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12



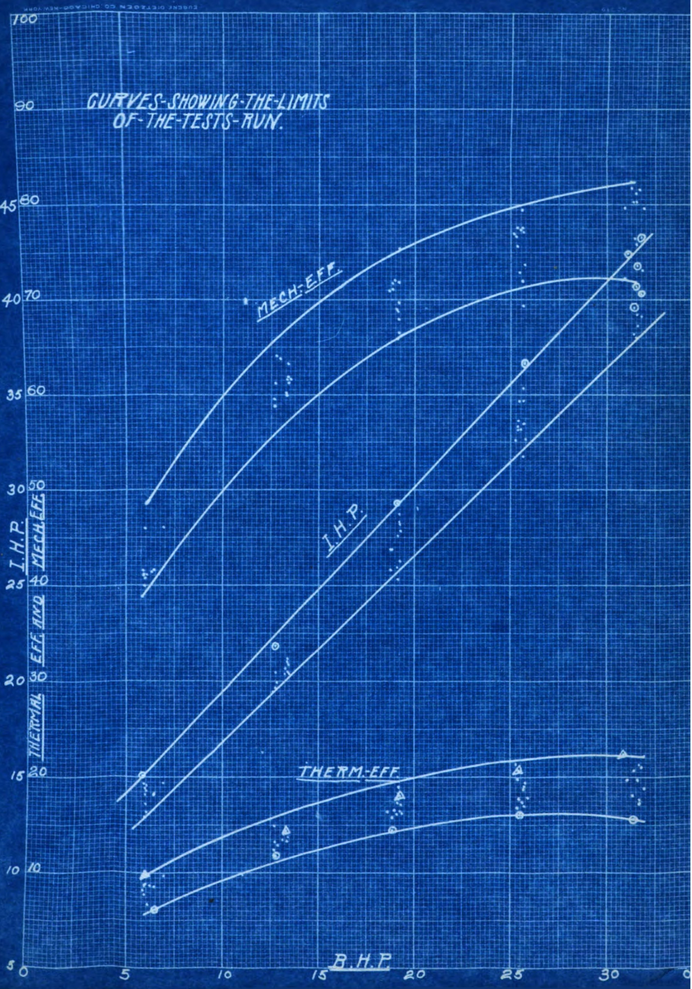
Test No.10.
Mech Eff
I.H.P.
Ratio of Air/Gas
Cu.ft. Gas/B.HP/hr
Thermal Eff.
B.H.P.
I.H.P.
Mech.Eff. Thermal Eff. and Cu.ft. of Gas/B.HP/hr
Ratio of Air/Gas.

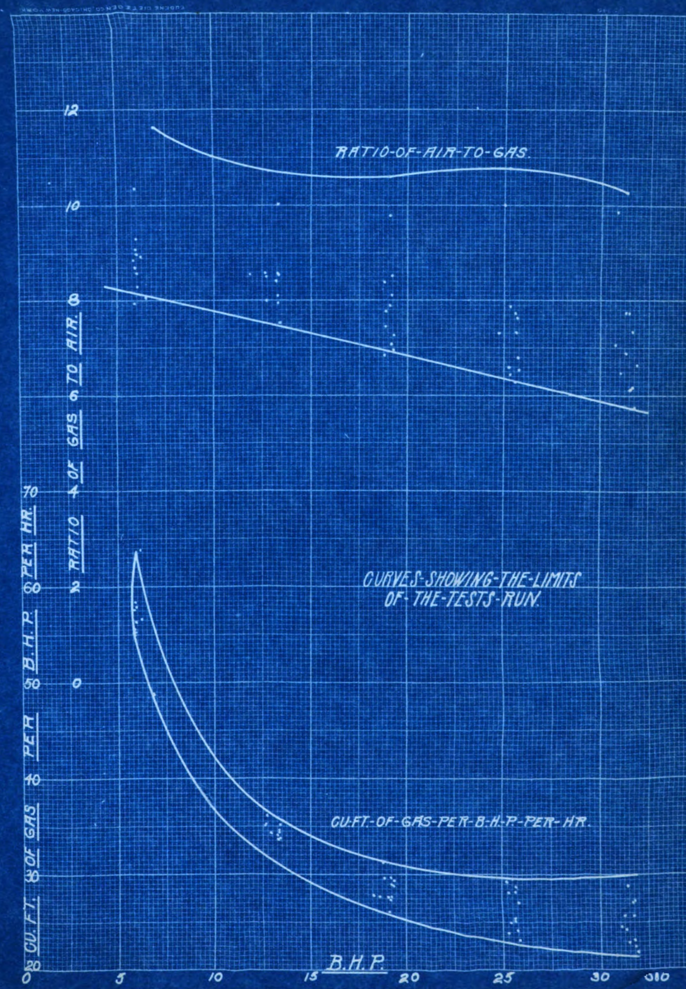


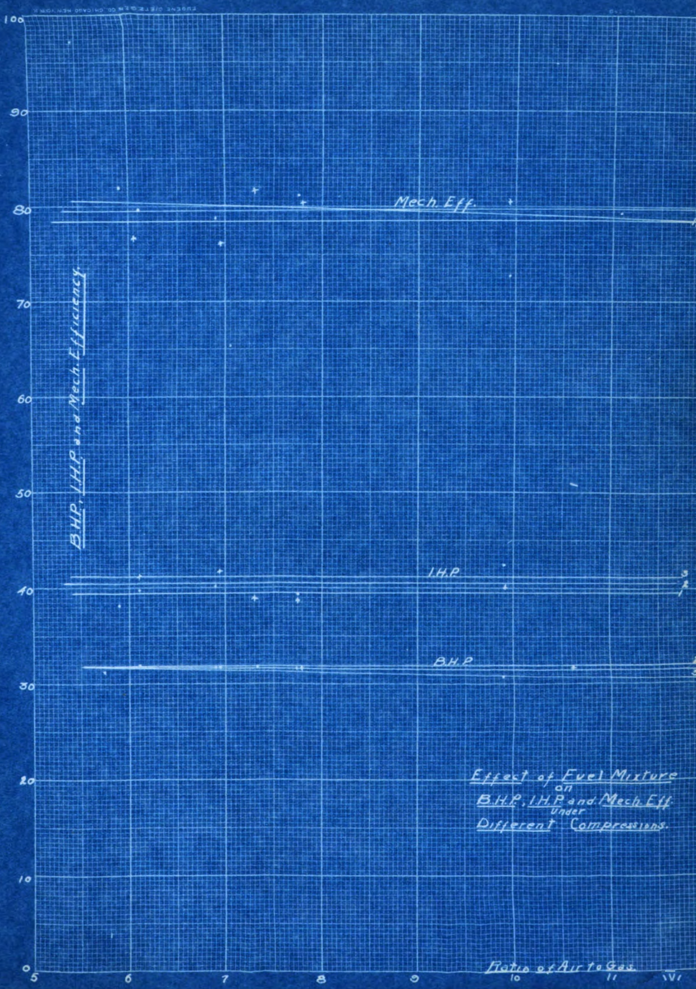
Test No. 11.
Mech. Eff.
I.H.P.
Ratio of Air/Gas
Cu ft Gas/B.H.P./hr.
Thermal Eff.
I.H.P.
Mech. Eff. Thermal Eff. and cu. ft. of Gas/B.H.P./hr.
Ratio of Air/Gas
B.H.P.
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12

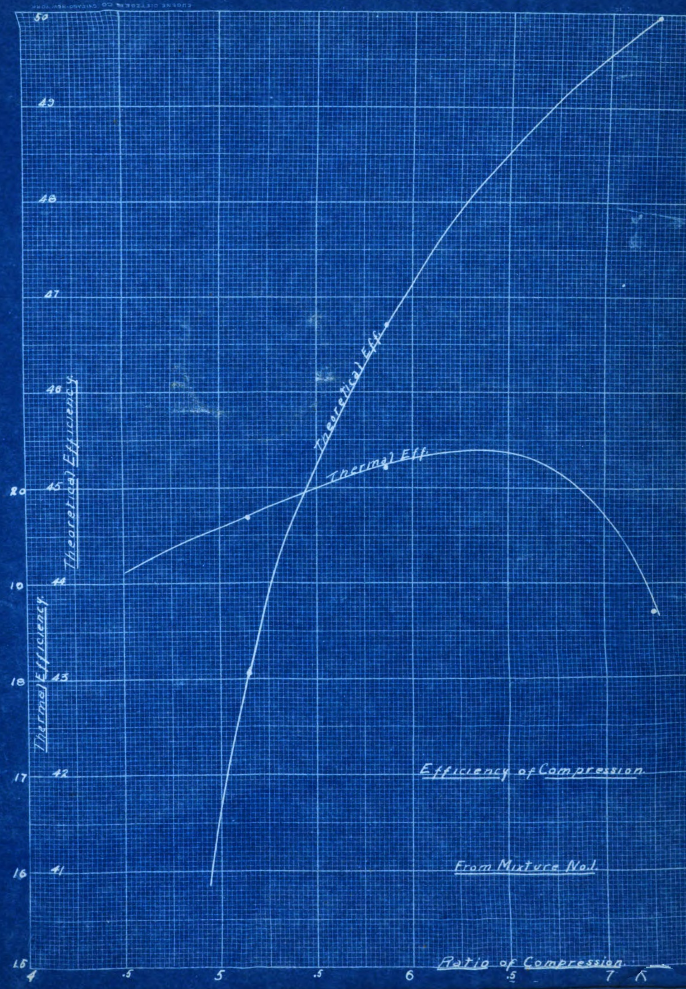


Test No.12.
Mech. Eff.
I.H.P.
Ratio of Air/Gas
Cu ft Gas/BHP/hr
Thermal Eff.
I.H.P.
Mech. Eff.
Thermal Eff. and Cu ft Gas/B.H.P./hr
Ratio of Air/Gas
BHP
0
5
10
15
20
25
30
35
40
45
60
100
90
80
70
60
50
40
30
20
10
12
10
8
6
4
2

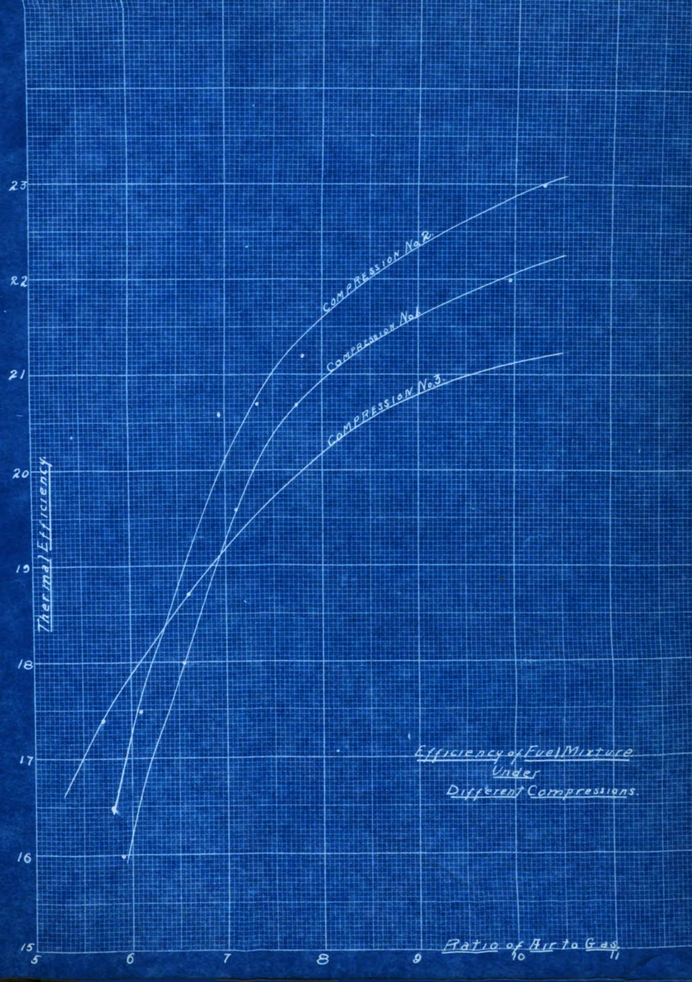

CURVES-SHOWING-THE-LIMITS
OF-THE-TESTS-RUN.
MECH-EFF.
I.H.P.
THERM-EFF.
I.H.P.
THERMAL EFF. AND MECH. EFF.
B.H.P.
100
90
45 80
40 70
35 60
30 50
25 40
20 30
15 20
10 10
5 0
5
10
15
20
25
30


RATIO-OF-AIR-TO-GAS.
CURVES-SHOWING-THE-LIMITS OF-THE-TESTS-RUN.
CU.FT.-OF-GAS-PER-B.H.P.-PER-HR.
RATIO OF GAS TO AIR.
CU.FT. OF GAS PER B.H.P. PER HR.
B.H.P.
12
10
8
6
4
2
0
70
60
50
40
30
20
0
5
10
15
20
25
30


Mech. Eff.
I.H.P.
B.H.P.
B.H.P., I.H.P. and Mech. Efficiency.
Effect of Fuel Mixture on B.H.P., I.H.P. and Mech. Eff. Under Different Compressions.
Ratio of Air to Gas.
100
90
80
70
60
50
40
30
20
10
0
5
6
7
8
9
10
11



Theoretical Eff.
Thermal Eff.
Theoretical Efficiency
Thermal Efficiency
Efficiency of Compression.
From Mixture No1.
Ratio of Compression.
50
49
48
47
46
45
44
43
42
41
20
19
18
17
16
15
4
.5
5
.5
6
.5
7



COMPRESSION No 2.
COMPRESSION No 1.
COMPRESSION No 3.
Thermal Efficiency
Ratio of Air to Gas
23
22
21
20
19
18
17
16
15
5
6
7
8
9
10
11
Efficiency of Fuel Mixture
Under
Different Compressions.

TEST No. 2.

TEST No. 3.

TEST No. 5.

TEST No. 12.

TEST No. 11.

TEST No. 10.

END -- H

Test No. 1.

50# spring.

END -- H

Test No. 4.

50# spring.

END -- H.

Test No. 5.

50# spring.

APPENDIX

OUTLINE OF TEST

Efficiency of a Gas Engine as Determined by Fuel Mixture and Compression.

The test will be run under different conditions of fuel mixture with different loads and different conditions of compression.

1. The loads are to be applied by means of a water cooled Prony brake and applied in this order; determine the largest load the engine will carry under operating conditions and divide it up into five increments, the loads to be applied successively. This will give five points on all curves plotted with loads.

2. The length of tests are to be from 30 to 40 minutes, taking readings every five minutes.

3. Readings necessary.

   Gas meter.

   Temperature on both sides of the meter, the inlet side and outlet side.

   Pressure on corresponding sides of the meter.

   R. P. M. of engine.

   Venturi-meter manometer readings.

   Air temperature at venturi-meter.

   Barometer reading, beginning and end of test.

   Loads.

   Time.

4. The gas is to be measured by a standard gas meter. Samples are to be pumped into a tank during the test and the calorific calue determined at the end of each test if possible. An ultimate analysis is to be run at the same time in order to check all work.

5. The air is to be measured by means of a suitable low pressure orifice arranged with a by-pass for starting.

6. The compression is changed by putting in or taking out shims in the connecting rod.

The amount of compression is measured by use of an indicator and reducing motion cutting out spark at the time of taking card.

7. An ultimate analysis will be made of the exhaust gases, thus giving a check on the amount of air passing through the engine.

8. The I. H. P. is measured by means of indicator cards, taken every five minutes, and the engine constant.

9. The B. H. P. is measured by means of brake load, which must be kept constant thruout the test, and the B. H. P. constant.

In refard to the different mixtures, the limits will be found by trial and work will be carried on within those limits.

The outlet temperature of the cooling water should be maintained as near as possible at 180 degrees F.

The angle of ignition is to be set at 15 deg. and is to be maintained constant thruout the test.

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--oo$oo--

Sample computations for data of test No. 2 Mixture No. 2, compression No. 1, load 170#.

--oo$oo--

Formula for computing the weight of air flowing thru an orifice.

Formula for a 2" orifice.

$W = .6299 \times cd^2 \frac{(i)}{(T)}^{\frac{1}{2}}$

W = weight of air in pounds per second.

c = diameter of discharge (.6 for 2" orifice"

i = Pressure in inches of water.

T = absolute temperature.

d = diameter of orifice in inches.

$W = .6299 \times .6 \times 4 \frac{(i)}{(T)}^{\frac{1}{2}}$

$W = 1.51176 \times \frac{(i)}{(T)}^{\frac{1}{2}}$

From test No. 2, mixture No. 2, compression No. 1, load 170#.

i = .73

T = 82.5 + 459.2 - .5 = 514.7

$W = 1.51176 \times \frac{(.73)}{(541.7)}^{\frac{1}{2}}$

W = .0555# per sec.

Weight of air per test of 30 minutes each

60 x 30 x .0555 = 99.9# air per 30 min.

1 cu. ft. air at 62° F weighs .076081#.

Cu. ft. air drawn thru orifice No. 1 = $\frac{99.9}{.076081}$ = 1314 cu. ft. air.

From orifice No. 2.

$W = 1.51176 \frac{(.87)^{\frac{1}{2}}}{(541.7)} = .0606\#$ per sec.

Cu. ft. of air drawn thru orifice No. 2 = $\frac{.0606x60x30}{.076081}$

= 1437 cu. ft.

Total air used per test of 30 minutes 1314 + 1437

= 2751 cu. ft. air.

STANDARD GAS USED PER TEST OF 30 MIN.

$\frac{P_1V_1}{T_1} = \frac{PV}{T}$

P_1 = Pressure of std. gas (30" Hg.)

V_1 = Volume of std. gas used.

T_1 = Temperature (Absolute) Std. gas (521.2° F)

P = Pressure (absolute) of gas used.

V = Volume of gas used.

T = Temperature (absolute) of gas feed to engine.

$V_1 = \frac{PV}{T}\frac{(T_1)}{(P_1)}$ $\frac{T_1}{P_1} = \frac{521.2}{30} = 17.373$

For 170# load.

Pressure of gas in main equals 2.44 inches water.

Absolute pressure equals barometric pressure plus $\frac{2.44}{12}$

$x \frac{15}{17} = .179$

P = 28.84 = .179 = 29.019" Hg.

T = 459.2 =-72 - .4 = 530.8° F.

V = 492.

Standard gas used per test of 30 minutes.

$$V_1 = \frac{(29.019 \times 492)}{(530.8)} \times 18.373 = 467 \text{ cu. ft.}$$

BRAKE HORSE POWER.

$$\text{B. H. P.} = \frac{2 \times 3.1416 \times wln}{33000}$$

$$\frac{2 \times 3.1416}{33000} l = .0006 = \text{brake constant.}$$

B. H. P. = .0006 x 170 x 308 = 31.4

INDICATED HORSE POWER.

$$\text{I. H. P.} = \frac{Plan}{33000}$$

$$\frac{la}{33000} = .00086 = \text{Engine constant rear cylinder.}$$

$$\frac{la}{33000} = .000812 = \text{engine constant front cylinder.}$$

I. H. P. rear cyl. = .00086 x 73.62 x 308 = 19.52

I. H. P. front cyl. = .000812 x 74.75 x 308 = 18.7

Total I. H. P. = 19.52 + 18.7 = 38.22.

MECHANICAL EFFICIENCY

$$\frac{\text{B. H. P.}}{\text{I. H. P.}} = \frac{31.41}{38.22} = 82.2\%$$

THERMAL EFFICIENCY

$$\frac{\text{B. H. P. in heat units}}{\text{B. H. P. in gas.}}$$

$$\frac{31.41 \times 33000 \times 30}{778 \times 467 \times 532} = 16\%$$

Cubic feet of gas per B. H. P. per hour.

$\frac{2 \times 467}{31.41} = 29.7$ cu. ft. gas per B. H. P. per hour.

Heating value and air required for combustion from chemical analysis.

Heating value (low)

$H = 275 \times .32 =$ 88

$CH_4 = 910 \times .216 =$ 197

$CO = 324 \times .145 =$ 47

$C_6H_6 = 3560 \times .05 =$ 177

$C_2H_4 = 1512 \times .0145 =$ 22

$CO_2 = 0 \times .0245 =$ 0

$O = 0 \times .245 =$ 0

Total - - - - 531 B. T. U.

Air Required.

$H = .282 \times 2.4 =$ .71

$CH_4 = .216 \times 9.61 =$ 2.08

$C_2H_4 = .0145 \times 14.3 =$ .20

$C_6H_6 = .05 \times 36 =$ 1.80

$CO = .109 \times 2.4 =$ .26

5.05 cu. ft.

8.4 CO_2 in exhaust

2.45 " " gas.

5.95 CO_2

$\frac{5.95}{3} = 1.98$ $2 \times 1.98 = 3.960$ in excess.

2.45 O in gas.

1.2 O in exhaust

1.25 O in exhaust from gas.

3.96 - 1.25 = 2.71 O in excess. Air is 21% O.

$\frac{21}{21 + 2.71} = \frac{5.06}{x}$ x = 5.74 air/ cu. ft. gas.

CALORIMETER TEST.

Temp. inlet water = 13.5° C
" outlet " = 44.5° C
Difference 30.° C

Liters of cooling water = 4.81

Condensation = 21 cc

Gas pressure = 2.5" = .1839 Hg.

" Temperature = 21° C

Liters of gas used. = 30 at meter.

$$\frac{PV}{T} = \frac{P_1V_1}{T_1}$$

$$V \text{ (Std. Gas)} = \frac{P_1V_1T}{PT_1}$$

St. conditions are 62° F and 30" Hg.

62° F = 16.66° C

Barometer = 29.04" Hg.

$$V = \frac{(29.04 + .1839)\ (30 \times .0353)\ (273.1 + 16.66)}{30(273.1 + 21)}$$

V = 1.015 cu. ft.

Heating value = Liters cooling water times difference in temperature.

$$1 \text{ cu. ft. of gas} = \frac{^{\circ}C \times 3.968}{\text{Cu. ft. gas burned.}}$$

$$= \frac{4.81 \times 30.8 \times 3.969}{1.015}$$

= 583 B. T. U. high value.

Heat of condensation =

$$\frac{2.381 \times \text{cc of condensation}}{\text{Cu. ft. of gas burned}}$$

$$= \frac{2.381 \times 21}{1.015}$$

= 49.2 B. T. U.

583 - 492 = 533.8 B. T. U. Low value.

Ratio of compression.

Displacement Rear Cyl. = 603.18 cu. in.

" Front " = 550.02 " "

Clearance rear cyl. = 141 cu. in = 23.4%

" front " = 138.5 cu. in = 25.2%

$$\text{Ratio of compression} = \frac{\text{Total volume}}{\text{Clearance.}}$$

$$\text{Front Cyl.} = \frac{550.02 + 138.5}{138.5} = 4.97$$

$$\text{Rear Cyl.} = \frac{603.18 + 141}{141} = 5.28$$

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