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Some Test Figures from an Oil Engine

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Chairman:

Sir Wm. HALL-JONES, K.C.M.G. (High Commissioner of New Zealand).

The oil engine upon which these tests were carried out has a single cylinder of $8\frac{1}{2}$ in. bore and 14 in. stroke. There is one fly-wheel 5 ft. 2 in. diameter which is fitted with a rope brake to take up the power. The normal speed of the engine is 250 revolutions per minute, at which speed the governor comes into action, holding open the exhaust valve and preventing the suction of fresh mixture until the speed has fallen to its normal value. The supply of oil to the engine is from a graduated tank to an automatic mushroom type valve. The oil passes through fine holes in the seating of the valve, which simply serves for the admission of air. This valve is mounted at the top of a vapouriser kept hot by means of a paraffin blow-lamp ; the lower end of the vapouriser contains the ignition tube. There is no timing valve and ignition takes place automatically at a point in the stroke which is governed entirely by the temperature of the ignition tube, the composition of the charge, and the compression in the cylinder.

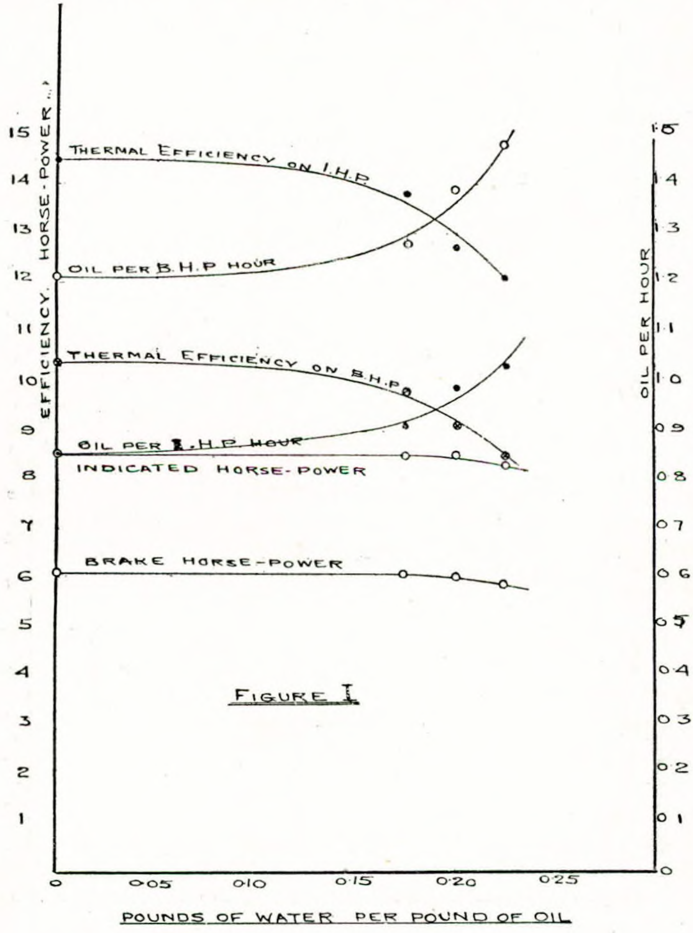
The exact nature of the contents of the cylinder is thus necessarily difficult to estimate and the problem is still further complicated by the difficulty of maintaining the firing point at any definite fixed period in the stroke for any length of time. Between the vapouriser and the cylinder itself there is a short circular cored passage passing through the water jacket but not communicating in any way therewith. This passage is fitted with an automatic valve of special design which allows water to be drawn into the cylinder and mixed with the oil vapour on the suction stroke of the engine, the mixture of oil vapour and water vapour being compressed and fired on the return stroke of the engine. The purpose of the water injection is to tone down the violence of the explosion and prevent the harsh metallic knocking within the cylinder which is such an objectionable feature of most paraffin oil engines, and this it does most effectively. The water supply comes from a small tank especially graduated for the purpose.

Having proved that the injection of water with the oil vapour diminishes the violence of the explosion, the question arises as to what the effect is upon the economy of the engine in working. To ascertain this the author had a series of tests made upon the engine, keeping the brake load constant and all other conditions as nearly as possible so, but varying the amount of water injected. The results of these tests, collected and worked out, are given in Table I and Fig. 1. They show that the thermal efficiency and the economy of the engine quickly decrease as the amount of water injected increases, but the noise and violence of the explosions get less and less, so that quietness of running is secured at the expense of economy in running costs.

The chemical formula for water being H_2O and for a paraffin $C_nH_{2n-6}H_6$, some interesting speculation was indulged in as to whether any dissociation of the H_2O would occur inside the cylinder during combustion.

It seemed to the author that if an approximate simple analysis was made of the exhaust gases, and if they were found to contain a marked difference of nitrogen (or other unknown commodities such as hydrocarbons), when the water was injected, such evidence would prove whether or not dissociation had taken place and whether it would be advisable to place the gas analysis in the hands of a qualified analyst.

He therefore began a series of experiments tentatively by himself and, encouraged by the results, proceeded with the full investigation. In running the engine tests the observa-



tions were made one minute after each other and timed by a stop-watch; there being five principal observations it took five minutes to start and stop a test, the intervening period allowing for gas sampling and indicating. Fig. 2, which is plotted from the observations given in Table 2, shows the results obtained from a series of experiments which were made under constant conditions. The outlet temperature of the jacket water was kept at 100° F., the load on the brake

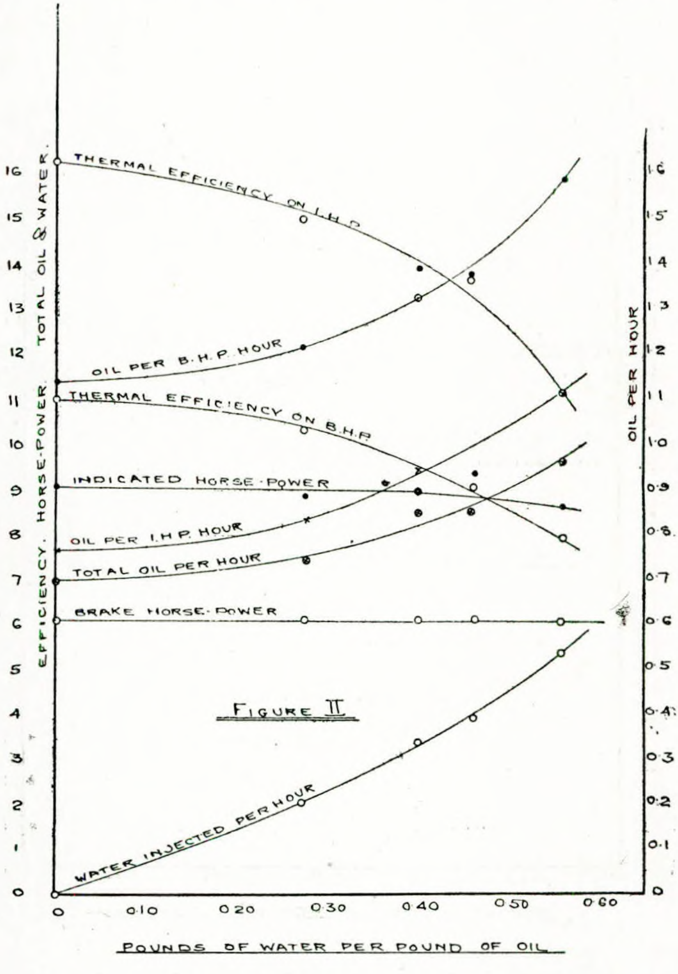


FIGURE II

at 50 lb. net, the oil cock $\frac{1}{8}$th turn open and the same tension on the mixture valve spring all through.

The blow-lamp was kept in a fixed position below the ignition tube and the flame maintained as nearly as possible at one definite intensity. The amount of water injection was varied both by opening the water cock and by releasing the tension on the water valve spring. It will be observed that the results obtained are very similar to those shown in Fig. 1, except perhaps that the amount of water injection is much

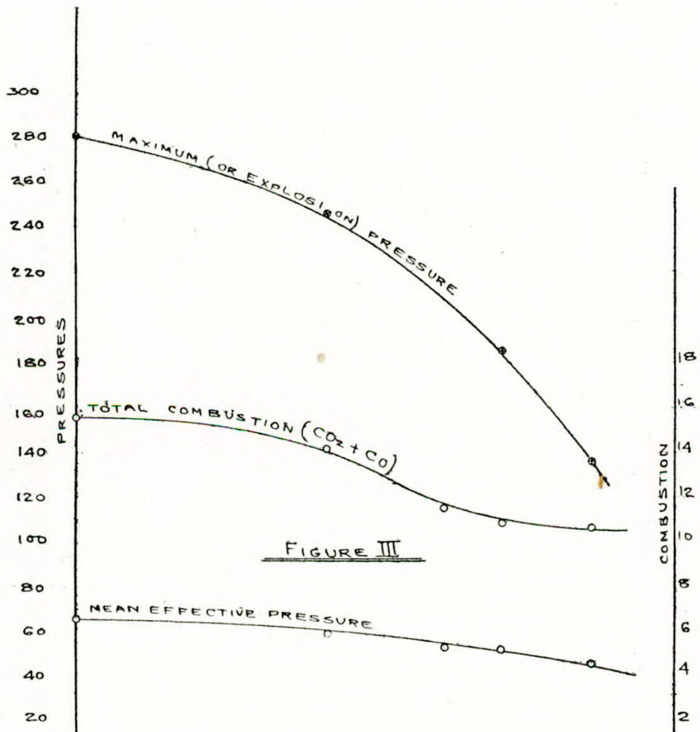
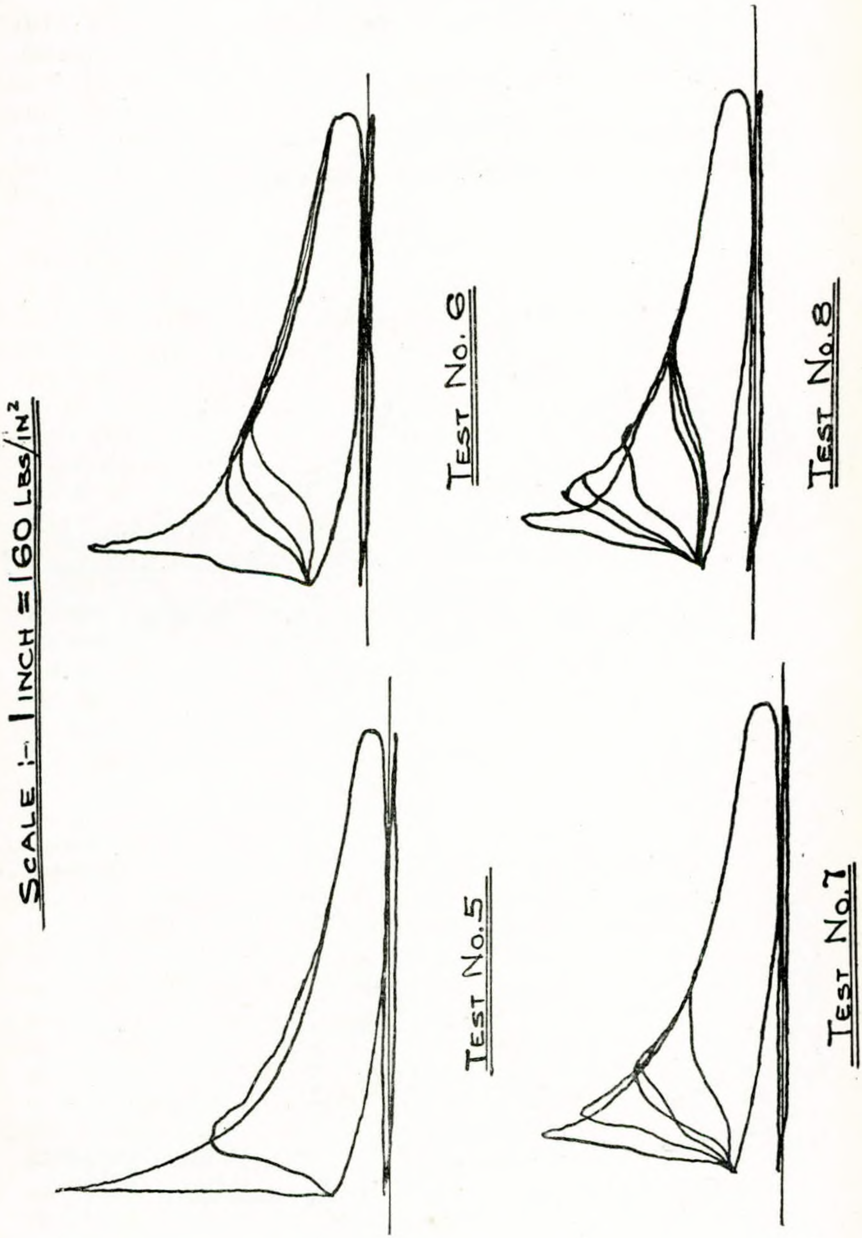


FIGURE III

greater, reaching the extraordinary figure of 56 per cent. With this amount of water injection the running of the engine was very similar to that of a single-acting steam engine (except for the noise made by the governor gear and the automatic inlet valves, the springs of which are not enclosed). The thermal efficiency falls off and the oil consumption rapidly increases with the amount of water injected, showing what an expensive means this is of obtaining a quiet running engine. The knocking does not cease until 30 per cent. of water is being injected, though even when 56 per cent. of water was being injected the noise of the explosions within the cylinder could still be heard, but they sounded very faint and reminded one of listening to distant long range gun practice at sea.

The exhaust gases were sampled in the usual manner and analysed by the author with the Orsat apparatus. The results of the gas analysis are given in Table III and plotted in Fig. 3, from which it will be seen how rapidly the total combustion (CO_2 + CO from volumetric analysis) falls off, but it seems to reach a minimum value at about 50 per cent. of water injection, which is no doubt due to condensation of the oil and water vapour during compression, the liquid leaking past the piston and leaving less combustible to be burnt with the same air supply. On the same diagram are shown also the explosion, or maximum pressure, occurring in the cylinder as measured from the indicator diagram and also the mean effective pressure. Examining the gas analysis figures we note that while the sum of CO_2 and CO by volume continually decreases, the free O continually increases, so that there is no evidence of any dissociation having taken place. Hence the author concludes that the effect of the water injection is merely to damp down the total combustion, causing the maximum or explosion pressure to occur later in the stroke and lowering its value.

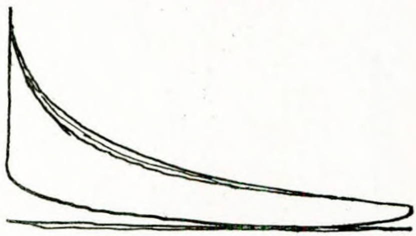
The author thought that perhaps dissociation might take place if the explosions were made more violent and a higher maximum and mean temperature obtained in the cylinder. Accordingly the vapouriser and ignition tube were kept much hotter, the outlet temperature of the jacket water being kept the same (100° F.). It was thought advisable, however, to admit more air and put a little more load on the engine so as to improve the running conditions generally. A difficulty now presented itself on account of the vapouriser getting so hot that ignition occurred much too early and the engine slowed down. However with patience and after several attempts two satisfactory tests were made, the results being given in Table IV. The gas analysis shows slightly improved combustion when the water is being injected, but only the CO_2 is increased, the percentage of nitrogen being almost


SCALE :- 1 INCH = 160 LBS/IN²
TEST No. 6
TEST No. 8
TEST No. 5
TEST No. 7

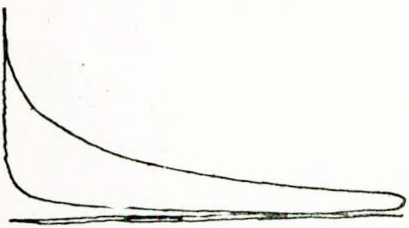
TEST No. 9

SCALE:- 1 INCH = 200 LBS/IN²

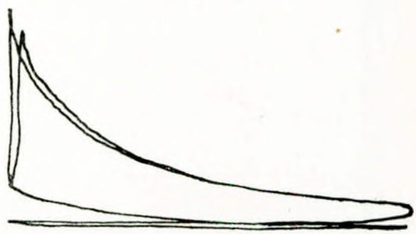
TEST No. 10A.



TEST No. 10B

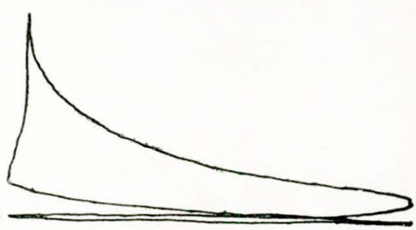


TEST No. 11A

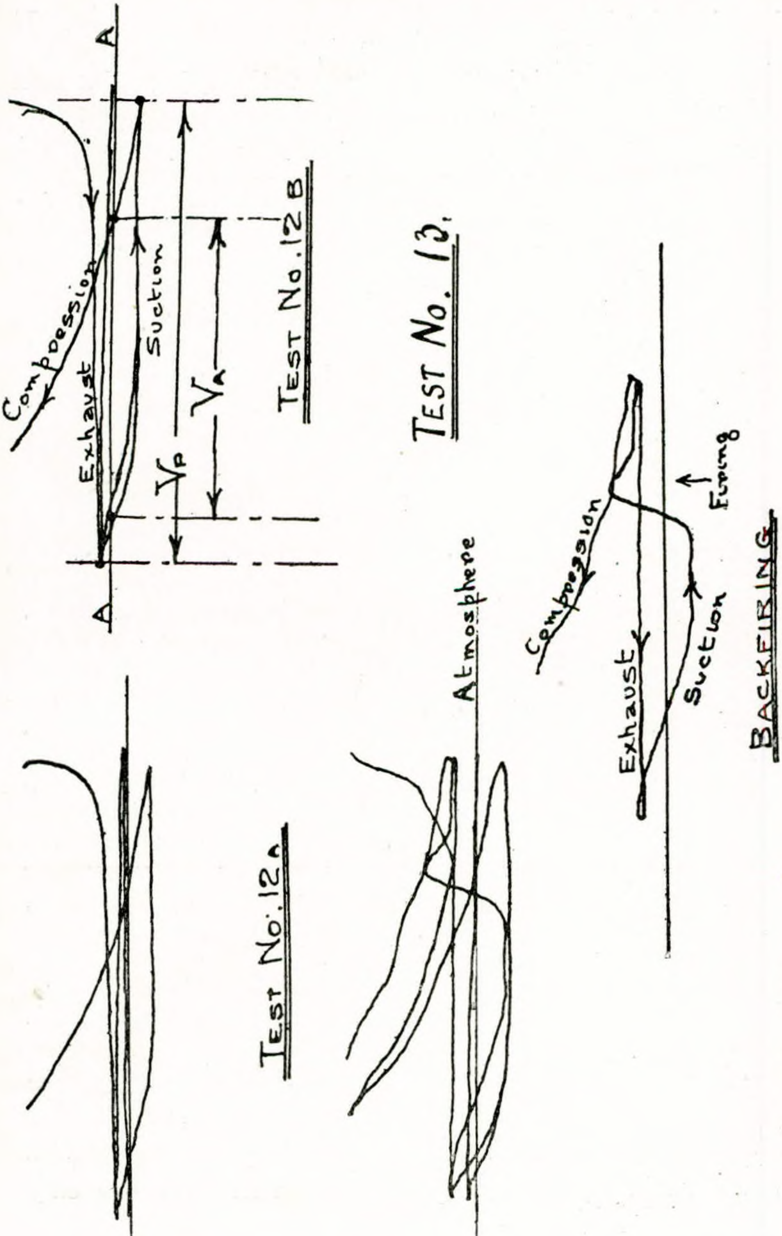


TEST No. 11B

TEST No. 12A



TEST No. 12B.



A
A
Compression
Exhaust
Suction
V_P
V_A
TEST No. 12 B
TEST No. 13.
Atmosphere
Compression
Exhaust
Suction
Firing
BACKFIRING
TEST No. 12A

identical for both conditions, while the free O decreases. If the indicator diagrams be examined, it will be seen that the effect of the water injection is to retard the firing point and bring it back nearly to the dead centre, the result being that a higher compression pressure is reached before ignition; this would, of course, slightly increase the efficiency of the combustion process. The author does not, at any rate, consider there is any evidence to show that dissociation has taken place. The last tests were made under similar conditions as regards the vapouriser, but with the mixture valve adjusted as in the first tests, the load being 50 lb. net, but more water being injected. In this case the total combustion is distinctly decreased, and the test is a very remarkable one in many ways, so that the author gives the working out in full below.

In test No. 12*a* ignition occurred when the compression pressure was as low as 25 lb. per sq. in. above atmosphere, whereas in test No. 12*b* ignition did not occur until the full compression pressure was reached, and under these conditions a very marked economy in oil consumption is obtained. This improved economy in the oil consumption was also noted on tests No. 10*b* and 11*b* under similar conditions. In 10*a*, 11*a*, and 12*a*, it was noted that during certain periods of the test the engine laboured rather heavily and seemed inclined to slow down, whereas in 10*b*, 11*b*, and 12*b* no such result was observed. The author shows the oil consumption figures in Table V for these tests; but it must be remembered that in 10*a*, *b* and 11*a*, *b* the *air* supply was greater than in the earlier tests. In test No 12*a*, *b* the *air* supply was the same as in tests 1 to 9 inclusive, so that 12*b* shows how by keeping the vapouriser much hotter the oil consumption may be greatly improved, the oil per horse-power hour in test No. 12*b* being much lower than that in test No. 5 for instance.

In summing up the author believes that he is justified in drawing the following conclusions from the results of his tests.

1. That in an oil engine the economy in oil consumption is greater with a moderately high compression than with a very low compression before ignition.
2. That the economy obtained by working with a very hot vapouriser is greater than that with one only moderately hot.

3. That the true effect of injecting water with the oil vapour is to damp down the total combustion and to lower the economy—that is to say, the engine becomes less efficient.
4. That if in case (3) a greater economy results such economy is not due to dissociation of the H_2O but is in reality due to improved conditions, (1) and (2), being realized as the result of injecting water with the charge.

TABLE I.

Test No.	Pounds of Water injected per pound of oil used.	Indicated Horse-Power.	Brake-Horse-Power.	Oil per I.H.P. per hour in pounds.	Oil per B.H.P. per hour in pounds.	Absolute Thermal Efficiency on the I.H.P. (per cent.).	Absolute Thermal Efficiency on the B.H.P. (per cent.).
1	0	8·55	6·10	0·86	1·21	14·5	10·4
2	0·174	8·50	6·04	0·91	1·28	13·8	9·8
3	0·198	8·50	6·05	0·99	1·39	12·7	9·1
4	0·232	8·30	5·81	1·03	1·48	12·1	8·5

TABLE II.

Test No.	Pounds of Water injected per pound of oil used.	Indicated Horse-Power.	Brake-Horse-Power.	Oil per I.H.P. per hour in pounds.	Oil per B.H.P. per hour in pounds.	Absolute Thermal Efficiency on the I.H.P. (per cent.).	Absolute Thermal Efficiency on the B.H.P. (per cent.).
5	0	9·10	6·12	0·77	1·14	16·3	11·0
6	0·274	8·88	6·10	0·84	1·22	15·0	10·3
7	0·400	8·99	6·11	0·95	1·39	13·3	9·0
8	0·463	9·37	6·16	0·91	1·38	13·7	9·1
9	0·560	8·65	6·07	1·11	1·59	11·2	7·9

Table III.

Test No.	Pounds of Water injected per pound of oil used.	Gas Analysis by Volume (per cent.).				Total Combustion $CO + CO_2$	Pressures from the Indicator Cards.	
		CO_2	CO	O	N etc. (by difference).		Maximum or Explosion.	Mean Effective.
5	0	9·4	6·2	0·4	84·0	15·6	280	63·1
6	0·244	9·6	4·5	0·6	85·3	14·1	245	58·6
7	0·400	6·9	4·6	6·9	81·6	11·5	190	52·9
8	0·463	6·7	4·1	6·0	83·2	10·8	185	51·3
9	0·560	6·7	3·9	6·4	83·0	10·6	136	45·3

Table IV.

Test No.	Pounds of Water injected per pound of oil used.	Gas Analysis by Volume (per cent.).				Total Combustion $CO_2 + CO$	Pressures from the Indicator Cards.	
		CO_2	CO	O	N, etc. (by difference).		Maximum or Explosion.	Mean Effective.
10*a*	0	11·5	2·3	3·0	83·2	13·8	280	60
10*b*	0·271	12·1	2·0	2·0	83·9	14·1	280	59
11*a*	0	10·1	2·6	1·5	85·8	12·7	280	55·5
11*b*	0·284	11·4	1·5	1·6	85·5	12·9	280	62·8

Table V.

Test No.	Total Oil per hour. lbs.	Total Water per hour (injection).	Pounds of Water per lbs. of Oil.	I.H.P.	B.H.P.	Mechanical Efficiency. %	Oil per I.H.P. hour. Lbs.	Oil per B.H.P. hour. Lbs.
10*a*	7·31	0	0	12·00	7·57	63·1	0·609	0·966
10*b*	6·93	1·88	0·271	11·12	7·53	67·7	0·623	0·921
11*a*	6·55	0	0	9·84	6·54	66·5	0·666	1·000
11*b*	5·99	1·70	0·284	9·64	6·37	66·1	0·622	0·941
12*a*	8·31	0	0	11·02	6·31	57·3	0·754	1·317
12*b*	6·61	3·1	0·469	11·65	6·29	54·0	0·567	1·051

TESTS NOS. 12A AND 12B.

Test number	12*a*	12*b*
Conditions	Very early firing without water injection	Very early firing with water injection.
Duration in minutes	30	30
Oil used per min. in the engine . . . lb.	0·139	0·110
Water injection to the cylinder per min. . lb.	nil	0·052
Pounds of water injected per pound of oil used in the engine	nil	0·469
Calorific value of the oil supply B.Th.U. per lb. (average value by calorimeter)	20,200	20,200
Average composition of the oil (Russian petroleum)	C. 86% H. 14%	C. 86% H. 14%
Speed in revolutions per min.	260·7	260·0
Explosions per min.	100·9	79·9
Explosion (or maximum) pressure lb. per sq. in.	275	275
Compression pressure (before firing) ,, ,,	25	48
Suction pressure (from light spring diagram) lb. per sq. in.	4·0	4·0
Release pressure . . ,, ,,	30·0	26·0
Mean effective pressure . ,, ,,	54·1	72·2
Indicated horse-power	11·02	11·65
Nett load on brake . . . lb.	50·0	50·0
Brake horse-power	6·31	6·29
Mechanical efficiency per cent.	57·3	54·0
Jacket water in lb. per min.	19·3	15·0
Inlet temperature. . . ° F.	58·0	58·5
Outlet temperature . . . ,,	100·0	102·0
Rise in temperature . . . ,,	42·0	43·5
Temperature of the air in engine-room . ,,	63·0	65·0
Exhaust pipe temperature . . ,,	754·0	732·0
Exhaust gas analysis by volume per cent.	CO_2 9·2 CO 5·5 O 1·4 N, etc. 83·9	CO_2 10·3 CO 2·3 O 3·7 N, etc. 83·7
Ratio of air to oil by weight—		
(1) From light spring diagram	21·6	20·8
(2) From gas analysis	14·66	17·22
Absolute thermal efficiency (on I.H.P.)	16·6%	22·2%
Absolute thermal efficiency (on B.H.P.)	9·5%	12·0%

Heat Account in B.Th.U. per Minute.

No. 12A

Dr.	B.Th.U.	%	Cr.	B.Th.U.	%
Heat supplied from the oil	2,808	100	Heat equivalent of I.H.P. . . .	467·2	16·6
			Heat rejected in jacket water. .	810·8	28·9
			Heat lost by incomplete combustion (forming CO) .	452·0	16·1
			Heat carried away by the products of combustion .	392·7	14·0
			Balance of heat account. . . .	685·3	24·4
			Radiation, errors of observation, etc., by difference. .		
Total	2,808	100	Total . . .	2,808·0	100·0

Heat Account in B.Th.U. per Minute.

Dr.	B.Th.U.	%	Cr.	B.Th.U.	%
Heat supplied from the oil	2,222	100	Heat equivalent of the I.H.P. . .	494·0	22·3
			Heat rejected in the jacket water. .	652·5	29·4
			Heat lost by incomplete combustion	174·5	7·8
			Heat carried away by the excess air	42·1	1·9
			Heat carried away by the products of combustion .	299·0	13·4
			Heat carried away by the steam from the water injection	70·9	3·2
			Balance of heat account		
			Radiation, errors of observation, etc., by difference .	489·0	22·0
Total	2,222	100	Total . . .	2,222·0	100·0

Calculations for the Heat Account.

No. 12a.

Converting the volume analysis to a weight analysis—

Volume fraction × Relative Density.		Fractional Weight.
CO_2	$0{\cdot}092 \times 22 = 2{\cdot}025$	0·1371
CO	$0{\cdot}055 \times 14 = 0{\cdot}770$	0·0521
O	$0{\cdot}014 \times 16 = 0{\cdot}224$	0·0152
N, etc.	$0{\cdot}839 \times 14 = 11{\cdot}750$	0·7956
Total	14·769 —	1·0000

Analysis of exhaust gases by weight—

CO_2 13·71% CO 5·21% O 1·52% N, etc. 79·56

Weight of carbon in 1 lb. of dry exhaust gas—

$= \frac{3}{11}$ of the CO_2 by weight $+ \frac{3}{7}$ of the CO by weight

$= \frac{3}{11} \times 0{\cdot}1371 + \frac{3}{7} \times 0{\cdot}052 = 0{\cdot}0597$.

Weight of dry exhaust gas per 1 lb. of carbon burned—

$= \frac{1}{0{\cdot}0597} = \mathbf{16{\cdot}75}$ **lb.**

Weight of dry exhaust gas per 1 lb. of oil burned—

$= 16{\cdot}75 \times$ (the weight of carbon in 1 lb. of oil)

$= 16{\cdot}75 \times 0{\cdot}86 = \mathbf{14{\cdot}4}$ **lb.**

Weight of steam formed—

$= 9 \times$ (the weight of hydrogen in 1 lb. of oil).

$= 9 \times 0{\cdot}14 = \mathbf{1{\cdot}26}$ **lb.**

Total weight of exhaust gas per 1 lb. of oil burned $= \mathbf{15{\cdot}66}$ **lb.**

Weight of air used per 1 lb. of oil $= 15{\cdot}66 - 1 = \mathbf{14{\cdot}66}$ **lb.**

Weight of air theoretically needed per 1 lb. of oil—

$= 11{\cdot}56 \times$ (carbon in 1 lb. of oil) $+ 34{\cdot}67 \times$ (hydrogen in 1 lb. of oil).

$= (11{\cdot}56 \times 0{\cdot}86) + (34{\cdot}67 \times 0{\cdot}14)$.

$= 9{\cdot}94 + 4{\cdot}85 = \mathbf{14{\cdot}79}$ **lb.**

Weight of products of combustion per 1 lb. of oil $= 14{\cdot}79 + 1 = 15{\cdot}79$ lb.

$$\frac{\text{Carbon burned to } CO_2}{\text{Whole carbon in 1 lb. of oil}} = \frac{CO_2 \text{ by volume}}{(CO_2 + CO) \text{ by volume}} = \frac{0{\cdot}092}{0{\cdot}147} = 0{\cdot}626$$

$\therefore$ Carbon burned to $CO_2 = 0{\cdot}626 \times 0{\cdot}86 = \mathbf{0{\cdot}538}$ lb. per 1 lb. of oil.

Carbon burned to CO $= 0{\cdot}86 - 0{\cdot}538 = \mathbf{0{\cdot}322}$ lb. per 1 lb. of oil.

Products of Combustion :—

		Per 1 lb. of products × specific heat.
CO_2	$= \frac{11}{3} \times 0{\cdot}538 = 1{\cdot}973$	$0{\cdot}127 \times 0{\cdot}216 = 0{\cdot}0274$
CO	$= \frac{7}{3} \times 0{\cdot}322 = 0{\cdot}752$	$0{\cdot}048 \times 0{\cdot}248 = 0{\cdot}0119$
O	$= 9 \times 0{\cdot}14 = 1{\cdot}260$	$0{\cdot}081 \times 0{\cdot}480 = 0{\cdot}0389$
N by difference	$= 11{\cdot}585$	$0{\cdot}744 \times 0{\cdot}244 = 0{\cdot}1816$
Total	15·570	1·000 Total 0·2598

Mean specific heat per 1 lb. of products $= \mathbf{0{\cdot}260}$.

No. 12B.

Converting volume analysis to a weight analysis—

	Volume fraction × Relative Density.	Fractional Weight.
CO_2	$0{\cdot}103 \times 22 = 2{\cdot}266$	0·1521
CO	$0{\cdot}023 \times 14 = 0{\cdot}322$	0·0216
O	$0{\cdot}037 \times 16 = 0{\cdot}592$	0·0397
N, etc.	$0{\cdot}837 \times 14 = 11{\cdot}732$	0·7866
Total	14·903	1·0000

Analysis of exhaust gases by weight—

CO_2 15·21% CO 2·16% O 3·97% N etc. 78·66%

Weight of carbon in 1 lb. of dry exhaust gas—

$= \frac{3}{11} \times 0{\cdot}1521 + \frac{3}{7} \times 0{\cdot}0216 = \mathbf{0{\cdot}0507}$ **lb.**

∴ Weight of dry exhaust gas per 1 lb. of carbon burned.

$= \frac{1}{0{\cdot}0507} = 19{\cdot}72$ lb.

Weight of dry exhaust gas per 1 lb. of oil burned—

$= 19{\cdot}72 \times 0{\cdot}86 = \mathbf{16{\cdot}96}$ **lb.**

Weight of steam formed $= 9 \times 0{\cdot}14 = \mathbf{1{\cdot}26}$ **lb.**

Total weight of exhaust gas per 1 lb of oil burned—

$= 16{\cdot}96 + 1{\cdot}26 = \mathbf{18{\cdot}22}$ **lb.**

Weight of air used per 1 lb. of oil $= 18{\cdot}22 - 1 = \mathbf{17{\cdot}22}$ **lb.**

Weight of air theoretically needed per 1 lb. of oil $= \mathbf{14{\cdot}79}$ **lb**

Excess air per 1 lb. of oil $= 17{\cdot}22 - 14{\cdot}79 = \mathbf{2{\cdot}43}$ **lb.**

Weight of products of combustion per 1 lb. of oil—

$= 14{\cdot}79 + 1 = \mathbf{15{\cdot}79}$ **lb.**

$$\frac{\text{Carbon burned to } CO_2}{\text{Whole carbon in the fuel}} = \frac{10{\cdot}3}{10{\cdot}3 + 2{\cdot}3} = \frac{10{\cdot}3}{12{\cdot}6} = 0{\cdot}818.$$

∴ Carbon burned to $CO_2 = 0{\cdot}818 \times 0{\cdot}86 = 0{\cdot}704$ lb. per 1 lb. of oil.
Carbon burned to $CO = 0{\cdot}86 - 0{\cdot}704 = 0{\cdot}157$ lb. per 1 lb. of oil.

Products of Combustion—

		Per 1 lb. of products × specific heat.
CO_2	$\frac{11}{3} \times 0{\cdot}703 = 2{\cdot}577$	$0{\cdot}163 \times 0{\cdot}216 = 0{\cdot}0352$
CO	$\frac{7}{3} \times 0{\cdot}157 = 0{\cdot}366$	$0{\cdot}023 \times 0{\cdot}248 = 0{\cdot}0057$
H_2O	$9 \times 0{\cdot}14 = 1{\cdot}260$	$0{\cdot}080 \times 0{\cdot}480 = 0{\cdot}0384$
N by difference	$= 11{\cdot}587$	$0{\cdot}734 \times 0{\cdot}244 = 0{\cdot}1791$
Total	15·790	1·000 0·2584

Mean specific heat of products of combustion $= 0{\cdot}258$.

No. 12A and 12B.

Heat lost by incomplete combustion—

$= \begin{cases} \text{(Weight of carbon burned to CO per 1 lb. of oil)} \times \text{(the difference} \\ \text{between the calorific value of carbon burned to } CO_2 \text{ and carbon} \\ \text{burned to CO)} \times \text{(the number of pounds of oil used per minute).} \end{cases}$

Heat carried away by the products of combustion—

$= \begin{cases} \text{(Weight of products per 1 lb. of oil)} \times \text{(mean specific heat of} \\ \text{products)} \times \text{(the difference between the exhaust pipe tempera-} \\ \text{ture and the atmospheric temperature)} \times \text{(the number of pounds} \\ \text{of oil used per minute).} \end{cases}$

Heat carried away by the excess air—

$= \begin{cases} \text{(Weight of excess air per 1 lb. of oil)} \times \text{(specific heat of air at} \\ \text{constant pressure)} \times \text{(the difference between the exhaust pipe} \\ \text{temperature and the atmospheric temperature)} \times \text{(the number} \\ \text{of pounds of oil used per minute).} \end{cases}$

Heat carried away by the steam from the water injection—

$= \begin{cases} \text{(Number of pounds of water injected per minute)} \times [(0{\cdot}48 \text{ times} \\ \text{the difference between the exhaust pipe temperature and } 212^\circ \text{ F.)} \\ +\text{(the latent heat of steam at } 212^\circ \text{ F.)} + \text{(the difference between} \\ 212^\circ \text{ F. and the air temperature)].} \end{cases}$

THE LIGHT SPRING DIAGRAMS.

Let Va = volume of charge drawn in at atmospheric pressure.

Vp = volume swept by piston.

Measure the lengths of Va and Vp on the diagram, then

$$\text{Actual volume of charge drawn in} = \frac{\text{length } Va}{\text{length } Vp} \times Vp \text{ in c. ft.}$$

(at atmospheric pressure Pa).

Assume the temperature of the charge (Ta ° F. absolute) to be the same as that of the jacket water at outlet. Calculate the density of air (ρ) at Ta ° F. absolute from the formulae.

(1) $Pa\ Vta = 53{\cdot}8\ Ta$ per 1 lb. of dry air.

(2) $= \rho \dfrac{1}{Vta}$ lb. per cubic foot.

Total volume of air drawn in per minute $= Va \times$ (number of explosions per minute).

Weight of air drawn in per minute $= \rho Va\ n$.

$$\text{Ratio } \frac{\text{Air}}{\text{Oil}} \text{ by weight} = \frac{\rho Va\ n}{w}$$

where w = weight of oil used per minute in the engine, as measured on the trial.

NOTE.—The diagram shown in No. 13 is rather interesting. When the mixture valve is admitting too much air the engine frequently fires back through the air inlet pipe (this effect being well known to motorists as a "carburettor blow-black," usually the result of an impoverished mixture), the indicator diagram showing exactly what happens. It may be explained by reference to what occurs on turning a gas stove cock off quickly, the mixture of air and gas being weakened until a mixture is obtained which will explode at atmospheric pressure."

Mr. W. P. DURTNALL: Both the papers we have listened to to-day have been of great interest, and this one more especially because Mr. Kean has given us the results of very elaborate and very interesting research work in oil engines. In the first of his conclusions he says: "In an oil engine the economy in oil consumption is greater with a moderately high compression than with a very low compression before ignition." That is one of the very important points he has put forward. What we want is something between the Diesel and the 80 or 90 lbs. per square inch pressure, and I believe the oil engine will be satisfactory when we develop the oil engine on the old and very interesting Braydon cycle, that is to say with a given moderately high pressure per square inch. The space between the top of the piston and the crown of the cylinder can be, consequently, reduced, and owing to the less amount of oil used in the engines of the four-stroke type better economy can be obtained. I think Mr. Kean will add to the interest of the paper if he gives us his views as to the possibilities of an engine of this description. In the second place Mr. Kean says : " The economy obtained by working with a very hot vaporizer is greater than that with one only moderately hot." There again he raises a very important question. Is it not possible to make a satisfactory gas direct from crude oil ? I think it will give an impetus to some of our members to investigate that subject. In view of the fact that the financial people are opening up the oil fields throughout the empire, it is for us to encourage this kind of paper and this class of research work. I quite agree with him in his remarks on the admission of water. That was illustrated on the industrial trials of heavy vehicles about three years ago. There was one vehicle with a single cylinder engine which gave very interesting results. It was amusing to watch the engine working, but as Mr. Kean so ably puts it, the thermo-dynamic efficiency of that engine, the actual work in foot lbs. performed by it is another question altogether. In thanking the author for this paper I would propose that we adjourn the discussion upon it, as I think there are several members who would like to take part.

Mr. F. M. Timpson : I would like to join in thanking Mr. Kean for his valuable paper, in which he brings out as the result of his experiments a good deal of what I have heard about engines in actual practice during the last two or three years. One thing I would like to point out in connexion with the use of water in marine practice is the addition to the dead-weight carried, and in small boats as fishing vessels, coasters, etc., this would tell against the principle. Again, with two-cycle engines at high compression greater economy of fuel is being got. I know of many types around the coast, and the two-cycle engines with high compression give better fuel economy, and many mention of engines being put in hand to use crude oil of a low grade, which will make them very cheap to run ; but to extend progress you must get some help on the commercial side. With regard to internal combustion engines generally there are propositions in which it is proposed to fit engines in vessels making about three weeks' voyage, and engineers are ready to undertake to build them. Taking the question all round, there have been more inquiries within the last three or four months than I have ever known, showing the increased interest that is being taken in this type of engine. We have a good deal to thank Mr. Kean for in giving us the results of these valuable experiments. I have much pleasure in seconding the vote of thanks, and the motion that the discussion be adjourned.

The motions were then put to the meeting and carried unanimously.

Mr. Kean : I thank you very much for the vote of thanks which you have so kindly given. It has given me great pleasure to be here this afternoon. I would just reply briefly to Mr. Durtnall and say that I am at present experimenting more or less on the particular subject he mentioned. One of the chief difficulties of the Otto cycle is that when drawing in the charge by suction you cannot get the full volume in, and it is necessary to use pressure. Of course it is done in the two-stroke engine, and if it is of the right type it acts perfectly well. I am using a two-stroke engine with a compression of 100 lbs. to the square inch, and it works perfectly. I should like to propose a very hearty vote of thanks to the Chairman for presiding to-day and for the interesting remarks he has made.

Mr. T. F. Aukland : I beg to second the motion very heartily indeed.

The motion was carried with applause.

Chairman : I thank you very much. While you as practical men have appreciated the papers read, I can assure you that I, as a layman, have gained some useful information. I am so interested that I want to hear the remainder of the discussion. I do not know whether the discussion will be limited to members only, but if not and I am at liberty, I will be delighted to be present. We owe a great deal to these gentlemen who have devoted their time to the study of this question, and it is with their help and with the help of those who criticize that we shall arrive at the final result. I again thank you and certainly hope this will not be our last meeting.

The Hon. Secretary: We always give a hearty welcome to visitors to our meetings, and we shall be delighted to see our chairman at any of our meetings.