2. COMBUSTION IN SPARK IGNITION ENGINES

Most of the research made on spark initiated combustion has been concerned with engines. Experiments have, however, been made [21] to determine the effect of grinding sparks on ignitable mixtures of a number of gases. From these experiments, conclusions were made as to whether or not spark free instruments are necessary when working in the presence of these mixtures. It was also shown that the upper limit for ignitability with grinding sparks may lie below the most explosive mixture. The ignitability of mixtures by grinding sparks was found to correspond with results using the criterion for safety from explosion with electrical traction - i.e. whether or not ignition occurs through a 0.8 mm mesh.

The most important and widely-studied phenomenon of combustion in spark ignition engines is that of knock. One report [59] describes it as occurring in a finite time range of approximately 10^{-4} seconds. The knock oscillations run back and forth in the combustion chamber as pressure waves of great amplitude, the steepness of which depends on the form of the combustion chamber. Although the primary wave of the knock oscillation is usually equal to that of the self oscillation of the chamber, oscillations of a higher order can be stimulated. The apparent pressure propagation speed is about 950 m/sec., and at strong knock the extent of the knocking zone may amount to several cms. The amplitude spectra of the knock shocks, even at frequencies of several 10,000 Hertz, still show amplitudes of some atmospheres, so that the knock disturbance may be explained as cavitation phenomena.

A.) Cause of Knock.

Knocking results from the combustion of the residual charge, and the cause of this combustion has generally been attributed to spontaneous ignition. Dreyhaupt [9] considered the possibility of other causes. He concluded that the formation of knock oscillations, without pressure increase, by resonance of the self oscillations, was highly improbable as was also the postulation of detonation to explain knock. He did not exclude, however, the preparation of the uninflamed charge by shock waves.

The prereactions which determine the residual charge have been studied [58] in an externally driven engine, without ignition. The temperature increase of the mixture during passage through the engine was taken as a measure of the prereactions. These were shown to depend markedly on temperature and induction time. A strict relationship between octane number and the prereactions was only found in chemically similar fuels. Raising the octane number by lead addition generally, but not invariably, caused a marked decrease in prereactions. It was observed that in some indicator diagrams a marked hump near T.D.C. occurred at every alternate cycle. This was assumed to be due to some residual gas being mixed with the fresh charge. Thus gas containing end products of prereactions would probably inhibit such reactions in the fresh charge, whilst gas containing products of prematurely interrupted prereactions would probably promote further reaction in the new charge.

The action of residual gases will vary with the mixture strength, and lean mixtures will probably have a mainly thermal effect. Analysing some of the products of these prereactions Damköhler and Eggersgluss [6] found the ratio of higher aldehydes to formaldehyde. This was such that, assuming the higher aldehydes were formed by progressive degredation the formaldehyde must have been produced by a different process, probably by radical chains.

The methods available for the quantitative determination of aldehydes in gasoline have been compared by Widmaier [80]. He concluded that of the usual recognised methods the hydroxylamine hydrochloride method is the most suitable as the others give results that are too low. From experiments in which butylaldehyde and benzaldehyde were added to leaded and unleaded gasolines he concluded that the effect on the antiknock value of the gasolines by the aldehyde group in these compounds was very small. The main effect could be attributed to their molecular structure.

Similar experiments made with peroxides [79] showed that both their active oxygen content and their molecular structure greatly influenced the octane rating of a gasoline. A comparison of the stannous chloride method and the thiocyanate method for determining peroxides in gasoline, favoured the latter.

The absence of a method of determination which is specific for any one peroxide or group of peroxides led to an attempt by Eggersgluss[12] to effect group separation by chromatographic adsorption. Six groups of peroxides were studied in experiments made using various solvents and adsorbents.

The various peroxide groups each showed a characteristic behaviour, and the adsorption was primarily dependent on the kind of polar group present in the peroxide. It was claimed that it was a practical possibility to devise a method, involving suitable combinations of adsorbents and solvents, to separate an unknown mixture of peroxides into the various peroxide groups.

B.) Prevention of Knock. Phenomena Occurring with High Valve Overlap.

In his previously cited paper Dreyhaupt [9] suggests the astatic fading out of the pressure rise resulting from the spontaneous ignition of the residual gas as a means of counteracting the obnoxious effects of knock. Shaped piston crowns may function as knock oscillation dampers as well as hindering any shock waves which originate from the primary flame. He also draws attention to the large compression ratios permissible in sleeve valve engines, presumably because of the absence of hot spots likely to cause glow ignition knock.

Tetraethyl lead was almost exclusively the only anti-knock material used in practice. It was usually limited to a maximum of 0.12 % vol. At one time the question of raising the anti-knock value of 87 octane number gasoline to 100 octane number, by the addition of methyl-aniline and by increasing the content of tetraethyl lead to 0.16 % vol., was considered. [100] It was not found practicable, however, because of valve corrosion etc., caused by the increased lead concentration.

Some experiments have been reported [95] in which a fluid of the composition : -

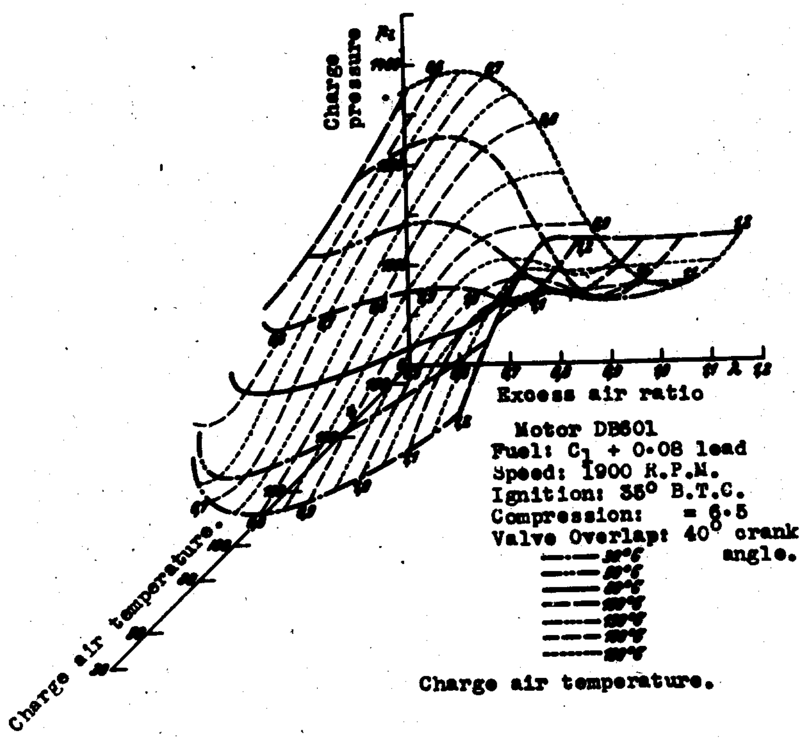
Gasoline	50 %
Iron Carbonyl	40 %
Methyl Aniline	10 %

was added to fuel to give a concentration of 0.05 % of iron carbonyl.

Other methods, besides the addition of anti-knocks were used in Germany to limit knocking. It is reported [98, 105] that coating the piston with fine colloidal graphite gave quite good results in preventing knock. With highly supercharged engines the D.V.L. distributed injection method was used, in which the bulk of the fuel was injected during the compression stroke and the combustion period. This resulted in a flattening and considerable raising of the knock limit curve, particularly with lean mixtures. Increases of mean effective pressure of 2 - 4 kg/cm^2 have been reported. [35]

Considerable research was made on the knock behaviour of fuels in engines with large valve overlap. The general effect of valve over-

Displacement of the minima of the knock limit curves into the rich region with decreasing charge air temperature.



Knock limit curves of C_1 + 0·08 lead with 40° valve overlap in dependence on the excess air ratio, charge pressure and charge air temperature.

FIG. 9.

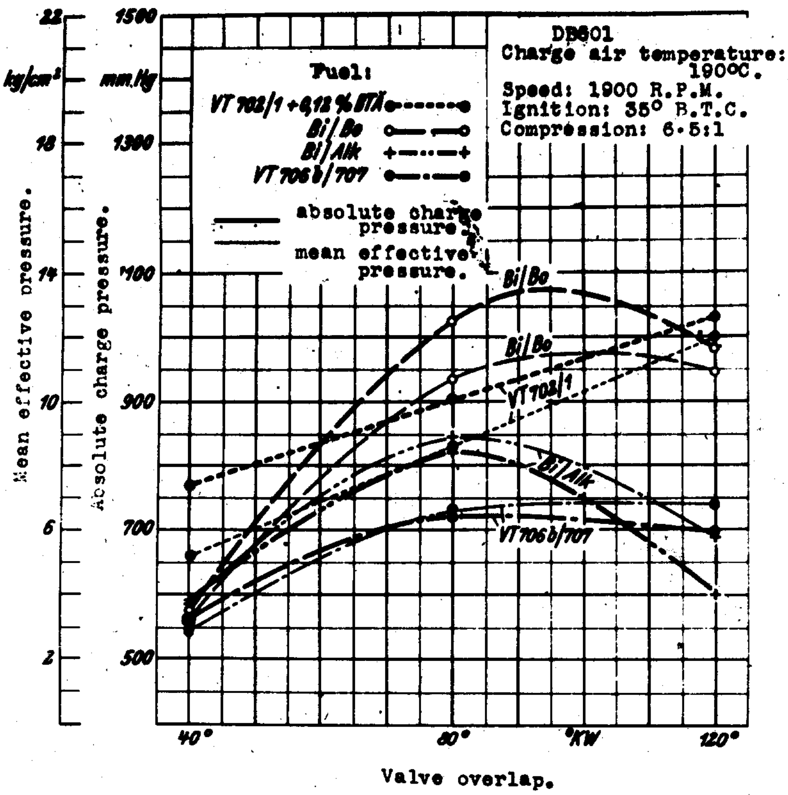
C_1 - Highly Paraffinic Gasoline (Motor Octane Number (Leaded) - 97) lap in raising and flattening the knock limit curve was fully appreciated by the Germans. Valve overlaps as great as 120° were used in some aero engines and enabled very good weak mixture performance even with highly aromatic fuels.[100]

The advantageous effects of valve overlap resulted from scavenging of the residual gases and cooling of the cylinder walls, valves etc. Use of high valve overlaps, however, introduced the problem of how far it was possible to apply the knock limit curves obtained by the D.V.L. supercharge testing method to main engines with large valve overlaps. Often, instead of the conventional knock limit curve, with its minimum near stoichiometric mixture strength, a knock limit curve was obtained with its minimum far in the rich region. Although most experiments, in which this type of curve was obtained, were made with the DB 601 engine, it was recognised that such a curve is not necessarily a characteristic of or peculiar to liquid cooled engines. Indeed, Penzig [50], in his experiment using the DB 601 engine with a valve overlap of 113°, seldom observed such curves.

The knock limit curves having their minimum in the rich region were also found to have a reverse temperature sensitivity; i.e. knock-free performance was actually improved by raising the boost air temperature. With highly aromatic or alcoholic fuels the phenomenon of a knock limit curve minimum in the rich region was not observed.

Franke [18] has explained the formation of the knock limit curve with its minimum in the rich region, and allied phenomena, by invoking Callendar's theory for the formation of peroxides on droplets. In the DB 601 engine the mixture formation had been reported [17] to be poor. This poor mixture formation would result in the formation of unvapourised fuel droplets increasing in proportion with increase in the mixture strength, and these droplets in most instances would be conducive to peroxide formation. Due to this peroxide formation the knock limit curve would be expected to decline continuously as the mixture is enriched. The conventional type of knock limit curve, would be expected with aromatic and alcoholic fuels, since aromatics are little affected by peroxidation in the presence of droplets; and alcohols, although easily peroxidised, require very little energy of activation for further oxidation. Their resulting products of oxidation do not lead to rapid reactions which can produce knocking because of their low energy of dissociation. The reversed temperature effect is readily explained; the increase of the temperature will hinder droplet formation, and thus the knock limit curves will be raised and their minima displaced further into the rich region. Indeed, above a certain temperature no droplets will appear for a certain range of mixture strength, and so a minimum will appear around the stoichiometric mixture strength. A second minimum, however, will appear in the extreme rich region. Fig. 9 is a three-dimensional representation showing how the knock limit curve is influenced by this effect of temperature on the mixture formation.

It was shown by Franke[18] that with regard to the characteristics of the knock limit curve, neglecting the position of the curve, a relationship existed between boost air temperature and



Variation of the knock resistance at the minima in the knock limit curves (λ = 1·05) with change in the valve overlap at a charge air temperature of 190°C.

FIG. 10.

VT 702/1 + 0.12% BTA - Leaded, Coal Hydrogeneration Gasoline (Motor Octane No.- 88)
Bi/Bo - Benzol Blend (Motor Octane No. - 88.5)
Bi/Alk - Alochol Blend (Motor Octane No.- 88)
VT 706b/707 - Blend of two Gasolines (Motor Octane No.75)

valve overlap. Thus, as far as the shape of the curves is concerned, the effect of valve overlap can be compensated by a corresponding alteration of the boost air temperature. As would be expected, the temperature change required to compensate for additional increase in valve overlap is smaller than that required for the first increase, since once scavenging is complete increase of valve overlap has a smaller effect in reducing internal thermal stress.

In the same paper were reported a series of tests made to ascertain the influence of valve overlap on the anti-knock value of fuels; i.e. on the position of the knock limit curve. These tests were made at high boost air temperatures, so that in all cases a minimum occurred near stoichiometric mixture strength. This facilitated comparison of results. Fig. 10 shows the change of the knock limit at the minimum with varying valve overlap. Due mainly to the decrease in internal thermal stress, it is seen that the anti-knock value of all fuels tested increased up to 80° valve overlap. The effects of further increase in valve overlap were irregular, in spite of the fact that thermal internal stress must have been further decreased. The anti-knock value of the fuels with high thermal sensitivity, i.e. benzol and alcohol blends, actually decreased. This outweighing of the effect of decrease of internal thermal stress was attributed to the fact that with these fuels, residual gases favourably affect the kinetics of reaction influencing the knock behaviour. Thus increased scavenging reduced the residual gas quantities until they were no longer of any importance, and so their favourable influence on the knock limit was lost. Whether or not decrease of internal thermal stress outweighed the loss of residual gas was dependent on the type of fuel.

In a later paper Franke [20] described a series of tests to ascertain if correlation with ratings by the D.V.L. supercharge method could be obtained from ratings from knock limit curves having their minima in the rich region. These tests were made on numerous fuels of differing chemical constitution, in the BMW 132 N, DB 601 A and DB 601 E engines.

Use of two valve overlaps (40° and 120°) with the DB engine gave the two types of knock limit curves, from which it could be seen whether any variation in rating was due to difference in engines or solely to the different shapes of the knock limit curves. Knock limit curves obtained from values of the mean effective pressure were completely temperature insensitive in the rich region when low aromatic content fuels were used. Thus the knock limit curves were plotted using absolute boost air pressure values.

Three graphs were plotted : -

(I) Minima of the knock limit curves for the various fuels at $\lambda = 1.05$ for the DB 601 A vs. those for the BMW 132 N. (λ = excess air coefficient)

(II) Anti-knock values at $\lambda = 1.05$ for the DB 601 E vs. the minima at the same λ for the BMW 132 N.

(III) Minima (in the rich region) for the DB 601 E vs. the minima at $\lambda = 1.05$ for the BMW 132 N.

With a few exceptions the ratings seemed superficially to be in good agreement. For the results obtained from the two engines to be in complete agreement, however, it would be necessary for the graph curves to be straight lines passing through the origin at 45°. Although this was approximately true in one graph, others differed in slope. Each difference in gradient results in the requirement of a different constant for the conversion to the BMW 132 N values. Thus it was evident that fuel rating by determining the anti-knock values according to the D.V.L. supercharge method in the BMW 132 N engine could not be used for engines with knock limit curves of different characteristics. Two engine types were recognised - the one where the anti-knock value of fuels rose with increasing boost air temperature, and the other where it fell. The fact that it might be possible to choose a temperature where test and theoretical curves agreed would not permit the fuel rating in one engine type to be applied to the other engine type. It was found that, quite accidentally, the value of 130°C for the boost air temperature of the D.V.L. supercharge test gave a good agreement between the anti-knock values in the DB 601 E and BMW 132 N, provided only the value at $\lambda = 1.05$ was considered.

It was concluded that where only a general evaluation of the anti-knock value of any fuel was required, the normal D.V.L. supercharge method with the BMW 132 N cylinder could be used. Even for this purpose, determination of the order of rating for fuels in engines giving knock limit curves differing from those obtained with the BMW 132 N cylinder is only permissible for fuels with a low aromatic content. Compared with the DB 601 E cylinder, the BMW 132 N cylinder underrated gasoline-benzol blends but, surprisingly enough, rated mixtures with a high isopropylbenzene content too favourably. For the temperature characteristics and the extent of the knock region, however, it is essential to test the fuels in engines which give knock limit curves of a similar kind over the whole operating range.