(c) Reference fuels.

(I) Octane Number Determination. – The C.F.R. and I.G. engines were used for testing fuels of less than 100 octane. As reference fuels for such tests iso-octane and n-heptane were used. Reference has already been made to the use of I.G. standard gasoline and "Z" gasoline as secondary reference fuels. The secondary reference fuel "Z" has the advantage over benzene that its standard curve is a straight line, giving simpler reading and easier extrapolation (if required) for Octane Numbers greater than 100. It has also better anti-freeze properties and lead sensitivity.

(2) Supercharge Testing. - Reference fuels used in the D.V.L. Supercharge Test depended on the type of fuel under test.

(I) For examining B 4 fuel, reference fuel "Eich B 4" was used, the latter being a Leuna hydrogenation gasoline containing 0.12% vol. of T.E.L.

(II) For examining C 3 fuel, reference fuel "Eich C 3" was used, the latter consisting of 80% DHD gasoline from I.G. Ludwigshafen, 20% iso-octane and 0.12% vol. of T.E.L.

(d) Knock measuring instruments.

In the I.G. and C.F.R. test engines the contact bouncing pin was in general use despite the known inaccuracies in this method of knock determination. Schutz [65] discussed the sources of error arising in the use of the contact bouncing pin both from the viewpoint of the theory of the method of measurement and of the mechanical errors arising during measurement. He assumed that knock is a spontaneous ignition arising from a number of points in the residual charge. On the basis that the size of this charge governs the knock intensity, and the energy distribution of the charge the point from which the knock wave starts, he suggested the following methods for determining the knock resistance of fuels:-

(I) Determination of the amplitude of the knock vibrations.

(II) Determination of the locality of the knock centre from the time interval by which quartz indicators differ as to the start of knock.

(III) Determination of the combustion time by the use of ionisation gaps, from the assumption that the combustion time ends at the onset of knock.

Lindner [40] has also discussed other methods of measuring knock resistance, and an electrical indicator, in which a capacitance is altered by change in cylinder pressure, has been described by Meurer. [44]

To eliminate contact burning, adjustment difficulties, etc., which occur with contact bouncing pins, an electrodynamic bouncing pin was developed. In this the pin carried a coil which, with knocking combustion, moved in a magnetic field. The alternating voltage induced, after being rectified, gave a measure of the knock intensity.

Experiments were made [31] to compare electrodynamic bouncing pin, contact bouncing pin and a pressure acceleration knockmeter. An I.G. engine was used, and the tests were made according to both the Motor and Oppau methods. It was considered that in the Motor method the use of the electrodynamic bouncing pin was unobjectionable. In the Oppau method, however, when the electrodynamic bouncing pin was compared with the pressure acceleration indicator, the latter gave a much flatter knock limit curve. This was particularly evident at high lead and benzol contents, where presumably machine vibrations due to the high compression ratios affected the bouncing pin. It was concluded that the acceleration meter has possibilities as an objective knock measuring instrument.

The D.V.L.-Zeiss-Ikon-acceleration meter has been described by Wende [77]. A quartz indicator of frequency between 35,000 and 50,000 Hz., screwed into the cylinder , was used to pick up oscillations in the cylinder, and the course of the second differential of the pressure was observed on a cathode ray oscillograph. The mean value of the amplitude of this d^2p/dt^2 impulse was indicated on an ammeter. This second differential of the pressure is very sensitive to knock and gives an objective measure of it.

It was reported [39] that developments were in progress to enable use of the indicator as an external attachment to the cylinder.

For the purpose of defining the knock limit, the onset of knock was considered of more importance than the knock intensity, and was obtained:-

(i) From the d^2p/dt^2 vs. motor operational value curve. The kink in the curve indicated the onset of knock.

(ii) In main engines, where variable charge pressures could not be used, from the d^2p/dt^2

vs. fuel consumption graph. Here the two bends in the graph indicated the knock region. The theoretical basis of the kink which characterises the beginning of knock was discussed by Lichtenberger [38]. He also reported that the kink always occurred at approximately the point where the incidence of knocking, as determined aurally, was 8 to 10 sharp knocks per minute. The accuracy of determination of the onset of knock was within ± 20 mm Hg. boost pressure even in the most unfavourable cases, while in most of the measurements it was within ± 5 mm Hg.

Utilizing the D.V.L. quartz indicator, a mechanical counter was developed which recorded the number of separate knocks per minute.

In the later piezo-electric instruments, accurate measurements could be obtained up to 100,000 cycles/second.

Another advance in knock measuring was the development of an electro-acoustic method for knock determination. This was described by Kneule [34]. The effect of the gas vibrations on a pick up, placed in any suitable position on the cylinder block, is measured. The basic engine sound can be damped out and the original signals are taken through amplifiers, sensitive to the knock frequency, and are observed either on a cathode ray oscillograph or on a sensitive galvanometer. The main advantages claimed for this system are : -

(i) Ease of attachment of pick up.

(ii) Recording of all intensities from light to strong knock.

(iii) Applicability to multicylinder engines.

(iv) Applicability to engines in actual operation.

It has the disadvantage, however, that the onset of knock may be detected at various compressions on degrees of supercharge, and not at any absolute fixed point, according to the sensitivity of the amplifier.

Agreement between electro-acoustic measurements and road tests was reported [57] to be fairly satisfactory.

It should be noted that in spite of the development of the pressure acceleration and electro-acoustic methods of knock determination, the observation of the onset of knock in the D.V.L.

Supercharge Test continued to be made aurally.

(e) Viewpoints on possible future methods of fuel testing.

Some thought was given to the possibility of characterising fuels from their ignition properties. On this basis it would appear possible to use the same characterisation for both spark ignition and diesel engines. Considering the applicability of ignition delay results for the fundamental characterisation of the self ignition process, F.A.F. Schmidt [62] concluded that the regularity of the self ignition process could be reduced to three values :-

(i) The velocity of the reaction process under a fixed standard state, depending on the nature of the fuel.

(ii) The temperature dependence of the reaction process.

(iii) The pressure dependence of the reaction process.

These characteristics do not remain constant in different pressure and temperature ranges.

Jost [28] pointed out that to form a simple classification of fuels in the test engine, the engine properties have to be eliminated, since knock is a combined quality of fuel and engine. Thus a physical apparatus might just as well be used for fuel testing. He considered that in the future it might be possible to state fuel properties by definition with physical characteristics, and to gauge engines by using in them two fuels of differing characteristics. A similar method was envisaged by Rögener [55], for determination of the decisive factors regarding knocking, such as final temperature, density and time for reaction. In his view, however, instead of a physical test, all fuels would be rated, for all engine types, from one engine test. Assuming that knock depends on temperature, T, density ρ and time τ, then the theoretically true expression for the knock limit of fuel 1 would be

$$f_1 (T . \rho . \tau) = 0$$

Calculating from engine results the expression would be

$$f_1 (T.' \rho .' \tau ')$$

i.e. different values in different engines corresponding to the same true variables.

If three, suitably chosen fuels had true knock limit surfaces (on a $T - \rho - \Upsilon$ diagram) intersecting at a point P, the knock limit surfaces obtained from engine results would intersect at P_1 for engine 1 and P_2 for engine 2. Repeating in different engines the equivalent points (i.e. intersection points) could be plotted as co-ordinates in a three dimensional system. Hence, with a new fuel, by plotting the knock limit surface in one engine, those of other engines could be calculated; since the positions of the surfaces are the same relative to the equivalence points of the other engines as the surface in engine 1 to the equivalence point of 1.

Philippovich [54] was doubtful if a simple laboratory method would be able to replace knock measurement in engines, since engine experiments had shown that knock in engines is not simply the result of a heat explosion but also of cold reactions with a negative coefficient of temperature in certain regions.

D.) Power Boost

Amongst the fuels used for temporary increase in output for such special purposes as starting and air combat were methanol and ethanol, leaded or unleaded.[89] A number of experiments were made [75] which confirmed the advantages claimed for secondary injection of methanol-water mixtures and pure water. In particular, water-methanol mixtures with more than 50 % methanol were found suitable for double fuel operation.

Over a period of four years nitrous oxide was extensively used as a means of temporarily boosting engine power at high altitudes. At first it was used liquefied under pressure at atmospheric temperature. This method gave somewhat erratic running since pressure altered with the external air temperature and with vapourisation. Later super-cooled, pressureless nitrous oxide was used, which allowed larger quantities to be carried and effected an improvement in the specific performance due to increased internal cooling. In spite of the wide use of nitrous oxide for boosting power, C.I.O.S. Report No. XXXII - 44 mentions the tendency to look upon it solely as a makeshift for a good supercharger and internal cooling.

The basic problems involved in the use of oxygen carriers such as nitrous oxide, were considered by Lutz [43]. His calculations were based on the fact that whilst boosting the power, the alteration of indicated power results from the change in the charge weight due to the injection of the carrier, and the energy content of the latter, according to the equation

$$\frac{\Delta N_i}{N_{iO}} = \frac{\Delta W_L}{W_{LO}} + \frac{\delta W_X}{W_{LO}} \qquad \ldots\ldots\ldots\ldots\ldots(19)$$

The "air value" is a complex quantity depending, amongst other things, upon the extent of vapourisation of the oxygen carrier. The other factor in equation (19), namely the charge weight change, depends on :-

(a) The influence of the blower due to the change in boost pressure.

(b) The change in boost air temperature because of the mixture effect.

It was shown that as regards these influences both the latent heat of vapourisation and the extent of vapourisation of the oxygen carrier are very important. Thus the absolute oxygen content of the carrier is not the only factor determining its suitability.

From its effect on the weight of air charge by reason of its great heat of vapourisation and its "air value", hydrogen peroxide would, if completely vapourised, even outstrip oxygen in the increase given in indicated power. Complete vapourisation, however, would be impossible since cooling of the boost air would be too great for the process to be controllable, and at the low temperatures involved hydrogen peroxide would become solid. The use of hydrogen peroxide as a carrier is thus excluded, and knocking and corrosion factors etc., limit the only practicable oxygen carriers to nitrous oxide and oxygen. Both liquid nitrous oxide and liquid oxygen are readily vapourised. Liquid nitrous oxide has the advantage that because of its high latent heat of vapourisation there is a higher absolute rise of output for the same thermal stress on the engine than is possible with oxygen. The specific output gain of liquid nitrous oxide, however, is only 60 - 75 % of that which is available from liquid oxygen.

Lutz, therefore, defined two ranges of application of these oxygen carriers. He suggested that for large gains in output over short periods nitrous oxide should be used, whilst for smaller gains in performance over longer periods, oxygen is best.

The high thermal loads encountered when operating with nitrous oxide, as compared with normal operation, could be countered by increasing the amount of fuel injected. The same effect could be obtained by using a nitrous oxide-alcohol combination, with or without water spraying. This also allowed a greater increase in output. Alcohol or water-alcohol mixtures require an ignition advance, whereas the quick pressure rise, when nitrous oxide is used, makes a retarded ignition desirable. It was expected,[82] however, that with simultaneous injection of nitrous oxide and alcohol no special ignition timing would be necessary.

The importance of place of injection of

nitrous oxide on the possible increase in output was investigated by F.K.F.S. [25] As was expected, injection in front of the blower resulted in a higher output yield than injection behind the blower.

Discussing the conclusions of Lutz, F.A.F. Schmidt referred to experiments showing that the actual temperature difference when working with liquid oxygen as compared with liquid nitrous oxide was not so great as theoretically calculated. Further, he envisaged the admixture of methanol as a coolant in order to achieve extremely high gains in performance with liquid oxygen.

Difficulties in the use of liquid oxygen because of its tendency to give rise to vapour lock and also to become surrounded with a non-conducting layer of gas which prevents evaporation, were said [104] to have been overcome by the insertion of a magnetically controlled valve in the supply line. This valve automatically vented any gas to the air.

The use of methyl alcohol as a fuel or as an internal coolant was sometimes complicated by the appearance of glow ignition phenomena.

Experiments made [88], did not result in an additive being found which would increase the ignition temperature and stop the catalytic reaction. An increase in the ignition temperature was attained, however, by a high percentage admixture of the hydroformed, hydrogenation naphtha, DHD - gasoline.