

THE EFFICIENT BURNING OF FUEL IN HIGH-SPEED OIL ENGINES WITH PARTICULAR REFERENCE TO A CLEAN EXHAUST.*

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SYNOPSIS.

The paper deals with the measures taken by a large passenger-transport undertaking to ensure efficient combustion of the fuel used by its fleet of oil-engined vehicles. The incentive is a dual one—viz., that of retaining the goodwill of the travelling public, and at the same time achieving an economy in fuel consumption. Incomplete combustion is visibly evidenced by exhaust smoke, four types of which are recognized; a fifth is attributable to excessive consumption of lubricating oil. The prime necessity for efficient combustion is an engine of satisfactory design using a fuel of suitable ignition quality. The combination will not show the desired result, however, without due attention being paid to cleanliness of the fuel and to careful maintenance of engine and accessories. The precautions taken in respect of the former, and the special methods employed for maintaining fuel-pumps and injectors in particular, are described in some detail. A brief account is also given of endeavours to apply exhaust-gas-analysis methods to combustion control in oil engines.

INTRODUCTION.

IN the early days of the development of high-speed oil engines in this country some anxiety was felt as to whether progress might not be retarded by reason of a tendency to produce exhaust smoke, and in certain localities oil-engined vehicles were the subject of adverse public comment. Even to-day it is possible to encounter vehicles—almost without exception, it should be said, of the heavy-goods type—the exhaust smoke of which may be fairly described as a public nuisance. This is quite inexcusable, and it is the purpose of this contribution to describe the measures taken by the London Passenger Transport Board to ensure that no such trouble should arise in respect of its oil-engined fleet, the size of which has been steadily increasing throughout the past six years. The problem is one of efficient combustion of the fuel, and could be discussed at length from the viewpoint of either quality of fuel or engine design, or both. These aspects will, however, only be touched upon lightly on the present occasion. At any given moment the characteristics of both engine and fuel used may be regarded as constants, and methods of maintenance must be so adapted as to obtain the best possible results in all circumstances.

The incentive to the efficient utilization of fuel is, of course, twofold: firstly, to retain the goodwill of the travelling public, and secondly, to reduce operating expenses. It may be thought that these two aims have been placed in the wrong order, but in justification it can be stated that in every step in the replacement of petrol engines by high-speed oil engines, it has been the Board's first consideration to make sure that public complaints in respect of smell or smoke shall not arise. So successful has this policy been that as the proportion of oil engines has increased, the number of complaints of "fumes" has substantially decreased.

* Paper presented for discussion at the Morning Session (A), 24th May, at the Summer Meeting of the Institute of Petroleum held in Birmingham, 22-24th May, 1939.

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That, for any given engine, elimination of "fumes" and economy in fuel consumption go hand in hand was demonstrated many years ago, when rigid standardization of carburettor settings was established in respect of petrol engines. Prior to that time carburettors were adjusted by the garages to suit local conditions, and this latitude resulted in a tendency for engine defects to be covered up by the use of larger jets, leading thus to wastage of fuel accompanied by an unpleasant exhaust odour. While a case might be argued in favour of individual "tuning," experience has abundantly shown that for a large fleet of vehicles standardization of all the factors concerned in combustion is the proper course. It was natural, therefore, that similar measures should be taken when petrol engines came to be replaced by oil engines.

EXHAUST SMOKE.

With a petrol engine, incomplete combustion is chiefly evidenced by the presence of carbon monoxide in the exhaust gases, although any obnoxious or irritating odour is, of course, attributable to other partly oxidized products also present, usually in very small amounts. With the high-speed oil engine the carbon-monoxide problem may be said to be practically non-existent; occasionally 0.2 per cent. of this gas may be found in the exhaust products, and very rarely up to 0.4 per cent. Incomplete combustion can, however, occur, and is visibly indicated by a smoky exhaust. Five types of exhaust smoke may be recognized, four being associated with incomplete combustion of the fuel, whilst the fifth is due to excessive consumption of lubricating oil. A dense greyish-white smoke is momentarily produced in the case of indirect-injection engines when starting from cold. The exhaust will present a blackish haze, more or less dense, if the injectors are in poor condition, the direct-injection engine being the more sensitive in this respect. With both types of engines continuous heavy black smoke will be emitted if the setting of the fuel-pump is such as to permit an excess of fuel being injected; the excess-injection point or "smoke limit" is more definite in the case of the indirect-injection engine. The fourth type of smoke attributable to incomplete combustion is really a special case of the third, and may appear as a black puff when the vehicle is taking off from a point. It is due to momentary over-injection, and can be eliminated by correct adjustment of the low-speed injection-stop on the fuel-pump. Excessive consumption of lubricating oil results in the production of a continuous grey smoke, and to avoid any possibility of complaints arising from this cause, it is the Board's practice to keep individual records of lubricating-oil consumption, so that engines may be removed for overhaul before the smoke-point is reached. In respect of odour of the exhaust products, it can fairly be claimed that in the absence of smoke, the oil engine is no more noticeable than the petrol engine, except perhaps on the first occasion on which it is encountered, when the qualitative difference between the respective odours might be detected.

CLEANLINESS OF FUEL.

A fuel of poor ignition quality will inevitably lead to inefficient combustion, perhaps accompanied by exhaust smoke, and the trouble will persist

despite careful maintenance of engine and accessories. A satisfactory fuel also will give trouble if it is not clean, since particles of adventitious matter will cause scoring of the fuel-pump plungers and promote blocking of pintle-holes and accumulation of carbon on injectors. In the very early days of oil-engine development this was one of the factors which had to be contended with, and we have record of an engine the power output of which was found to have decreased by over 20 per cent., due to scoring of fuel-pump plungers. A residual oil, which was in use for a short time, led to considerable accumulation of sludge in the storage-tanks. Even when oil engines were in more common use, it was the suppliers' practice to blend a little fuel-oil with the distillate fuel. They can now justifiably claim, however, that any contamination of the fuel is derived from the users' storage- or service-tanks. Certain operators pass the fuel through a centrifuge immediately before filling service-tanks, although the Board has not considered it necessary to go to this length. Adequate precautions are, however, taken to ensure that the fuel reaches the fuel-pump in as clean a condition as is possible. A sample of fuel taken from the supplier's tank-wagon is forwarded to the laboratory from each garage weekly, and, in addition to inspection for water and dirt, it is subjected to routine tests to establish consistency of supply. Every storage-tank in the fleet (some garages have as many as fifteen) is inspected twice yearly, a bottom sample being taken on one occasion, and on the other the sample is obtained from a point some 2 feet below the level of the fuel. In the event of any appreciable amounts of water or suspended matter being detected in the fuel, the tank concerned is cleaned out. To assist in this operation tanks are, where possible, installed at an angle with the horizontal, and are provided with a sludge-cock at the lowest point. It is also the practice to clean out service-tanks during the overhauling of vehicles. As a further precautionary measure, the fuel is passed through a gauze filter during its discharge from the supplier's tank-wagon, and is again filtered when being pumped from the storage-tanks to the service-pumps. It receives a third filtration while being issued from the service-pumps, filters in which are removed for cleaning at weekly intervals. Finally, a Bosch filter is fitted on each vehicle, in the fuel-line between the service-tank and the fuel-pump; this filter is of the fabric-bag type, the fabric being renewed after each 12,000 miles' service.

MAINTENANCE METHODS.

The efficient burning of the fuel is also dependent on the design of both engine and injectors. The earlier types of direct-injection engines, despite an inherent advantage in respect of both fuel consumption and maintenance costs, were very prone to give a smoky exhaust, and it was for this reason that the Board originally decided on the standardization of the air-cell or indirect-injection type of engine. Comparatively recently, however, direct-injection engines have been improved, particularly in respect of injector design, to a degree such that the smoke problem no longer exists, and it has been possible to commence operating them in numbers on the London streets.

As was indicated at an earlier stage, the fact of having obtained in some measure a satisfactory combination of engine and fuel does not in itself

ensure efficiency, this being achieved only by regular and careful maintenance. Garages are provided with Maintenance Bulletins in which the chassis (including, of course, engine and accessories) is fully described and the various measures to be employed in servicing are laid down in precise terms; these Bulletins have proved to be most valuable, particularly during a period when new equipment is being rapidly introduced. Amongst the various factors which contribute to efficient combustion, the fuel-pump and injectors must be regarded as the most important. The former controls the quantity of fuel injected per cycle, whilst the injectors determine the manner in which the fuel is sprayed into the combustion space; over-injection, unbalanced injection, or a distorted spray will lead to imperfect combustion, with possible production of exhaust smoke and adverse effect on fuel consumption. The procedure adopted in maintaining these essential parts will be described in some detail.

Fuel Pumps.

For each type of engine operated a standard fuel-pump setting is established. The setting is arrived at following bench and road tests, and on occasions employing groups of vehicles running in service. The aim is to provide adequate power, but at the same time to avoid any possibility of the production of smoke. In the case of indirect-injection engines full power is developed when the fuel-pump output is just below the point at which over-injection occurs; with the direct-injection engine the "smoke limit" is not so definite. Experience indicates that plunger outputs tend to increase with extended mileage, although to no great extent within the adjustment period laid down. It has further been found that within practical limits an increase in pump output does not adversely affect fuel consumption.

A special testing equipment, originally designed by the Board's engineers, is installed at each docking garage, and three such units are provided at the overhaul works. The apparatus, which is shown in Fig. 1, permits accurate balancing of the individual fuel-pump plungers and measurement of their output under accurately repeatable conditions, whilst the pump timing can also be set. Quite briefly, the equipment consists of six special test-type injectors, the nozzles being fitted with a cap containing a valve which converts the spray into a steady stream of liquid. The test injectors are carefully matched so that for any one apparatus the output from each is practically identical. The stream from each nozzle is directed into a channel leading to a test-fuel reserve tank, or may be caused to flow down a chute from the end of which the liquid is collected in a glass measuring-cylinder graduated in millilitres. Two racks are provided, each holding six cylinders, the racks being reversible, so that while one set is being filled, the other is drained in an inverted position. The fuel-pump under test is mounted in a cradle, and is connected to the nozzles by steel pipes of identical length and shape. The pump is driven at a standard speed of 600 r.p.m. by an electric motor, provision being made so that rotation may be clockwise or anti-clockwise, according to requirements. When any necessary adjustments have been made, the output from the plungers is measured by putting into operation a trip mechanism which causes the

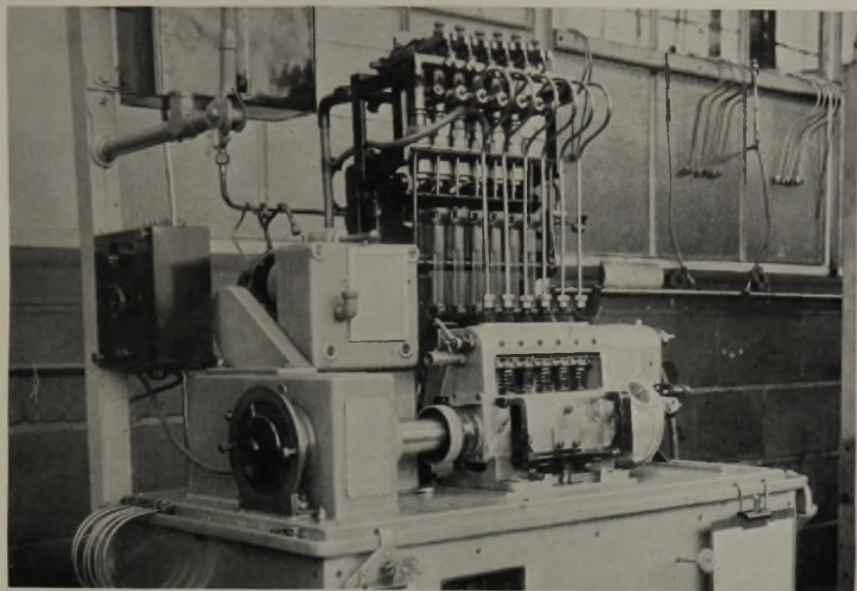


FIG. 1.
FUEL PUMP TESTING EQUIPMENT

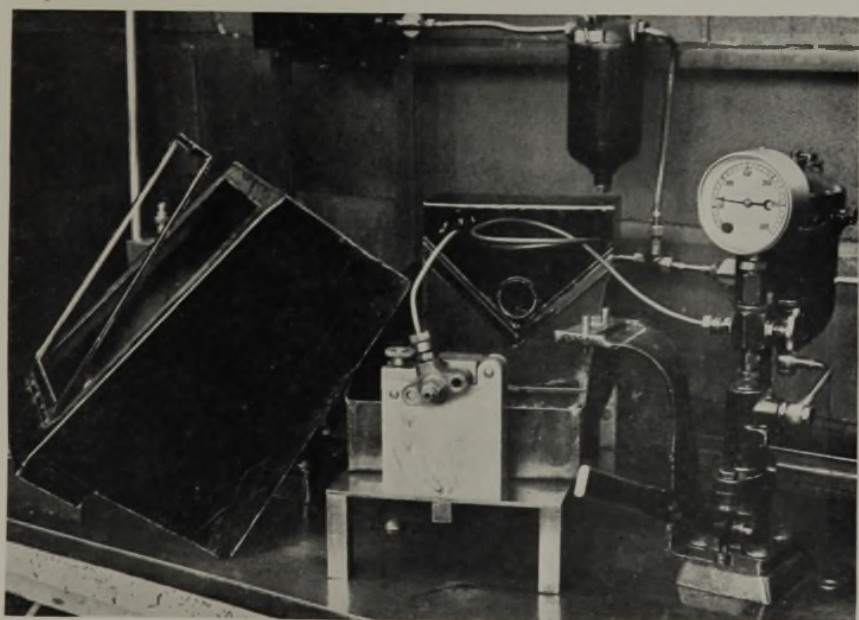


FIG. 2.
INJECTION TESTING APPARATUS.

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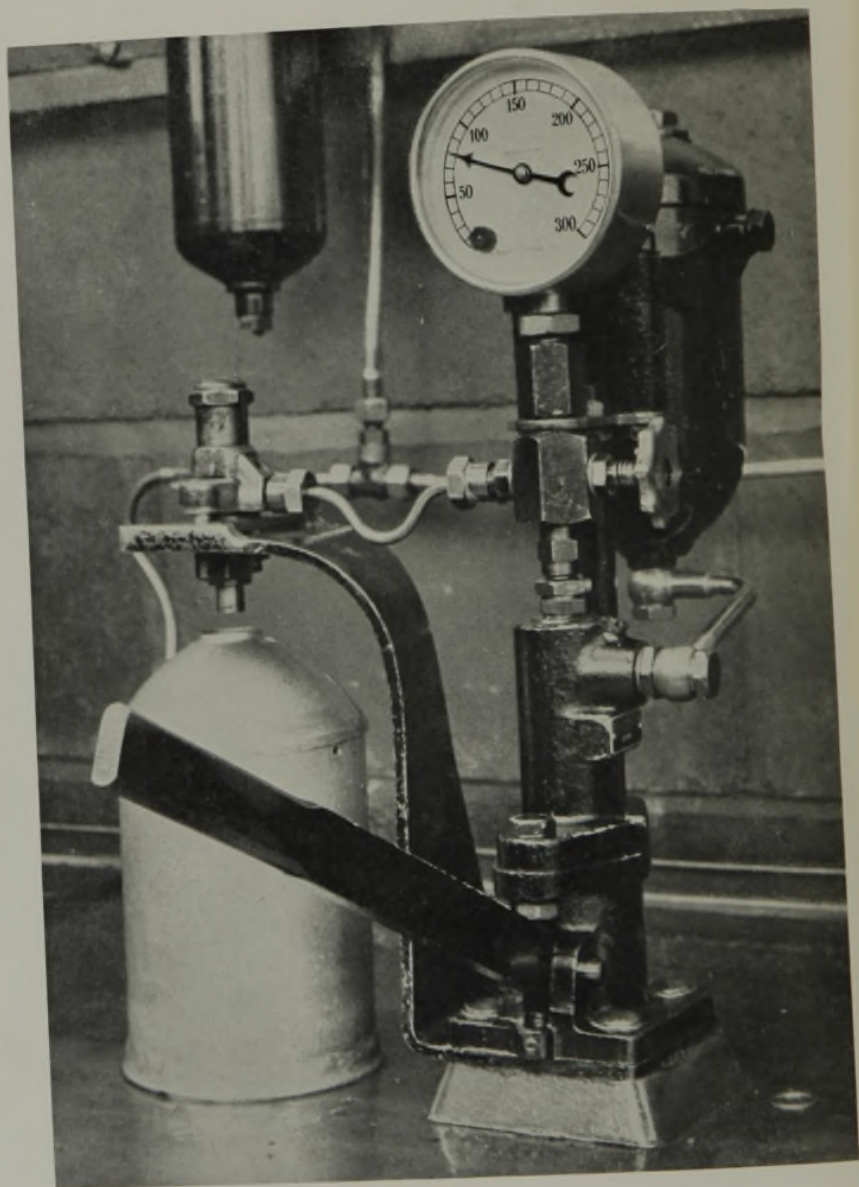


FIG. 3.
INJECTOR TESTING APPARATUS

stream from the injectors to be directed into the cylinders for a period of exactly 250 revolutions of the pump. The test speed of 600 r.p.m. has been chosen as representing the point at which variation of output with speed, amongst a number of pumps, is at a minimum; moreover, the speed corresponds to 1200 r.p.m. engine speed, an average one under conditions of operation in service. A period of 250 revolutions permits the collection of a convenient volume of liquid per cylinder (between 9 and 21 millilitres, depending on the size of the pump and type of engine concerned).

A special test fluid is used in the apparatus, it being employed also in injector-testing equipments to be described later. It is made up by mixing equal parts of white oil and kerosine of the following characteristics :—

	White Oil.	Kerosine.
Specific gravity at 60° F.	0.867	0.806
Viscosity (Redwood) at 70° F.	120 secs.	—
Closed flash-point (Pensky Marten)	300° F.	125° F.

Distillation range of kerosine—approximately 160–280° C. with 50 per cent. over at approximately 210° C.

The fluid is preferable to the standard diesel fuel for testing purposes, since it is less objectionable from the point of view of the operator, and is also less prone to frothing. It is kept in a main storage-tank fitted to the apparatus, and after use flows into a reserve tank, from which it is returned to the former tank by a pump, a filter being fitted in the fuel line. To ensure absolute cleanliness during the actual test, each of the special injectors incorporates a filtering device. As a further precaution, the test fluid is discarded after a week's use.

Fuel-pumps are initially calibrated, and re-calibrated following repair, at the overhaul works. Individual plungers are balanced to within 0.2 millilitre, and the required average output is obtained by turning the throttle-stop adjusting screw. The output is checked to ensure that the plungers remain balanced, the screw being then locked and a sealed cover fitted over it. The low-speed injection stop is then adjusted so that for starting a small excess injection is provided, amounting to from 0.2 to 1.0 millilitre, according to the type of engine. The pumps are timed by an electrical device (shown on the left in Fig. 1), this method being more convenient than, although correlating with, the more usual "spill" method. Finally, the front cover-plate of the pump is refitted and the locating screw is sealed. The identification plate on the pump is stamped with a code letter indicative of the setting, and charts interpreting this code are issued to garages at six-monthly intervals, or more frequently if any standard setting has been changed in the meanwhile.

Fuel-pumps are checked at garages in respect of plunger output after each 12,000 miles in service. Any alteration required is carried out on the adjusting screw only, the seal on the cover being broken and subsequently renewed. (Re-sealing is necessary to prevent the setting being altered while the vehicle is on the road, or by night staff.) Garages are forbidden to break the seal on the front cover-plate, and any adjustment to the governor mechanism or re-balancing of plungers is invariably carried out

at the overhaul works. In respect of variation between plunger outputs, an overall tolerance of 1.0 millilitre is at present allowed before a pump must be returned for re-calibration.

One of the three fuel-pump testing equipments at the works is regarded as the standard, and is calibrated daily against a "master" test injector; the remaining equipments are checked against the standard by means of a fuel-pump used for this purpose only. A second "master" pump is employed for checking equipments at garages, this being carried out at six-monthly intervals by a specially trained inspector. On each occasion the correction for each injector is recorded on a cardboard strip fixed in a frame attached to the apparatus, so that within very close limits there is agreement between all the testing machines in use.

Injectors.

Equal care is taken in the maintenance of injectors, and after each 6000 miles in service they are dismantled, the various parts being cleaned with special tools provided for the purpose. Garages are impressed with the importance of using nothing other than these tools, and of avoiding any treatment which would tend to scratch the parts. Paraffin is used to assist in cleaning, any wiping required being done with a clean cloth, free from fluff. The use of metal polish is permitted to give a final polish to the valve, but it is forbidden to attempt to lap the valve, and if this is required, the injector complete must be returned to the works for repair. Upon re-assembly the injectors are submitted to various tests, differing somewhat according to the type.

The venturi-type injector (for indirect-injection engines) is clamped in the vertical position, and is connected to a hand-pump fitted with a pressure gauge, control valve, and supply of test fluid, and its "blowing-off" pressure is determined. The equipment is shown in Fig. 3. The pressure is set to 100 atmospheres, by adjustment of the valve-spring, if necessary. The character of the spray is carefully observed; it must be in the form of a conical, finely divided mist, free from distortion or dribble. As a subsidiary test the experienced operator notes the characteristic buzz produced when the pressure is released. The nozzle valve-seats are tested for tightness by bringing the fuel pressure to within 10 atmospheres of the operating pressure, under which conditions the nozzle face must remain dry for at least five seconds. Leakage past the valve is determined by observing the time required for the pressure to drop from 100 to 75 atmospheres, the limits being a minimum of 6 seconds and a maximum of 45 seconds. If an injector fails to meet any one of these tests, it is returned to the overhaul works for repair.

Even more care is required in the cleaning and adjustment of injectors for direct-injection engines, since the pintle orifice is of very much smaller diameter than that of the venturi-type injector, the spray produced being a narrow cone of considerable penetration. The injector cannot be set to a precise "blowing-off" pressure, but by means of shim washers fitted at the top of the spring this can be adjusted to within 10 atmospheres. While the permissible range of operating pressures is 140-170 atmospheres, all the injectors for a particular engine must be set within a 10-atmospheres range

inside these limits. The "blowing-off" pressure is again determined by connecting with a hand-pump, but since the accuracy of the spray cannot be judged by mere observation, the hand-pump forms part of a "target" testing apparatus, in which the injector is mounted horizontally (see Fig. 2). The whole of the spray must pass through a $1\frac{1}{8}$ -in.-diameter hole in a plate positioned at a distance of $14\frac{1}{2}$ ins. from the injector orifice. To prevent the oil mist being breathed by the operator, the apparatus is enclosed by a hood, the top being fitted with a glass cover, hinged to facilitate cleaning. A dry-face test is also applied, the injector being required to hold a fuel pressure of 100 atmospheres for 3 seconds without appreciable leakage. Back leakage past the valve stem is determined by setting the pressure to 150 atmospheres and noting the time taken for it to fall to 100 atmospheres; the permissible limits are 12 seconds minimum and 35 seconds maximum. The test is a critical one, and to assist operators in judging the time, a simple device is provided consisting of two accurately adjusted sand-glasses mounted in a frame which can be pivoted through 180° .

Pressure-gauges fitted to injector-testing equipments are checked every six months against gauges standardized at the National Physical Laboratory. Correction figures are not given, but red lines are painted on the faces of the gauges to indicate the pressures which the various types of injectors should register when correctly adjusted; the lines are easily removable by a solvent when re-calibrating.

EXHAUST GAS ANALYSIS.

As a further measure of combustion control, recourse is made to exhaust-gas analysis, some 6000 samples in all being handled yearly. The methods employed for oil engines are similar to those adopted in respect of petrol types, and have been previously described.* In the case of samples from oil engines it is normally sufficient to determine the percentage of CO_2 , since this is directly proportional to power, and, in the absence of any disturbing factors, to fuel-pump output also. To obtain comparable results it is essential for the samples to be taken under strictly standardized conditions, and for tests on the road, engine speed is maintained at 1200 r.p.m. with the accelerator pedal depressed to its fullest extent. To achieve these exacting conditions, a revolution counter is provided, whilst a load is imposed on the engine by judicious application of the brakes. It may be conceded that the analytical figures are not so clearly indicative of engine defects as is the case with samples from petrol engines. Nevertheless, the CO_2 content of the exhaust gases provides a rapid check on the correctness or otherwise of the setting of the fuel-pump on an indirect-injection engine. It is not at the moment possible to exercise so close a control with direct-injection engines, but the reasons for this are known, and a new technique is being developed. With either type of engine it is an easy matter to detect a fuel-pump the setting of which is approaching the "smoke limit," and the percentages of CO_2 in the exhaust gases corresponding to this point have been carefully established; they are in

* *Jour. Inst. Fuel*, Vol. VI, No. 27, p. 131.

the region of 13 per cent. for indirect-injection engines and 10 per cent. for direct-injection engines. This difference is, of course, largely due to the fact that the direct-injection engine utilizes a higher proportion of air than does the indirect-injection type.

ORGANIZATION.

A special section is established at the overhaul works for dealing with fuel-pumps and injectors, and an individual record is maintained in respect of each of the former, being brought up to date every time the pump is received for re-adjustment. At garages the testing is deputed to one man who has received previous training in the section at the works. Results of fuel-pump tests, both prior to and following the limited adjustment permitted, are recorded on special forms, and each one of these is scrutinized by an inspector. Any irregularities revealed, such as the refitment of unbalanced pumps, or pumps exceeding the tolerance on output, are immediately followed up. The inspector is one of a small staff solely concerned with fuel-economy matters, and whose duties include periodic checking of testing equipments, exhaust-gas sampling, investigation of complaints of "fuming," and a continuous observation on fuel consumption. Data in respect of the latter are available for every vehicle in the fleet, and are collected in a weekly return which shows the average-miles-per-gallon figure for each vehicle type at all garages.

The description given in the foregoing of the various precautions taken to ensure efficient combustion of the fuel in high-speed oil engines is not exhaustive, although the items which require the most careful attention and which, if maintenance methods are relaxed, are the most likely to cause a smoky exhaust, have been dealt with in detail. Visible evidence of the success of these measures is provided by the three-thousand five-hundred oil-engined buses and coaches operated by the Board within its area.

In conclusion, the author would express his thanks to the London Passenger Transport Board for granting him permission to present this paper.

EXPERIMENTS WITH DOPED FUELS FOR HIGH-SPEED DIESEL ENGINES.*

By J. J. BROEZE † and J. O. HINZE.†

INTRODUCTION.

THE use of dopes may be considered to be one of the most promising methods for improving the ignition quality of diesel fuels, should such improvement appear to be necessary. In particular their use may make it possible to meet special requirements with respect to a high cetane number combined with a low cloud- and pour-point of the fuel. To take a concrete case, the authors would refer to such a combination as a minimum cetane number of 55–60 and a pour-point below -40° F. Such a combination is included in tentative and recommended specifications by the U.S.A. Navy and Army Air Corps, and a somewhat similar combination would certainly be required for many diesel aero-engines.

As ignition quality beyond 45 cetane is, in many cases, linked up with the presence in the fuel of paraffinic chains, and as the tendency to congeal at low-temperatures goes, to some extent, parallel with the amount of paraffinic chains contained in the fuel, it is clear that such special requirements can scarcely be fulfilled by any straight-run or cracked fuel. The use of low-boiling fractions seems to make an exception, which, however, has the disadvantage of greatly reducing the output of suitable fuel and the risk of involving too low a viscosity for diesel-engine practice. One has to have recourse to special treatment of fuels suitable for that purpose.

Of the other important treatments, may be mentioned hydrogenation, polymerization, mild cracking, dewaxing, admixture of pour-point depressors, acid treatment, and solvent extraction,¹ especially the latter, possibly combined with the use of dopes.

For a pour-point below -40° F. one has to start usually with a fuel of cetane number 30–35; this may be a straight-run highly aromatic and/or naphthenic fuel, or a cracked one. When from this fuel, by solvent extraction, a fuel with a cetane number of 55 is obtained, only about 50 per cent. yield would be obtained; hence this method has the same disadvantage of greatly reducing the output of suitable fuel as the use of low-boiling fractions. Moreover, by solvent extraction also the pour- and cloud-points are often raised, whereas the additional use of pour-point depressors—as *e.g.*, parafflow—would not cause a corresponding decrease of the *cloud-point*—that is, in the temperature at which filter troubles may appear.

On the other hand, a minimum of 2.5–3 per cent. by weight of even the most effective dopes would have to be added to bring the cetane number up to specification, which will call for an increase of some 20–25 cetane numbers.

Hence, to meet such a special fuel requirement the most efficient way would be to start from fuels with a low pour-point (non-waxy fuels)

* Paper presented for discussion at the Morning Session (A), 24th May, at the Summer Meeting of the Institute of Petroleum held in Birmingham, 22–24th May, 1939.

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which may be extracted to give cetane numbers up to 40, and then to add 1-1.5 per cent. dope.

In other cases, where a total increase of not more than about 10 cetane numbers is required, the addition of dope only would suffice. Of course, one of the other treatments mentioned above may be used, but which of them is to be preferred, however, depends also on economical considerations.

2. REQUIREMENTS FROM A DOPE.

A dope for the improvement of the ignition quality of a fuel has to fulfil the following requirements :—

- (a) it must be as effective as possible;
- (b) it must be soluble in the fuel up to high concentrations;
- (c) it should not be soluble in water;
- (d) it should not be influenced by acidic components in fuels (unless the fuel be previously soda-treated);
- (e) it must have a high degree of stability in storage;
- (f) it must not be explosive under moderate temperature conditions, when in solution;
- (g) its manufacture, yielding a constant product, should be reasonably easy;
- (h) it should not have corrosive properties;
- (i) it should be inexpensive.

These requirements are all more or less evident. However, it will be clear that all requirements cannot be fulfilled to the same degree without influencing each other. The requirements (a), (e), and (f), are more or less contradictory: the effect of a dope during the ignition period of the fuel in the engine is due entirely to its highly unstable character at higher temperatures, or, to put it in other words, to the fact that the dope molecules are easily activated, implying at the same time a greater chance of instability at lower temperature, and this the more so the more effective is the dope.

In the technical and patent literature a great number of diesel dopes are mentioned, but only a few of them fulfil the above requirements in a satisfactory way. The latter dopes belong mainly to the class of nitrates and peroxides.

Of course, the chemist has not spoken the last word on this subject, but according to the experience of the authors, the best results have, up to now, been obtained with acetone peroxide, which seems to fulfil all requirements satisfactorily, whilst good results are also obtained with ethyl nitrate, apart from some corrosion troubles.

In this paper the authors will discuss their results obtained with acetone peroxide and ethyl nitrate as dopes, and mainly with respect to :—

- (a) their influence on the ignition delay of a fuel;
- (b) their influence on the further stages of the combustion process;
- (c) their influence on wear (corrosive action) and incrustations in the engine;
- (d) various subjects, as storage tests, etc.

3. INFLUENCE OF A DOPE ON THE IGNITION DELAY OF A FUEL.

Very little is known about the effect of a dope on the chemical processes occurring during the ignition period. The theories which may be given to explain the phenomena resulting from the effects of a dope are still in a hypothetical form. It is not the authors' intention to enter now into this physicochemical labyrinth. Only this can be put forward, that it seems possible to include the working of a dope in the theory of chain reactions.

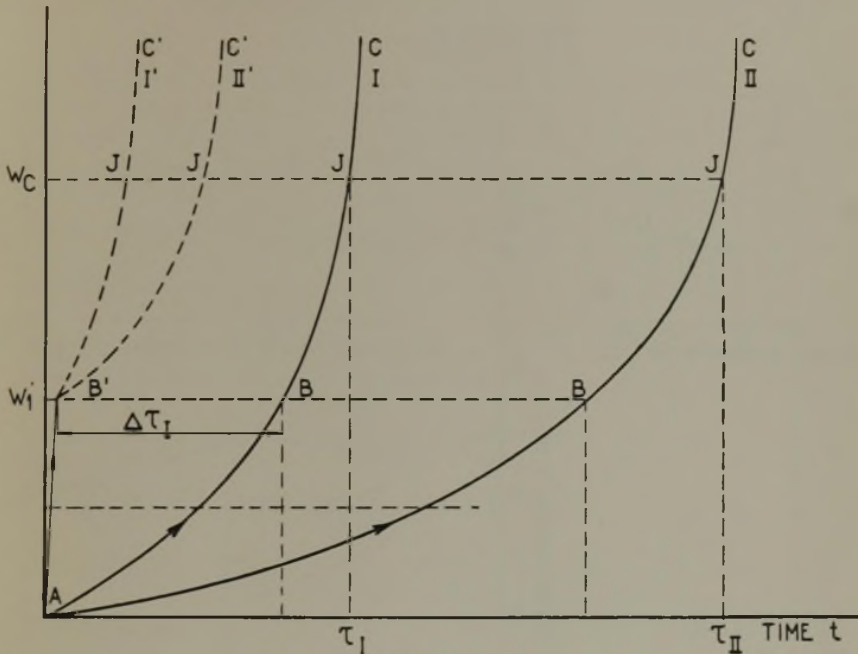


FIG. 1.

Semenoff² has given the following formula, based on this theory for the reaction velocity w at time t :—

$$w = A(e^{\phi t} - 1)$$

In this formula A and ϕ are dependent on the kind of molecules, pressure, and temperature. As ϕ appears in the exponent, its effect on the reaction velocity is predominant.

In Fig. 1 reaction velocity has been plotted against time, for various values of A and ϕ (curves I and II). When the reaction velocity has reached a critical value w_c , explosive reaction or inflammation occurs. The time necessary for w to reach this value (ignition delay) is the shorter the lower the oxidation stability of the molecules, and the higher the pressure and the temperature of the reacting substances.

Now we may consider the dope molecules as being of extremely low thermal stability.

In Fig. 1 the reaction of the undoped fuel is represented by curve ABC , whereas for the doped fuel it is represented by curve $AB'C'$.

The reaction velocity w_1 which results from the influence of the dope molecules, and which is proportional to the number of these molecules, will be reached practically in a time zero, so that the effect on the whole ignition delay will be found in its reduction with the value $\Delta\tau$.

From the exponential shape of the curves I and II it may be deduced first that this reduction in delay time is the greater the higher the value of τ , and secondly, that reduction of delay time per unit of dope percentage in the

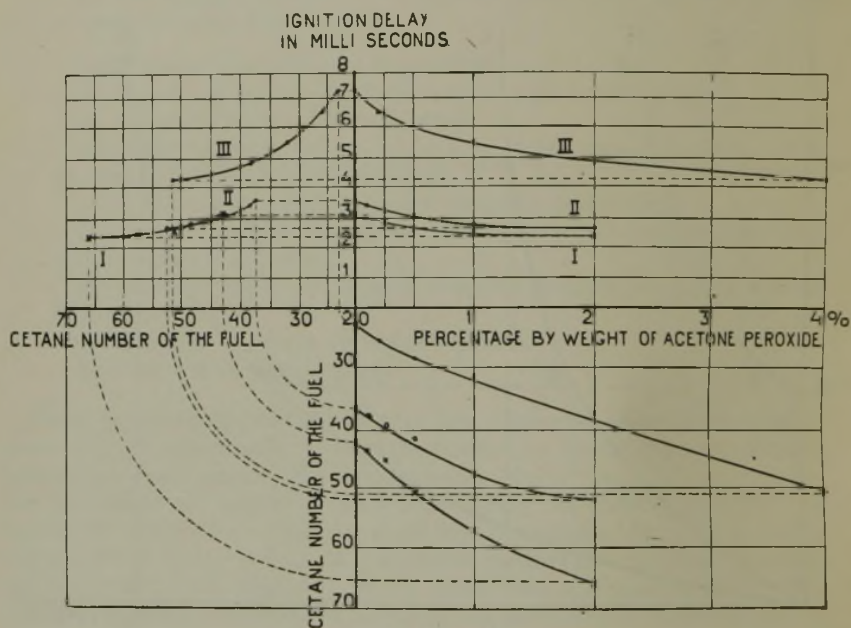


FIG. 2.

ENGINE : SLOW SPEED, HORIZONTAL ENGINE WITH DIRECT INJECTION.

FUELS : (I) STRAIGHT RUN MIXED BASE.

(II) STRAIGHT RUN ASPHALTIC BASE.

(III) STRAIGHT RUN AROMATIC BASE.

fuel is lower the higher is the percentage of dope. Hence one may expect that the effect of a dope, expressed in terms of the reduction of the ignition delay, will be dependent on the ignition delay of the undoped fuel, which means the ignition quality of the fuel and/or the engine conditions and the amount of dope already added to the fuel.

Experimental results of the effect of a dope on the ignition delay will be discussed with respect to the dependence on :—

- (a) the chemical activity of the undoped fuel ;
- (b) the physical delay of the fuel ;
- (c) the engine conditions.

These experimental results seem to correlate fairly well with the above-given representation of the working of a dope.

(a) *Chemical Activity of the Undoped Fuel.* Fig. 2 gives the ignition delays in milliseconds and the cetane numbers for three fuels of different base and for various percentages of acetone peroxide added to these fuels. All three fuels are straight-run gas oils; fuel I is of mixed base, fuel II of asphaltic base, and fuel III is a highly aromatic one. The delay measurements were carried out on a low-speed single-cylinder horizontal diesel engine (bore and stroke : 210 × 370 mm.), four-cycle, direct-injection, at a speed of 275 r.p.m. and a b.m.e.p. of 1.55 kg./cm.² In Fig. 2 the following may be noted :—

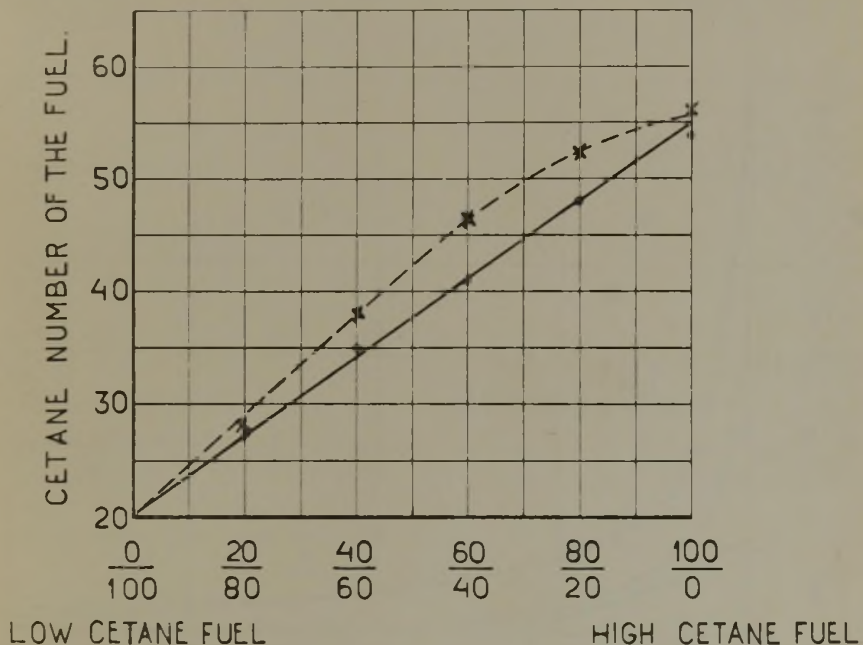


FIG. 3.

● ————— ● BLENDS OF A LOW CETANE FUEL AND AN UNDOPED HIGH CETANE FUEL.
 × ————— × BLENDS OF A LOW CETANE FUEL AND A DOPED FUEL OF HIGH CETANE NUMBER.

First the effect of the dope, expressed in the decrease of the ignition delay, is greater in a low-cetane fuel than in a high-cetane fuel. However, due to the hyperbolic character of the curve of cetane number *versus* ignition delay, the effect of a dope when expressed as the increase in the cetane number is greater in a high-cetane fuel than in a low-cetane fuel.

Secondly, comparing two fuels of equal cetane number, one undoped and the other doped, and further adding equal amounts of dopes to both fuels, then the effect of this dope addition is greater on the undoped than on the doped fuel. The consequence of this will be that when a doped fuel of high cetane number is blended with an undoped low-cetane fuel, a linear relation between the cetane numbers of the blends and the weight percentage of the blending agents no longer exists, as would occur if both blending agents were undoped fuels (Fig. 3).

Thirdly, the effect of a dope, expressed either as an increase in the cetane number, or as a decrease of the ignition delay, decreases the more dope has already been added to the fuel.

These results are more clearly demonstrated when one determines the decrease of ignition delay per unit of percentage of dope—that is, the differential quotient $\frac{\partial \tau}{\partial p}$, where p denotes the percentage of dope. In

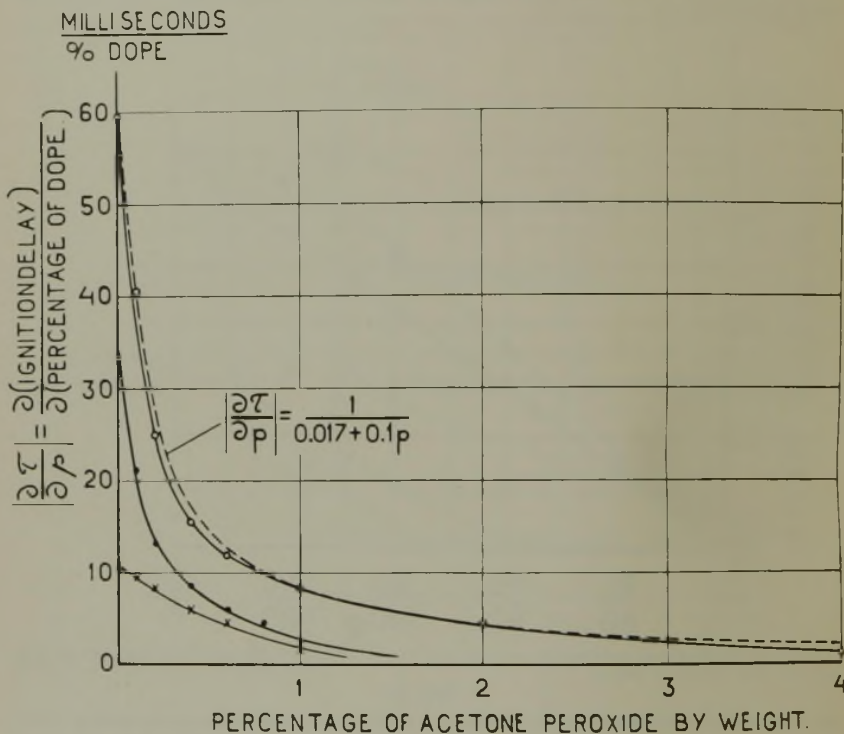


FIG. 4.

ENGINE : SLOW SPEED HORIZONTAL ENGINE WITH DIRECT INJECTION.

FUELS : (I) STRAIGHT RUN MIXED BASE.

(II) STRAIGHT RUN ASPHALTIC BASE.

(III) STRAIGHT RUN AROMATIC BASE.

Fig. 4 the value of $\frac{\partial \tau}{\partial p}$ for the three fuels has been plotted against the percentage of dope p .

(b) *Physical Delay of the Fuel.* As the working of a dope is purely chemical, it is clear that its effect will be greater the greater is the "chemical" part of the ignition delay, for it could do nothing to shorten the "physical delay," which is due to the absence of sufficient vapours in the very first moment of the ignition delay.^{3,4} With light distillate fuels many experiments have shown that this physical delay is usually

very small with respect to the total delay. In heavy fuels the physical delay will become relatively more important, hence the effect of a dope will then become relatively less great. This is clearly shown in Fig. 5, where a comparison is made between a straight-run gas oil of asphaltic base (curves I) and a peanut oil, Arachis oil (curves II), both of practically

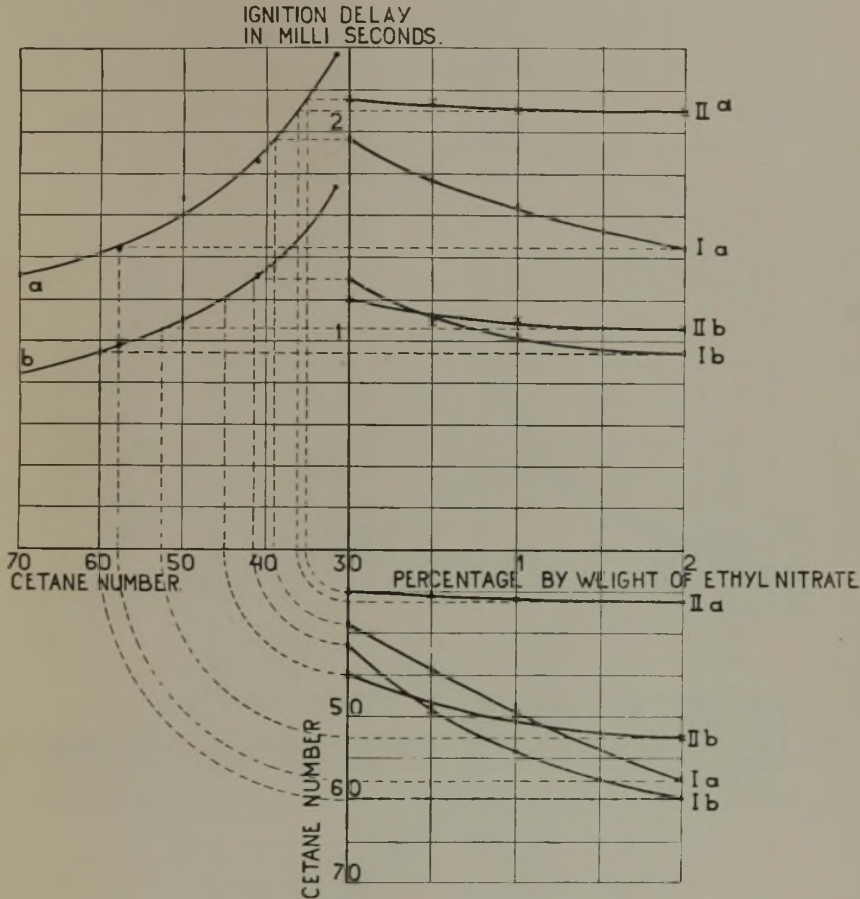


FIG. 5.

ENGINE: HIGH SPEED, SEPARATE SWIRL-CHAMBER.

FUELS: (I) STRAIGHT RUN ASPHALTIC BASE.

(II) PEANUT OIL (ARACHIS).

a = LOW INJECTION PRESSURE.

b = HIGH INJECTION PRESSURE.

the same ignition quality. Ethyl nitrate was used as a dope. The tests were carried out on a single-cylinder, high-speed, four-stroke vertical diesel engine, fitted with a separate swirl-chamber (bore and stroke 120×140 mm.), at a speed of 1300 r.p.m. and a b.m.e.p. of 2.5 kg./cm.^2 In Fig. 5 the curves "a" refer to tests at which the opening pressure of the injection

IGNITION DELAY IN MILLI SECONDS.

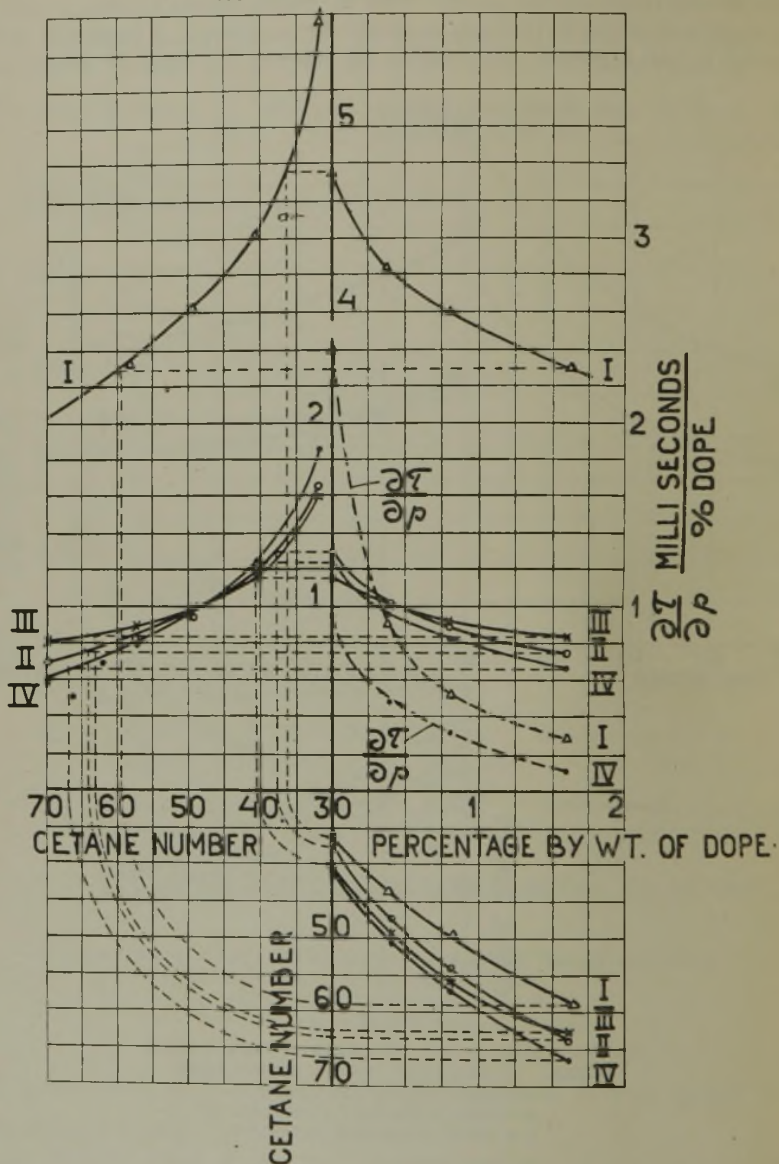


FIG. 6A.

- ENGINES : (I) SLOW-SPEED DIRECT INJECTION.
 (II) HIGH-SPEED DIRECT INJECTION.
 (III) HIGH-SPEED SEPARATE SWIRL-CHAMBER.
 (IV) HIGH-SPEED SEPARATE SWIRL-CHAMBER.

FUELS : STRAIGHT-RUN, ASPHALTIC BASE, WITH ACETONE PEROXIDE AS A DOPE.

IGNITION DELAY
IN MILLI SECONDS.

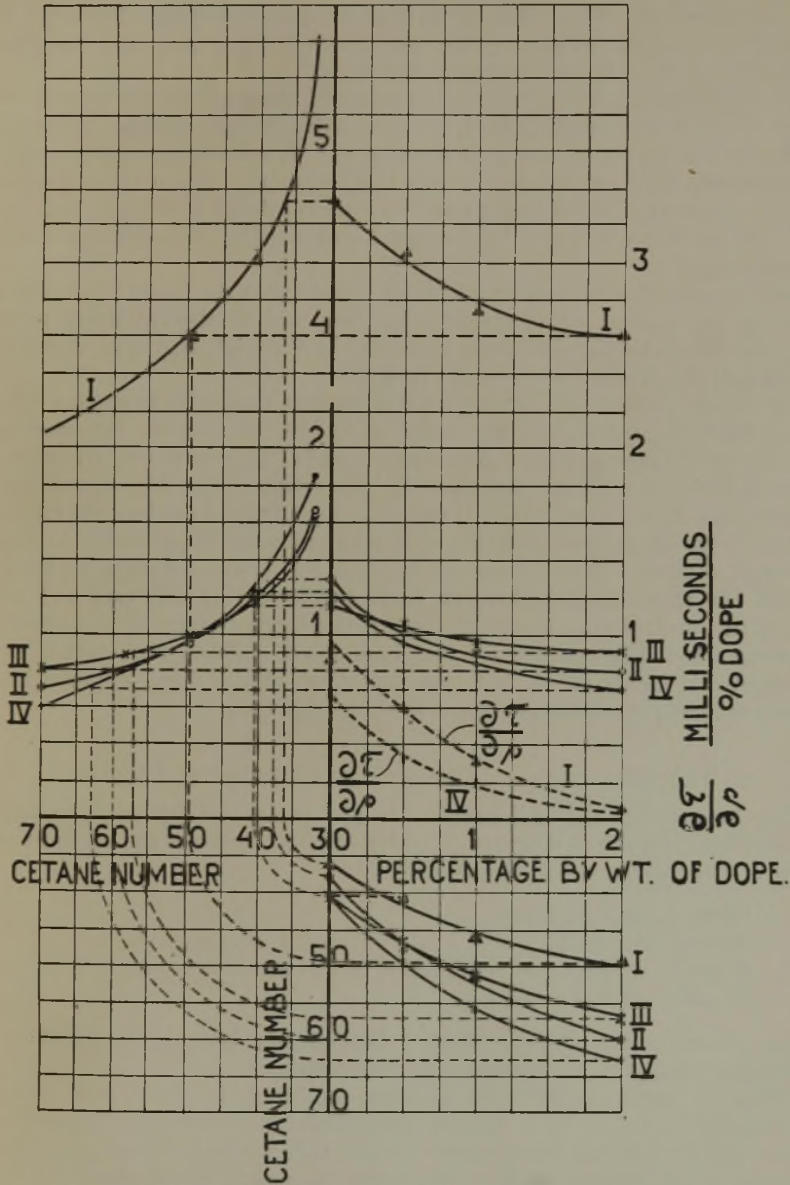


FIG. 6B.

- ENGINES : (I) SLOW-SPEED, DIRECT INJECTION.
 (II) HIGH-SPEED, DIRECT INJECTION.
 (III) HIGH-SPEED, SEPARATE SWIRL-CHAMBER.
 (IV) HIGH-SPEED, SEPARATE SWIRL-CHAMBER.

FUELS : STRAIGHT-RUN, ASPHALTIC BASE, WITH ETHYL NITRATE AS A DOPE.

nozzle was fixed at 150 kg./cm.², whereas the curves "b" refer to tests at which this opening pressure was increased up to 300 kg./cm.²

The chemical nature of the peanut oil is such that a short chemical delay can be expected. The effect of this short chemical delay, however, is spoiled to a certain extent by the very low volatility and high viscosity of the oil—that is, by the long physical delay.

At the lower injection pressure the effect of the dope on the peanut oil (curve IIa) is very small indeed, whereas this effect on the gas oil has a normal value (curves Ia, compare also Fig. 6). When the injection pressure is increased, finer atomization of the fuel, especially of the more viscous one, is obtained. The influence on the physical delay is evident, and the effect of the dope will now be increased (curves IIb), although this effect remains small.

For the sake of completeness, it must be said that the small effect of the dope in the peanut oil is attributable not only to the relatively great importance of the physical delay, but also to the high degree of chemical activity of the original fuel (see (a) p. 661).

(c) *Engine Conditions.* In high-speed engines, especially in engines with a hot turbulence-chamber, the value ϕ in the formula for the reaction velocity will be greater than in low-speed engines. This, however, also means a lower effect of a dope, expressed in delay time, in a high-speed (hot) engine than in a low-speed (cold) engine. Figs. 6a and 6b show the results of the effect of acetone peroxide and ethyl nitrate, respectively, in four different engines. The differences between the low-speed engine (curves I) and the three other high-speed engines (curves II, III, and IV) are clearly demonstrated. However, due to the steeper shape of the cetane-versus-ignition-delay curves for the high-speed engines, not only is the undoped fuel higher rated, but also the effect of the dope, expressed in cetane number, is relatively greater in these engines.

4. THE EFFECT OF A DOPE ON THE COMBUSTION PROCESS.

Fig. 7 represents the well-known "ideal" pressure diagram (I) in comparison with the actual diagram (II) with the four stages of the combustion process, as introduced by Ricardo :—

- Stage 1, ignition delay ;
- Stage 2, combustion of the fuel injected during stage 1 ;
- Stage 3, ignition and combustion of fuel injected later ;
- Stage 4, after burning.

The influence of a dope on stage 1 has already been dealt with above. The three further stages will now be considered.

These stages of the pressure diagram represent the main part of the combustion process as far as development of heat is concerned. In previous publications^{4, 5} it has been amply shown that for light diesel fuels this process, given certain engine conditions, is mainly determined by the ignition quality and the volatility (and/or viscosity) of the fuel. Combustion, once initiated, is then governed practically by the state reached by the mixing of air and injected fuel (stage 2 of Fig. 7) and by the way in which mixing of subsequent injected fuel with the remaining air takes

place (stage 3 of Fig. 7). Therefore it has not yet been possible to detect clearly an influence of the chemical composition of the fuel on the combustion process, apart from the influence determined by the ignition quality. Of course, the chemical composition of the fuel plays its part, as it effects, through the C : H ratio, the amount of heat liberated during combustion.

Referring to Fig. 1, which may also be representative of the process occurring in a nucleus, in which combustion originates, it may be observed that beyond the point of inflammation an influence of the chemical composition of the fuel on the reaction velocity would scarcely be noticeable.

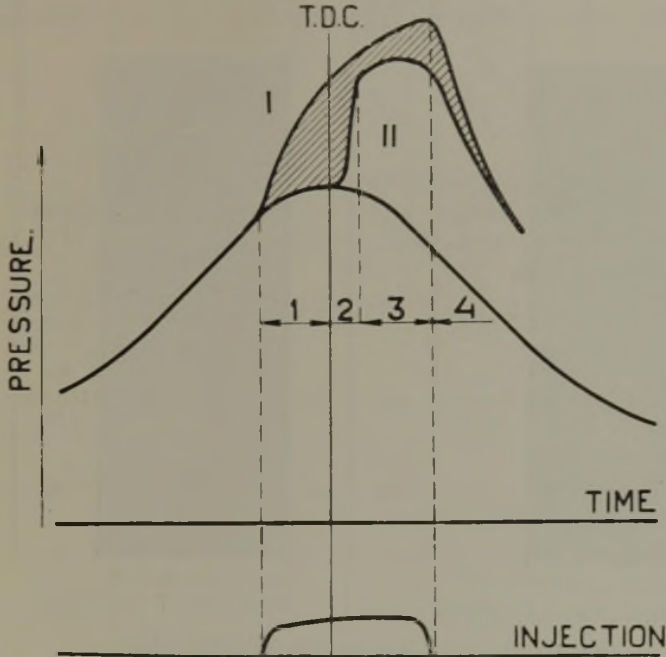


FIG. 7.

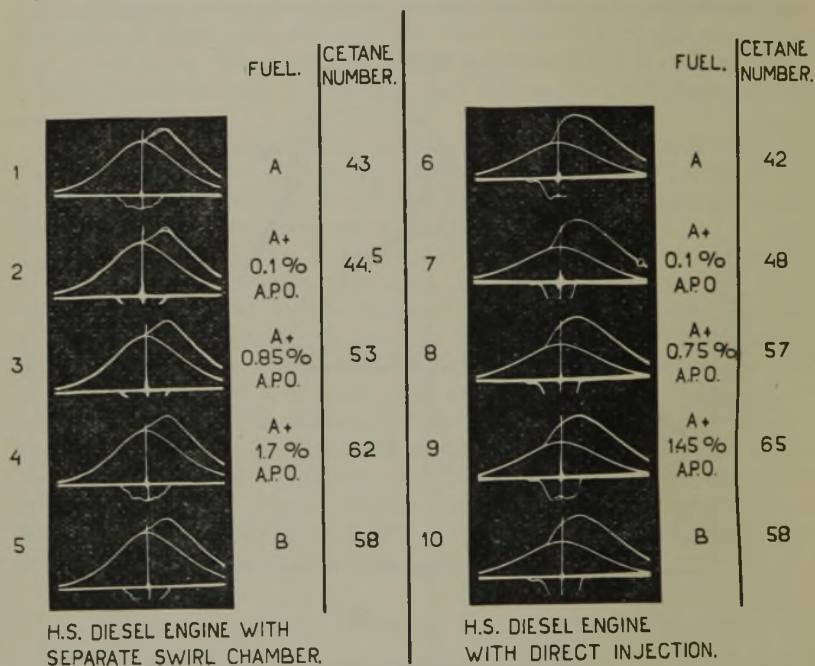
In the light of these facts, an effect of dope addition to a fuel on the combustion process as a whole may be expected only in the shape of an effect on ignition quality, the more so when the small percentages are considered in which dopes are added to a fuel.

This has been confirmed by experiments in the diesel engine. In engine practice, the combustion process can be investigated directly by studying the pressure diagram, and indirectly by comparing the output, specific fuel consumption, and exhaust temperature.

Fig. 8 shows a series of pressure diagrams on two high-speed diesel engines, one being of the direct-injection type, the other of the separate swirl-chamber type. An undoped straight-run paraffinous gas oil with a cetane number 58 and a straight-run, mixed base gas oil doped with acetone peroxide in different percentages are compared. Differences in the diagrams for the undoped and doped fuels of practically equal cetane

number can scarcely be found, even if a close investigation is made of the different stages of combustion, by analysing the diagram as to the rate of heat liberation, by means of well-known methods, based on simple thermodynamical laws for ideal gases.

In Fig. 9 this rate of heat liberation, expressed in calories/degree crank-angle, is given for the undoped and doped fuel of equal cetane number, calculated from the pressure diagrams obtained on the direct injection engine (Fig. 8, numbers 8 and 10).



FUEL A = STRAIGHT RUN GASOIL OF MIXED BASE.

FUEL B = STRAIGHT RUN GASOIL OF PARAFFINOUS BASE. F1065

FIG. 8.

A slight difference is found, which, apart from errors of measurement, may be attributed to differences in specific gravity and calorific value.

In Fig. 10 are given the specific fuel consumption, exhaust temperatures, maximum pressure, and maximum rate of pressure rise for a fuel doped with various percentages of acetone peroxide. These results have been obtained on a 12-cylinder, V-type, rail-car engine, with direct injection, the output being maintained at 300 b.h.p. at 1400 r.p.m. (b.m.e.p. = 5.3 kg./cm.²). The above-mentioned quantities are plotted against the percentage of dope added to the fuel and against the corresponding cetane numbers (the latter figures have been determined on another direct-injection engine). As Fig. 10 shows, fuel consumption and exhaust temperatures increase with increasing dope percentage or cetane number, which is in accordance with what is generally observed in direct-injection engines.^{5,7} The lower

graph also shows the results obtained with an undoped fuel of 58 cetane number and of practically the same viscosity and distillation range (points A). Specific fuel consumption is now somewhat smaller than for the

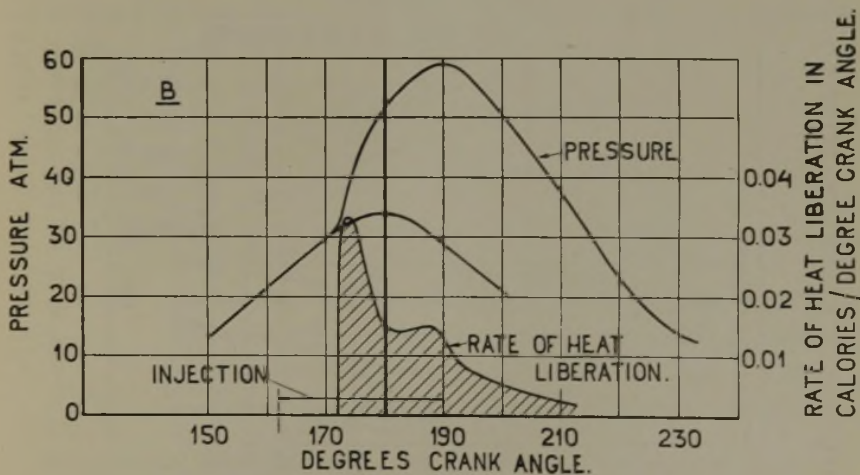
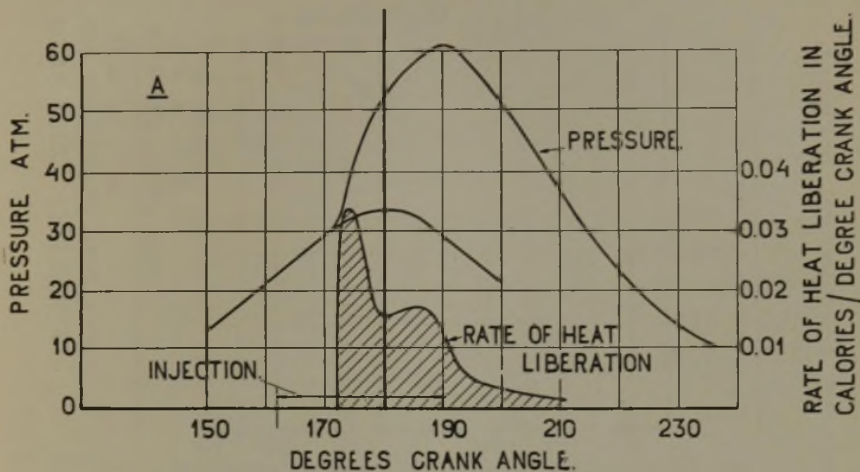


FIG. 9.

ENGINE : HIGH-SPEED DIRECT INJECTION.

FUELS : A. S.R. MIXED BASE WITH ACETONE PEROXIDE.

B. S.R. PARAFFINOUS BASE.

corresponding doped fuel, but this may be ascribed to the difference in calorific value between both fuels, which in this case amounts to about 2 per cent. in favour of the undoped fuel. The maximum pressure on the undoped fuel is somewhat lower. This may be explained by a difference in specific gravity, so that with the same pump and fuel-valve character-

istics, more fuel is injected per unit of time for the heavier fuel and, when burning, more heat is liberated per unit of time, even when the difference in calorific value is taken into account. On the other hand, the spreading

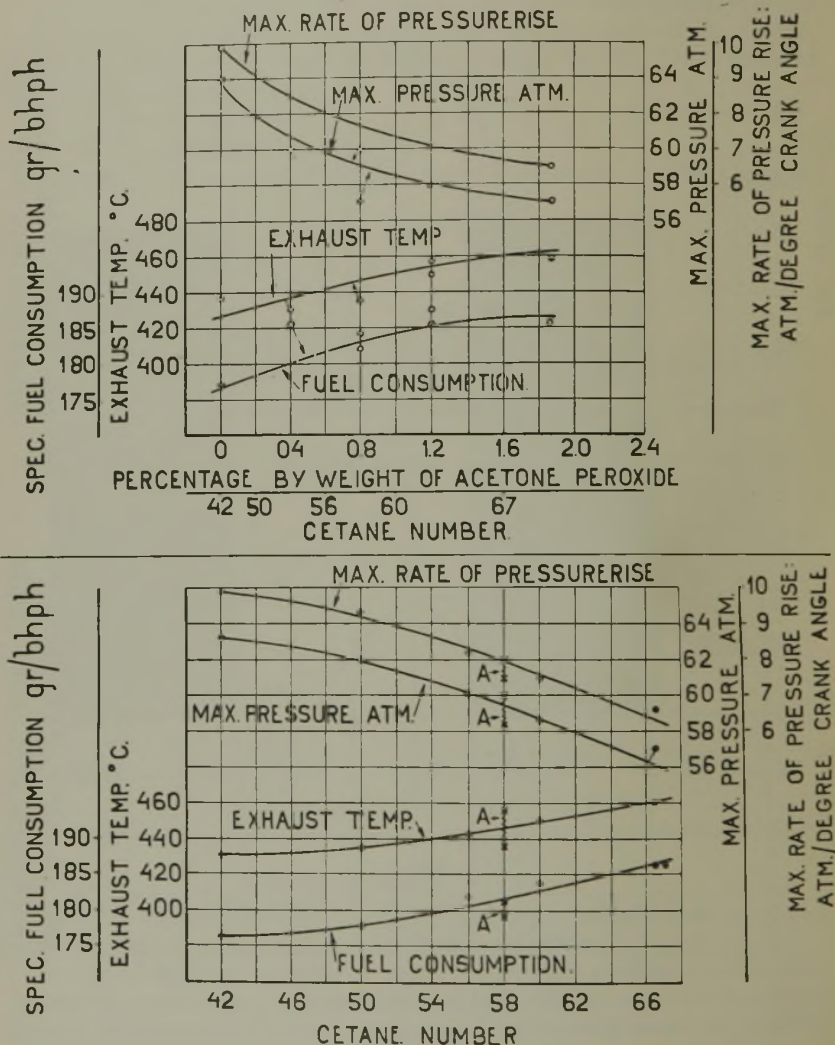


FIG. 10.

in the test data for the maximum pressures should warn against over-estimating the importance of this deviation.

A more complete comparison between undoped fuels and fuels doped with ethyl nitrate, with respect to fuel consumption and exhaust temperatures, is given in the following Fig. 11, where these values have been plotted against the ignition delay of the fuels. The fuel-consumption figures have been

corrected for differences in calorific value of the various fuels. The results, which have been obtained on a single-cylinder, high-speed diesel engine of the direct-injection type at 1500 r.p.m., b.m.e.p. 7.4 kg./cm.² are self-evident.

5. INFLUENCE OF A DOPE IN A FUEL ON WEAR AND INCRUSTATIONS IN THE ENGINE.

Numerous experiments on wear and incrustation problems have so extended our knowledge on the subject as to allow the authors to predict what results will be obtained in this respect with a certain fuel.

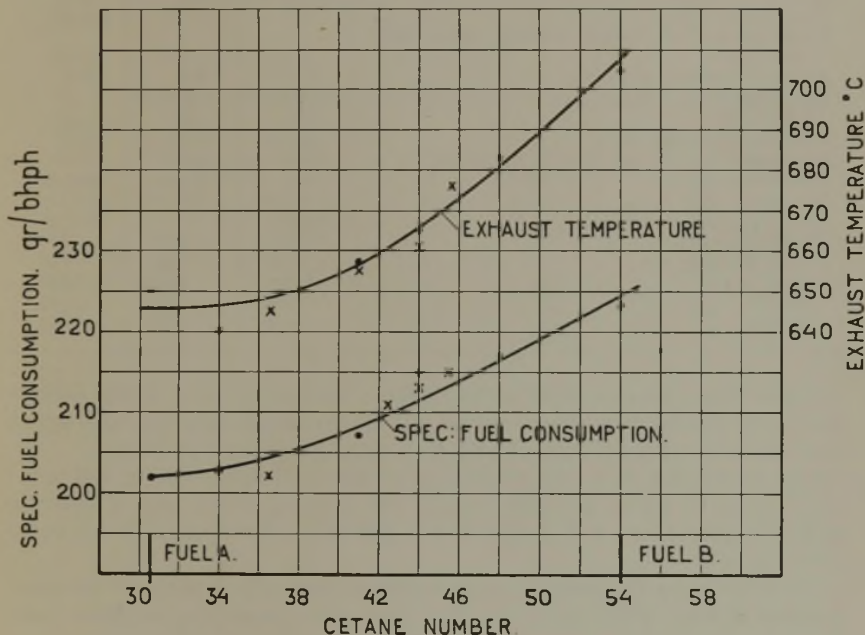


FIG. 11.

ENGINE: HIGH-SPEED DIRECT INJECTION.

FUELS: • BLENDS OF A LOW CETANE FUEL A AND A HIGH CETANE FUEL B.
 x LOW CETANE FUEL A WITH DOPE ADDITION.

Wear is mainly affected by: suspended matter (sand, dirt) and water (in quantities exceeding 2 per cent.), ash content (certain metallic oxides), high sulphur content, and by bad or incomplete combustion.⁸

The origin of incrustations may be sought in incomplete combustion, due to poor ignition quality, high residue content, and/or high viscosity (poor atomization and poor evaporation) of the fuel.⁵⁻⁹

Apart from the effect on the ignition quality, none of the other fuel properties will be unfavourably affected by a good ignition dope. Hence one can scarcely expect any other effect of a dope on wear and incrustation than will be determined by the increase of the ignition quality.

Table I gives an example of a complete analysis of an undoped fuel *A*, of a base fuel *B*, and of the latter fuel doped with about 1 per cent. acetone peroxide, the fuel *A* and the doped fuel *B* both having equal ignition quality.

TABLE I.

Fuel.	A.	B.	B + 1% Acetone Peroxide.
Specific gravity, 15/4° C.	0.843	0.865	0.867
Viscosity, c.c., 50° C.	3.09	2.72	2.82
Acidity	<0.05	0.7	0.70
Pour-point, ° C.	-7	<-20	<-20
Cloud-point ° C. (after refining with 20% Terrana)	+1	-21	-20
Sulphur content, % by wt.	0.7	0.9	0.9
Ash content, " "	traces	nil	nil
Asphaltenes, " "	nil	nil	nil
Conradson carbon test	zero	0.02	0.02
Conradson carbon test in 10% bottoms	0.04	0.09	0.09
Water content	nil	traces	traces
Bromine value	<1	<1	<1
Upper calorific value, cal.	10,897	—	10,756
Distillation I.B.P., ° C.	237	227	227
10% by vol., ° C.	263	246	246
65% " " "	298	288	288
90% " " "	332	322	322
F.B.P.	370	345	345

Some long duration tests lasting over a total of 80 hrs., under various loads and speeds, have been carried out on two single-cylinder, high-speed engines, both with the fuels *A* and *B* + dope, mentioned in Table I.

One engine is a direct-injection engine (bore and stroke 108 × 152 mm., developing 15 b.h.p. at 1500 r.p.m.), the other is fitted with a separate swirl-chamber (bore and stroke 117 × 149 mm., developing 15 b.h.p. at 1500 r.p.m.).

Table II gives the weight of incrustations on various parts of the combustion space. (The tests on the first mentioned engine have been duplicated.)

TABLE II.

Weight of Incrustations in Grams on Various Parts of the Engine after Long Duration Tests of 80 Hours.

Engine Fuel.	Direct-Injection Engine.				Engine with Separate Chamber.	
	A.		B + dope.		A.	B + dope.
Cylinder head	1.96	2.08	2.4	2.9	2.47	2.70 gms.
Piston crown	0.96	1.04	1.08	1.18	0.78	0.96 "
Piston ring grooves	0.12	0.20	0.20	0.38	0.57	0.94 "
Nozzle	0.68	0.12	0.12	0.14	—	—
Separate chamber + nozzle	—	—	—	—	0.94	0.80 "

In both engines the amount of incrustations is slightly higher with the doped fuel, which may be ascribed to the difference in residue content (compare the figures for the Conradson Carbon test in 10 per cent. bottoms).

Taking into account, moreover, that these differences are of the same order as the spreading in test results, the conclusion may be reached that the dope did not affect these results except in so far as it affected the ignition quality of the fuel.

Neither did the results on wear of piston-ring and cylinder liner give marked differences between both fuels. For the doped fuel, the piston-ring wear is somewhat higher (Table III), but the liner wear is less (Table IV, where the increase in cylinder diameter after each test is given, measured at the spot opposite the upper ring in top dead centre position of the piston).

TABLE III.

Decrease of the Piston-Ring Weight in m Grams after each Test.

Engine.	Fuel:	Direct-Injection Engine.				Engine with Separate Chamber.	
		A.		B + dope.		A.	B + dope.
Piston ring 1		158	161	193	228	398	505 m. gm.
„ „ 2		51	42	54	58	94	107 „
„ „ 3		39	32	44	51	70	49 „
„ „ 4		24	18	26	30	61	39 „

TABLE IV.

Increase in Cylinder Diameter after each Test.

Engine.	Fuel:	Direct-Injection Engine.				Engine with Separate Chamber.	
		A.		B + dope.		A.	B + dope.
Perpendicular to crankshaft . .		0-018	0-015	0-004	0-010	0-010	0-004 mm.
Parallel to crankshaft		0-009	0-009	0-001	0-007	0-007	0-002 „

For sake of completeness, a sample of each fuel was circulated, for 300 hrs., through a Bosch-injection pump and injectors, but no traces of corrosion or deposits on the pump- and injector-elements could be found after these tests.

6. VARIOUS RESULTS.

Besides the above results on the behaviour of doped fuels in the diesel engine, there are still some other points which may be of importance—*e.g.*, their stability during storage and the question of safety (explosiveness).

Storage for several years of pure ethyl nitrate did not have a measurable influence on its effectiveness as a dope.

The experience of the authors have so far only covered storage tests with acetone peroxide of a period of over 10 months. These tests have been made in connection with fuels of various bases; during storage in small drums, the doped fuels were kept at a constant temperature of 30° C. (tropical conditions) and in contact with iron, zinc, and water. Table V summarises the results giving cetane numbers of the undoped base fuels and the doped fuels before and after storage. These tests have proved the practical stability, during storage, of a fuel doped with acetone peroxide.

From both dopes investigated, the acetone peroxide, which, in the pure state, is obtained in form of white crystals, has an explosive character. When in solution, however, this explosive character is reduced practically to zero. At room temperature acetone peroxide is soluble in gas oil up to a maximum concentration of 5-6 per cent.

TABLE V.

Fuel.	Percentage of Dope by Weight.	Cetane Numbers of—			
		Base Fuel.	Fuel + Dope (Acetone Peroxide). Storage—		Duration of Storage.
			Before.	After.	
S.R. asphalt-base gas oil .	1.03	42	51	50	4 months
Clear cracked gas oil .	1.56	36	50	51.5	10 "
S.R. mixed base gas oil I.	1.00	38.5	46.5	46.5	10 "
" " " " " II.	1.00	34	44.5	41	10 "
" " " " " III.	1.00	38.5	45.5	43	10 "

The authors will conclude the paper by giving some data on the effect of acetone peroxide or ethyl nitrate on the flash-point of the fuel, which, of course, is of practical importance. The flash-points have been determined according to the Pensky-Martins closed-cup method. The results, given in Table VI, show that acetone peroxide as a dope has no important effect on the flash-point when any trace of acetone is removed by washing the doped fuel with water.

Ethyl nitrate causes an appreciable decrease of the flash-point, which in the case mentioned has brought the flash-point under the value tolerated in many specifications (compare A.S.T.M. specifications).

TABLE VI.

	Fuel.	Flash-point, ° C.
I	S.R. asphalt-base gas oil	70
II	I + 2% acetone peroxide	61
III	I + 7% acetone peroxide	51
IV	III, but washed with water	68
V	S.R. mixed-base gas oil	72
VI	V + 2% acetone peroxide	67
VII	VI, but washed with water	71
VIII	S.R. mixed-base gas oil	89
IX	VIII + 2% ethyl nitrate	59

APPENDIX.

Some interesting properties of the effect of a dope on the ignition delay may be deduced theoretically from the formula, given by Semenov :—

$$w = A(e^{\phi t} - 1) \dots \dots \dots (1)$$

MILLI SECONDS.

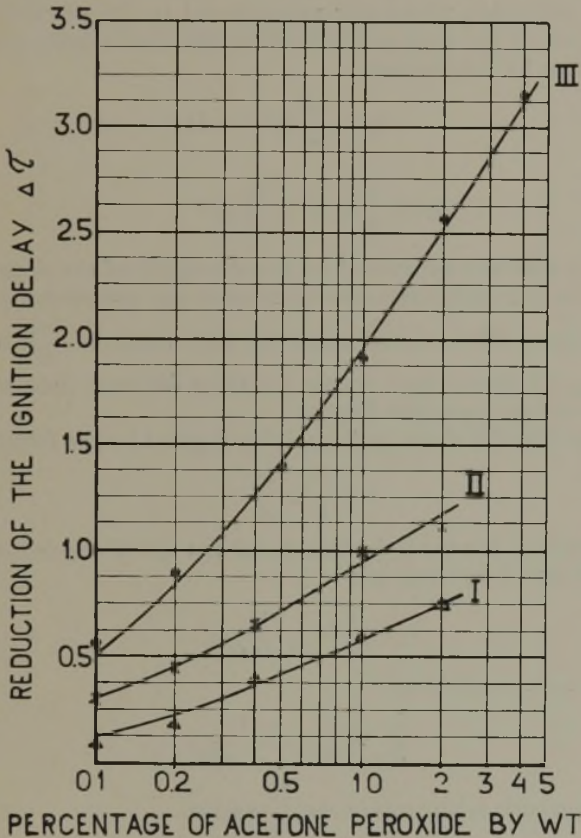


FIG. 12.

ENGINE : SLOW SPEED, DIRECT INJECTION.

FUELS : (I) S.R. MIXED BASE Δ — Δ .

(II) S.R. ASPHALTIC BASE \times — \times .

(III) S.R. AROMATIC BASE \circ — \circ .

THE FULL DRAWN CURVES REFER TO THE THEORETICAL FORMULA :

$$\Delta\tau = \frac{w}{\phi} \ln \left(1 + \frac{\phi \epsilon}{A} p \right)$$

For reactions which lead to inflammation, and excluding the initial periods for small values of t , unity may be neglected with respect to $e^{\phi t}$, and formula (1) may be written :—

$$w = Ae^{\phi t} \dots \dots \dots (2)$$

Integration of this formula gives :—

$$c = \int_0^t w dt = \frac{A}{\phi} (e^{\phi t} - 1) \quad (3)$$

where c is the amount of reactive substances, which may be considered as peroxides in their most general signification.

Assuming that when a dope is added to a fuel, the reaction starts with an amount of peroxides, practically proportional to the percentage of dope, then the effect of the dope on the ignition delay is a reduction of this delay with $\Delta\tau$, given by the formula :—

$$\epsilon p = \frac{A}{\phi} (e^{\phi \Delta\tau} - 1) \quad (4)$$

or :

$$\Delta\tau = \frac{1}{\phi} \ln \left(1 + \frac{\phi \epsilon}{A} p \right) * \quad (5)$$

where ϵ = a constant dependent on the effectivity of the dope.

Plotting on a logarithmic scale $\Delta\tau$ against the percentage p of dope in the fuel, a curve will be found which for high values of $\frac{\phi \epsilon}{A} p$ is practically linear. Fig. 12 gives these curves for three different fuels with acetone peroxide as a dope (compare Fig. 2).

For the undoped fuel the ignition delay is given by the formula :—

$$\tau = \frac{1}{\phi} \ln \frac{w_c}{A} \quad (6)$$

With formula 5 for the reduction $\Delta\tau$ of the ignition delay, the ignition delay of the doped fuel will be :—

$$\tau_1 = \frac{1}{\phi} \ln \frac{w_c}{A + \epsilon \phi p} \quad (7)$$

from which may be deduced :

$$\frac{\partial \tau}{\partial p} = \frac{-1}{\epsilon \phi^2 (A + \epsilon \phi p)} \quad (8)$$

giving a hyperbolic relation between $\frac{\partial \tau}{\partial p}$ and p .

As Fig 4 shows, the experimental results correlate fairly well with this relation.

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* This formula has been deduced by L. J. Oosterhoff and P. L. Kooyman (Amsterdam Laboratory of the Royal Dutch Shell). The authors wish to express their sincere gratitude for their suggestions in respect to this subject. Also the authors are much indebted to their collaborator Dr. G. H. Reman for his co-operation.

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THE APPLICATION OF GRAPHICAL AND STATISTICAL METHODS OF HYDROCARBON ANALYSIS TO DIESEL FUELS.*

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SYNOPSIS.

It does not appear to be desirable at the present time to derive a new formula for the correlation between chemical composition and the ignition delay of diesel fuels, but this might be possible in the near future if more data on accurately analysed diesel fuels with known cetene values were available.

If the influences of various percentages of different dopes are not taken into consideration, and attention is restricted, therefore, to the examination of hydrocarbon mixtures, then the work started by Kreulen is promising. This is confirmed by the authors' own results.

A more thorough investigation of a large number of diesel fuels will be necessary in order to study the influence of chemical composition on the cetene or cetane value. In this respect it will be advisable to examine a large number of hydrogenated fuels, practically free from sulphur-, nitrogen-, or oxygen-containing bodies, together with extracts and raffinates derived from these fuels, and also oils obtained by polymerizing olefines or olefine mixtures.

THE ring-analysis method developed by the authors enables the number of rings in saturated hydrocarbon mixtures to be determined with a high degree of accuracy. The advantage of this method is that it demands only a certain number of physical constants—*e.g.*, specific gravity, refractive index, mean molecular weight, aniline point, etc. Many of these constants can be determined easily, although some of them (*e.g.*, mean molecular weight) demand some experience. It seems that the ring-analysis method, which can also be called the specific refraction-molecular weight method, has now been adopted in the majority of those countries which are interested in the analysis of hydrocarbon mixtures. Two years ago it was shown, by the ultimate analysis of several saturated hydrocarbon mixtures, that the method has a high degree of accuracy.

Since the method is based on values for the atomic refractions of carbon and hydrogen, it can easily be understood that the greater the progress made in the preparation of pure hydrocarbons, the more accurately can these values be calculated and the higher becomes the accuracy of the method.

Although the method was at first employed for the analysis of saturated hydrocarbon *mixtures* of higher molecular weight, it has also proved of value for testing preparations of pure individual saturated hydrocarbons. The method has been verified by the ultimate analysis of mixtures having a *molecular weight above 250*.

In the analysis of unsaturated mixtures the aromatic ring content has also been taken into consideration, so that it is possible to represent the composition of an unsaturated olefine-free hydrocarbon mixture by :

* Paper presented for discussion at the Morning Session (A), 24 May, at the Summer Meeting of the Institute of Petroleum held in Birmingham, 22-24th May, 1939.

† Chemical Engineering Laboratory, Delft University.

Per cent. aromatic rings *
 Per cent. naphthenic rings
 Per cent. paraffinic side chains.

It must be emphasized that such an expression for the analysis of, e.g. a lubricating-oil fraction is based on certain suppositions concerning the type of rings (rings with six or with five carbon atoms, etc.) present. It is also more convenient to express results in percentage of the carbon atoms present as aromatic rings, as naphthenic rings, and as paraffinic side-chains.† Such a suggestion has already been made by Kreulen.

As mentioned above, the greater the progress made in the preparation of pure hydrocarbons and in the knowledge of the types of hydrocarbons present in hydrocarbon mixtures, either natural or synthetic, the more accurate will become the methods of analysis. This is particularly the case with an extension of the graphical statistical method worked out in recent years by Dr. J. J. Leendertse in which the specific parachor was introduced. This method enables one to estimate the degree of branching.

As already stated the method is suitable for mixtures with molecular weight above 250. Diesel fuels have a mean molecular weight of about 200 to 260 and it is evident that we come close to the limit of application, and such definite conclusions as were reached in the investigations of lubricating oil fractions cannot be attained.

The graphical statistical methods will not be strictly necessary for the analysis of *gasoline fractions*.‡ For mixtures boiling below 150° to 200° C. the constituents can be isolated. Analytical rectification enables individual hydrocarbons to be separated. The method last mentioned has also been successfully applied to the isolation of the low boiling constituents of some crude oils by Rossini and his collaborators.

An attempt only can be made to see how far the application of the graphical statistical methods can be successful in the case of diesel fuels. Supposing that for saturated mixtures with low-boiling constituents the ring-analysis method can be confirmed by ultimate analysis, there still remains the problem as to whether the analysis will enable one to predict some of the practical properties of diesel fuels.

Since the work of Boerlage and the members of his staff (Broeze a.o.)² it is known that there exists a close relationship between the ignition quality of diesel fuels and the cetene or cetane number. By comparative work carried out at Delft (Shell group) and Sunbury-on-Thames (Anglo Iranian), it has been proved that in many cases the rating against the primary fuels cetene and α -methylnaphthalene results in very nearly identical cetene numbers.³

With the exception of substances like peanut oil, it can be said that in general a tolerance of plus or minus 5 per cent. in cetene numbers can be allowed in practice.

* This percentage can be calculated from the difference of the aniline point before and after hydrogenation by multiplying it by a certain factor. This factor will not always be constant. (D. J. W. Kreulen, *J. Instrn. Petrol. Tech.*, 1937, 23, 262, compare also below.)

† This method has been investigated, and the results will be published shortly.

‡ For routine-analysis, however, the authors apply such a method to aromatic-free gasoline fractions boiling up to 180° C., the results of which have been shown to be very useful.

Kreulen⁴ studied the influence of the composition of gas oils (expressed in percentages of aromatic and naphthenic rings and paraffinic side chains) on the cetene number. From his experiments he derived the formula:

$$\text{Cetene value} = -0.2A + 0.1N + 0.85P,$$

in which A , N , and P represent, respectively, the percentage of aromatic rings, naphthenic rings, and paraffinic side-chains, of the gas oil, determined by means of the ring analysis method for saturated hydrocarbon mixtures.

By means of this formula he obtained the following results:

TABLE I.

Gas Oil.	Cetene Value, Determined.	Cetene Value Calculated.	Difference.
1	23½	25	+1½
2	35	36	+1
3	37	34	-3
4	41	49	+8
6	51	49	-2
5	51½	54	+2½
11	53	53	0
7	60	52	-8
8	62	60	-2
9	62	63	+1
10	65	61	-4

From the work of Boerlage and Broeze⁵ it is known that the molecular ramification has a decided influence on the ignition quality of diesel fuels, since these investigators found that the ignition quality of tetra-*isobutylene* was very low compared with that of *n*-cetene, which has the same empirical formula, $C_{16}H_{32}$.

It was therefore quite reasonable that, although a certain broad relationship between the chemical composition as found by the ring-analysis method and the cetene value exists, there are still other influences which must be considered.

The authors have not at their disposal a large number of data in connection with the relationship between chemical composition and cetene or cetane values. Some data, however, were obtained in 1932 when working with three gas oils (1, 4, and 7); from each of them was derived an Edeleanu raffinate and a hydrogenation product. Nos. 1 and 4 were natural distillates, whereas No. 7 was a cracked product. Therefore No. 7 and the Edeleanu raffinate derived from it (No. 8) contained a certain percentage of olefines. For the investigation Nos. 7 and 8 therefore were first hydrogenated under high pressure with nickel catalyst at low temperature (<100° C.). In this way the olefines were eliminated. The percentage of olefines was calculated from the bromine value, assuming for the olefines the same molecular weight as the mean molecular weight of the gas oil. The hydrogen consumption during the hydrogenation was in accordance with these bromine values.

The content of aromatics (aromatic rings) of the nine gas oils was

calculated *approximately* from the difference of the aniline point before and after hydrogenation by assuming 1° C. increase proportional to 1 per cent. of aromatics.

In Table II is given a summary of the constants of the oils before and after hydrogenation. The specific parachor was not determined because this factor was not used in 1932 for calculating the degree of branching or ramification.⁶

TABLE II.

No.	Natural Gas Oil, No. 1.			Natural Gas Oil, No. 4.			Cracked Gas Oil, No. 7.		
	Original.	Edeleanu Raffinate.	Hydrogenated.	Original.	Edeleanu Raffinate.	Hydrogenated.	Original.	Edeleanu Raffinate.	Hydrogenated.
	1.	2.	3.	4.	5.	6.	7.	8.	9.
<i>Properties of the diesel fuels:</i>									
Molecular weight	212	234	213	232	261	229	205	228	221
n_D^{20}	1.5008	1.4733	1.4724	1.4974	1.4628	1.4598	1.4880	1.4541	1.4528
d_4^{20}	0.9002	0.8660	0.8630	0.8801	0.8306	0.8320	0.8632	0.8144	0.8192
$\frac{n^2-1}{n^2+2d}$	0.3272	0.3241	0.3247	0.3327	0.3315	0.3291	0.3338	0.3326	0.3298
Aniline point	42.0	70.0	63.6	63.5	86.4	80.6	52.0	76.6	78.4
Bromine value (McIlhenny)	0.2	—	-0.2	1.1	0.5	-0.2	13.8	14.3	-0.4
Cetane value*	37	53	49	53	80	68	61	85	79
Cetane value*	32	46	43	46	70	59	53	74	69
<i>Properties of the completely hydrogenated diesel fuel:</i>									
Molecular weight	218	233	217	236	259	225	208	225	217
n_D^{20}	1.4719	1.4700	1.4663	1.4615	1.4541	1.4560	1.4535	1.4462	1.4506
d_4^{20}	0.8687	0.8627	0.8559	0.8406	0.8218	0.8280	0.8230	0.8059	0.8167
$\frac{n^2-1}{n^2+2d}$	0.3223	0.3234	0.3238	0.3267	0.3296	0.3283	0.3287	0.3310	0.3294
Aniline point, °C.	69.6	74.6	70.6	83.4	91.2	84.0	77.2	85.4	80.6
Mean number of rings per molecule	2.0	1.9	1.8	1.4	1.0	1.2	1.1	0.8	1.0
Aniline point increase by hydrogenation	27.6°	4.6°	7.0°	19.9°	4.8°	3.4°	20.1°†	4.0°†	2.2°
Per cent. by wt. of olefines	—	—	—	—	—	—	16‡	20‡	—
Per cent. by wt. of aromatic rings	28	5	7	20	5	3	20	4	2
Per cent. by wt. of naphthenic rings	30	46	45	17	18	29	13	16	26
Per cent. by wt. of paraffinic side chains	42	49	48	63	77	68	67	80	72

* Determined by the Engine Research Laboratory, Bataafsche Petroleum Co., Delft.

† For the olefine-free oil aniline point is taken as 57.1° and 81.4°, respectively.

‡ Calculated from bromine value and from hydrogen consumption at low temperature (<100° C.) hydrogenation.

If we apply Kreulen's formula to the nine diesel fuels it is seen that

the results do not agree with the determined cetene values, the differences are smaller however if the same formula is used for calculating the cetane values.

TABLE III.

Diesel Fuel.	Cetene Value, Determined.	Cetene Value, Calculated.	Difference.	Cetane Value.*	Cetane Value, Calculated.	Difference.
1	37	33	-4	32	33	+1
2	53	45	-8	46	45	-1
3	49	44	-5	43	44	+1
4	53	51	-2	46	51	+5
5	80	66	-14	70	66	-4
6	68	60	-8	59	60	+1
7	61	54	-7	53	54	+1
8	85	63	-16	74	67	-5
9	79	63	-16	69	63	-6

* Corresponding with the determined cetene values.

It would be possible to derive another formula of the same type which would give better agreement with the determined cetene or cetane values. Kreulen determined the specific parachor, but the results cannot explain the differences observed with his gas oils 4 and 7. Moreover, it can be expected also that molecular weight has a marked influence on the ignitability of hydrocarbons of the same class.⁷

The authors are of the opinion that all these considerations make the derivation of a new formula for the correlation between chemical composition and the ignition delay of diesel fuels unnecessary. But what is useless to-day might be very useful in the near future if more data on accurately analysed diesel fuels with known cetene values were available.

If we leave out of consideration the influences of various percentages of different dopes, and if we restrict ourselves therefore to the examination of hydrocarbon mixtures, then the work started by Kreulen is promising. Our own results confirm this opinion.

A more thorough investigation of a large number of diesel fuels in order to study the influence of chemical composition on the cetene or cetane value will be necessary. In this respect it will be advisable to examine a large number of hydrogenated fuels, practically free from sulphur, nitrogen, or oxygen containing bodies, together with extracts and raffinates derived from these fuels, and also oils obtained by polymerising olefines or olefine mixtures.

We are indebted to the N. V. De Bataafsche Petroleum Maatschappij for permission to publish these data.

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DIESEL FUEL CHARACTERISTICS INFLUENCING ENGINE OUTPUT.*

By A. J. BLACKWOOD † and G. H. CLOUD. †

It appears to be generally recognized that the small high-speed diesel engine, the rapid development of which has been one of the outstanding engineering accomplishments of the past decade, still lacks the ability to digest the broad variety of fuels on which its slow-speed predecessors seemed to thrive.

Inasmuch as fuels vary in quality, depending on many factors, including crude source and method of processing, the engine manufacturer is faced with the problem of reducing the fuel sensitivity of his high-speed engine so that customer acceptance may not be limited. His problem is serious, because there is as yet no widely standardized pattern for high-speed diesel fuels such as exists for gasoline.

It happens not infrequently that engines are built and then experimentally tested on fuels available at or near the engine manufacturer's plant. The engines may perform satisfactorily on the fuel used. Later, when placed in the customer's hands in different parts of the world, a multitude of troubles often develop due to the wide differences in the various fuels sold for the engine.

Numerous engine-design features and mechanical devices have helped to alleviate this handicap, since they tend to eliminate the necessity for "tailor-made" fuels. At the same time, the refiner is also concerned in engine-design trends, because if the fuel sensitivity of the engine is reduced, then the widespread availability of suitable products becomes increasingly feasible from the economic viewpoint. It is thus readily apparent that co-operation between the two interests will aid greatly the development and use of the small high-speed power plant.

There are many pressing diesel fuel problems on which the engine-man and the fuel technologist can advantageously co-operate, and there is increasing evidence that each is beginning to realize that, while he may be hard pressed to reach a solution of immediate problems of his own, it may pay dividends to have a sympathetic look at the other fellow's kindred problem and work co-operatively towards a mutually satisfactory solution.

This paper is very largely a study of data obtained on a programme of tests intended to provide information on questions of importance to engine-builder, fuel-supplier, and the oft-forgotten man—the customer. No attempt will be made to analyse such problems as cold starting, smoking, roughness, odour, or engine deposits. Rather an analysis of those fuel factors influencing principally power and fuel economy will be attempted. In order to study the effects of a large number of physical and chemical fuel characteristics on engine performance, as well as to be able to permit a dissociation of the separate effects due to any one particular characteristic,

* Paper presented for discussion at the Morning Session (A), 24th May, at the Summer Meeting of the Institute of Petroleum held in Birmingham, 22-24th May, 1939.

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a group of gas oils selected from widely different crudes were each fractionated into four cuts of 100° F. boiling range. This provided a series of some thirty samples, to which have been added numerous commercial fuels. It should be realized that the special cuts are impractical commercially and of interest only from a research viewpoint. All inspection data that might seemingly affect engine-performance characteristics were determined on each of the original gas oils and on each cut, and although these inspections are not included in this paper, they form the basis of correlations which are presented. It would be an enormous task to present the entire mass of original data together with the interpretation of the engine results. For this reason, it has seemed desirable in most cases to present "cross-plotted" data on final results only, rather than to give the detail development and original data.

The various fuels have been run in a variety of engines from time to time, although the most complete set of data has been obtained on a six-cylinder, $3\frac{1}{4} \times 4\frac{1}{2}$, ante-chamber engine capable of running up to about 2600 r.p.m. Considerable data were also obtained on a C.F.R. diesel engine attached to an electric dynamometer. Tests were run covering a wide variety of test conditions, and a study has been made of the relationships between performance and fuel properties, particularly with respect to the factors influencing power and economy. With a variety of fuels covering such a wide range of ignition quality, boiling range, and gravities, groups of samples can be selected which have certain characteristics in common, and these studied as being independent of other variables.

From strictly practical considerations, and to simplify the selection of that part of the complete data suitable for this paper, the multi-cylinder engine results which are presented are very largely those obtained when operating at combinations of load and speed which correspond to the conditions of driving a vehicle on a level road at the speeds designated. In this way, fuel consumptions are comparable generally with those realized in service, and the variations due to the fuel properties discussed have a practical application.

It may be well at this point to emphasize an important consideration which is very frequently overlooked in analysing fuel-consumption data. Engineers have been trained to evaluate engine efficiency in terms of pounds of fuel per horse-power hour. From a heat-efficiency standpoint, this is sound, since the heat content of fuels on a pound basis does not change very much with other properties. On the other hand, fuels are sold on a gallonage basis, and there is an appreciably greater number of B.T.U.s in a gallon of low-A.P.I. (*i.e.*, high-specific) gravity fuel than in a gallon of high-A.P.I. (low-specific) gravity fuel. For example, a gallon of 30-A.P.I. gravity fuel (sp. gr. = 0.876) may contain 6-8 per cent. more B.T.U.s than a gallon of 50-gravity fuel (sp. gr. = 0.78). So long as fuels are sold on a volume rather than a weight basis, this is the important thing from the user's viewpoint, and it is for this reason that volumetric fuel economy is used in this paper. The following short table of data for road-load conditions is presented to illustrate this point, since it is not uncommon to find diesel engineers and operators who express strong preferences for the fuel which is most efficient in their engine on a basis of specific fuel consumption in pounds per horse-power per hour.

	Pounds of Fuel per Brake Horse-power per Hour.	U.S. Pints of Fuel per Brake Horse-power per Hour.*
Fuel A. . . .	0.577	0.672
Fuel B. . . .	0.580	0.660
Fuel C. . . .	0.585	0.653

* 1 Imp. Gallon = 1.2 U.S. Gallons.

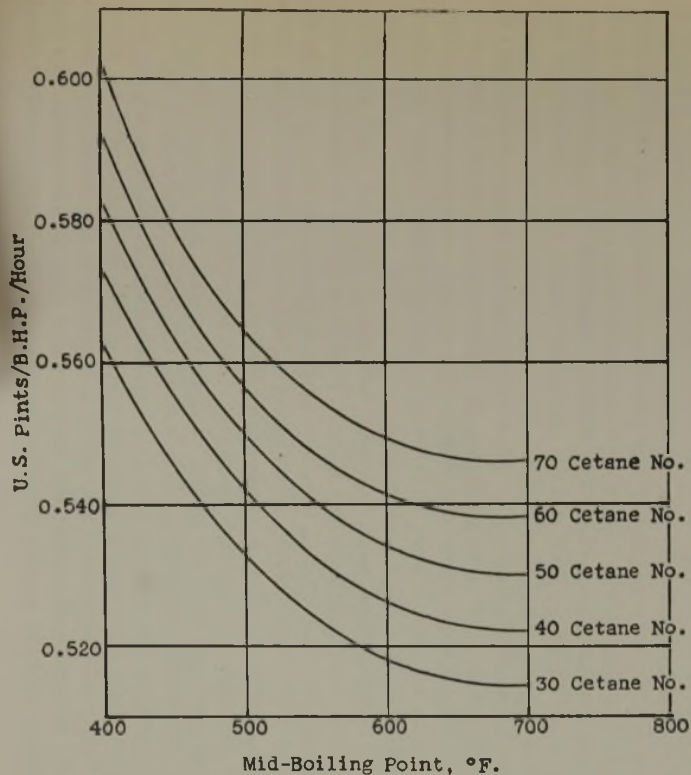
Fuel A is the best of the three fuels on a weight basis, showing about 1.4 per cent. better fuel consumption, and the normal tendency would be to select this fuel as the best of the three. Actually, however, the customer would be losing money by buying Fuel A, since for the same power output on a volume basis Fuel C would give about 3 per cent. lower consumption. It might be, of course, that operation at high speeds would not be satisfactory on the heavier, lower-cetane-number fuel, in which case the selection of Fuel A would be justified. This phase of the problem will be covered in more detail in the discussion on effect of ignition quality.

EFFECT OF FUEL VOLATILITY.

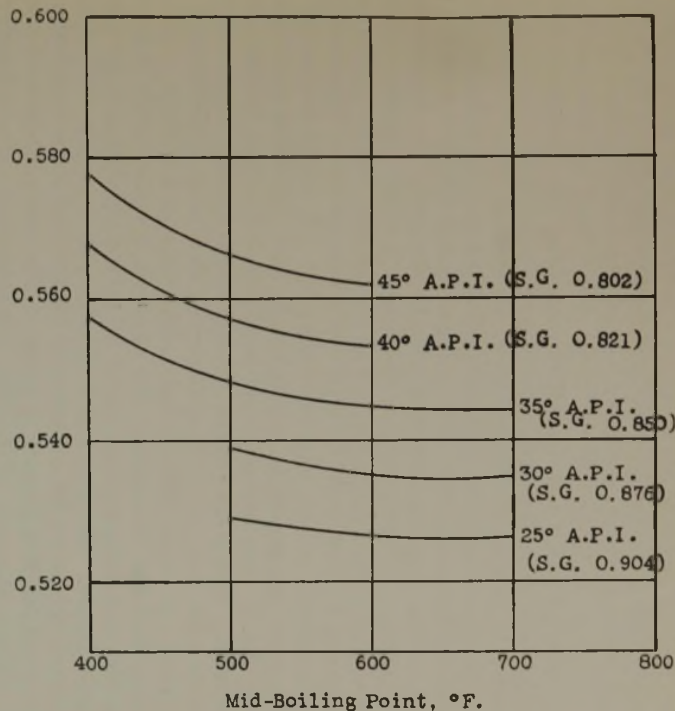
Although a discussion of the importance of fuel-ignition quality might logically come first on the list of fuel properties, it seems more desirable to discuss briefly the effect of fuel volatility. Unlike the gasoline engine, where the fuel is mixed with the air in a carburettor and delivered through a manifold to the various cylinders, the diesel has its fuel injected directly into the combustion chamber, and it would not be anticipated that the volatility of the fuel, unless carried to extremes, would have any great influence on power or economy. This, of course, assumes that the fuel burns properly when sprayed into the hot air in the combustion chamber. The effect of fuel volatility at moderate speed (1500 r.p.m.) and corresponding road load is illustrated in Fig. 1, which, under these particular conditions, shows the relation of mid-boiling point to specific consumption in U.S. pints per brake horse-power hour for fuels of constant gravity and ignition quality. Results at increasing speeds with the same injection setting show a similar relation between mid-boiling point and consumption. For constant cetane number, then, the volumetric fuel economy improves with increasing mid-boiling point, which, as will be shown later, is no doubt due to the fact that, for either constant gravity or cetane number, an increase in mid-boiling point of a fuel is accompanied by a corresponding increase in heating value per gallon. However, it is generally true that the customer will obtain better fuel mileage on high-boiling fuels provided the engine can efficiently burn them. This depends on the type of engine, speed of operation, and cetane number of the fuel.

EFFECT OF IGNITION QUALITY.

A great deal has been said and written concerning the importance of ignition quality of diesel fuels. Boerlage and Broeze were among the first to study the ignition delay characteristics of diesel fuels, and they proposed a method of evaluating this delay property by means of matching the



EFFECT OF VOLATILITY FOR FUELS OF CONSTANT CETANE NO.
(Road Load. 1500 r.p.m.)



EFFECT OF VOLATILITY FOR FUELS OF CONSTANT GRAVITY.
(Road Load. 1500 r.p.m.)

FIG. 1.

unknown fuel with a blend of two primary reference fuels in much the same general way that gasolines are evaluated for anti-knock.¹ From this early work has developed the present system of expressing ignition quality in terms of cetane number. There is no doubt that ignition quality has received more attention and study than any of the other fuel characteristics which affect engine performance, and it is still considered by many to be of the utmost importance. Nevertheless, there still remains considerable doubt as to the influence of ignition quality *per se* when stripped of other fuel property influences, since it is believed that insufficient work has been reported in the literature to demonstrate definitely the importance of cetane number or to obtain a clear distinction between the effect of cetane number and other fuel properties. The engine performance on the special cuts prepared for the work being described provided an opportunity to study some phases of this important question. It might be assumed, for example, from the preceding discussion on fuel volatilities and from the curves in Fig. 1, that fuel economy is impaired by going to high-cetane-number fuels. This is not always the case when economy is expressed on a volumetric basis, and probably not ever the case when it is expressed on a pound basis. A consideration of the data presented in Figs. 1, 2, and 4 will clarify the latter statement. For example, consider in Fig. 1 (left) two fuels of 600 mid-boiling point, one of 30 cetane number and the other of 70 cetane number. The physical properties read from Fig. 4 indicate that the first fuel will have a heat content of 148,000 and the second fuel a heat content of 138,000 B.T.U. per U.S. gallon. The ratio of these heat contents is 1.07, whereas the ratio of the pints per brake horse-power hour is 1.06, indicating that the change in economy with cetane number is the result of the change in heat content. Consider another pair of fuels on Fig. 1 (left), both of 50 cetane number, one of 700 mid-boiling point and the other of 450 mid-boiling point. The physical properties as read from Fig. 4 show that these have heat contents of 144,000 and 136,000 B.T.U. per U.S. gallon, the ratio of which is 1.05, which compares with a ratio of 1.05 for the indicated experimental economies. The same interrelation exists on any pairs of fuels chosen on Fig. 1, either left or right. However, changes in fuel economy are not invariably due to differences in heating value, as is shown by Fig. 2, which gives the relation between the consumption, gravity, cetane number, and r.p.m. On Fig. 2 by the dotted lines have been indicated the change in consumption with cetane number which would occur if heat content were the only influence. In each case the 47.6-gravity fuel has been taken as a basis. It will be noted, in the lower curve represented by 1500 r.p.m., that the consumption is directly proportional to the heat content, whereas when speed is increased and ignition lag more important, consumption deviates from the heat-content basis in favour of cetane number. It appears, therefore, that there is an optimum balance between heat content per gallon, cetane number, and speed. In other words, under relatively low-speed conditions, where quickness of ignition is of secondary importance, the best consumption is obtained on the fuel of highest heating value, whereas at high speeds, under conditions where quick ignition is imperative and where the quality of the combustion might logically be expected to influence output more than at low speeds, the fuel of superior ignition quality gives fuel economies which may readily exceed

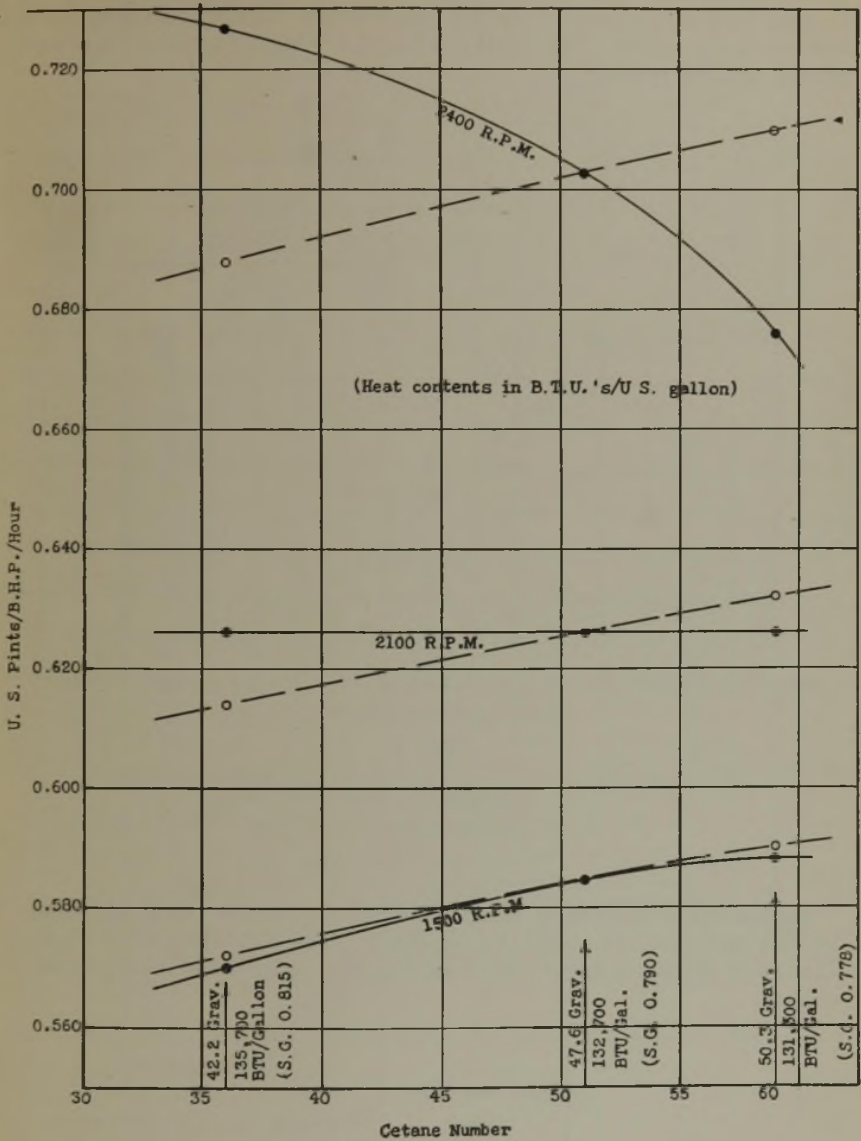


FIG. 2.

EFFECT OF GRAVITY AND IGNITION QUALITY ON FUEL CONSUMPTION FOR FUELS OF SIMILAR VISCOSITY AND VOLATILITY.

(The dotted lines show how volumetric fuel economy would change if dependent only upon B.T.U./Gallon—based on the 47.6 gravity fuel.)

those attained on fuels of higher heat content but poorer ignition quality. It may be that, on engines having provision for varying injection timing and rate of injection, even greater advantage may be realized from fuels of high ignition quality.

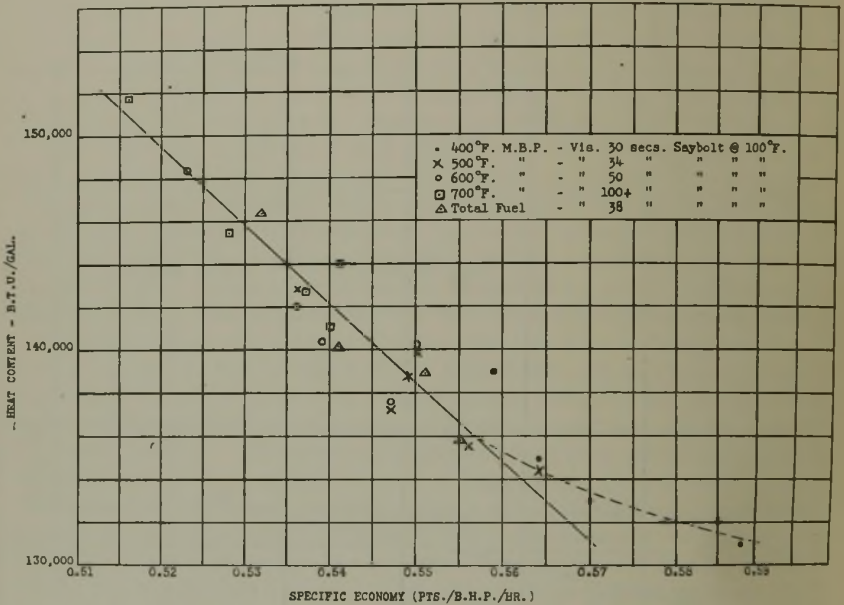


FIG. 3.

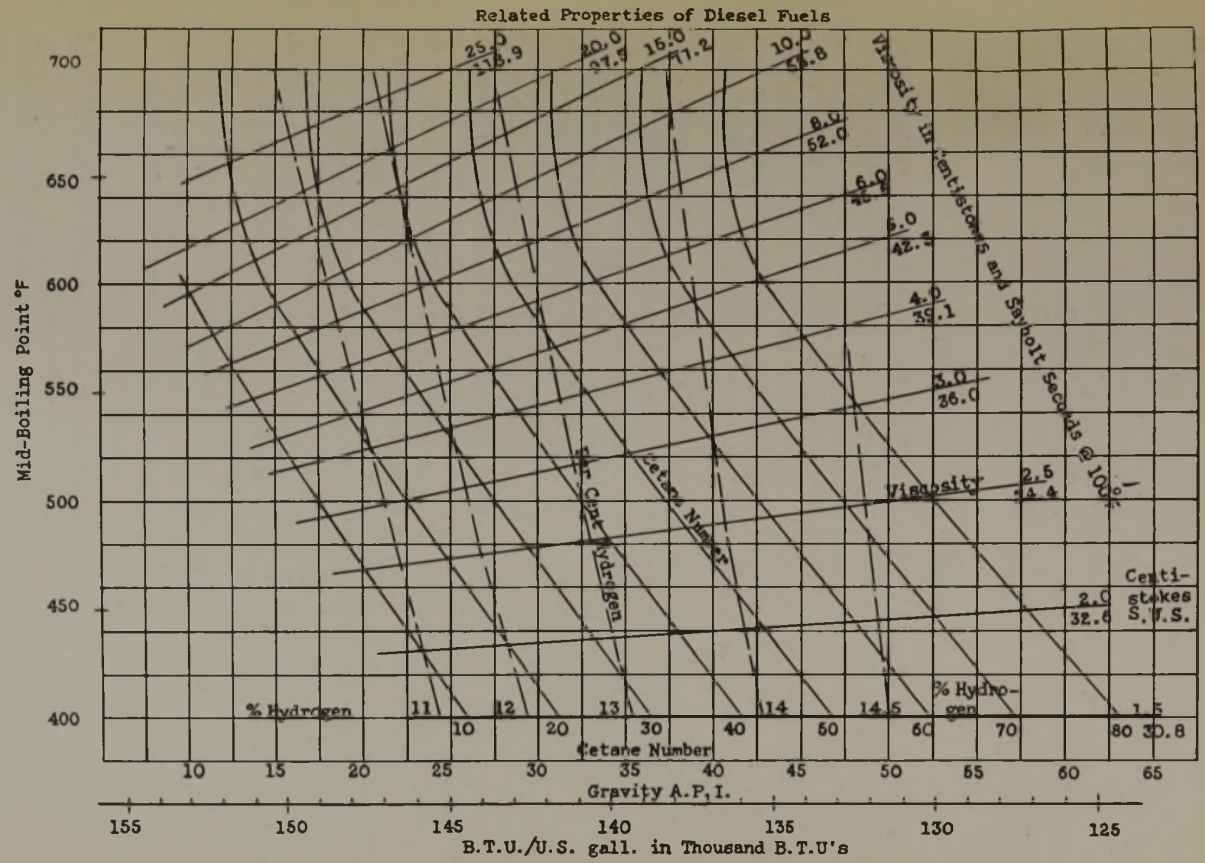
HEAT CONTENT (B.T.U.'S/U.S. GALLON) *v.* VOLUMETRIC ECONOMY
(U.S. PINTS/B.H.P. PER HOUR.)

6-CYLINDER ANTECHAMBER ENGINE.

(Road Load. 1500 r.p.m.)

Engine-power is likewise affected by ignition quality in a way similar to fuel economy, as might be expected. The following table of data illustrates this point for two fuels having fairly wide differences in ignition quality.

	Fuel Properties.		Power Output.			
			800 r.p.m.		2100 r.p.m.	
	Fuel A.	Fuel B.	Fuel A.	Fuel B.	Fuel A.	Fuel B.
Gravity, ° A.P.I.	33.3	37.9	27.3	24.5	64.0	66.8
Specific gravity	0.859	0.835				
Cetane number	43.7	67.8				
Pounds/U.S. gallon	7.15	6.96				
B.T.U./U.S. gallon	140,500	137,800				
B.T.U./pound	19,650	19,800				



Although Fuel A has about 2 per cent. higher heating value per gallon and delivers some 11 per cent. more power at 800 r.p.m. than does Fuel B, the situation is reversed at 2100 r.p.m., where Fuel B develops between 4 and 5 per cent. more power than Fuel A. Evidently, under the conditions of these tests, the combustion of low-ignition-quality fuels is not efficient at high speeds, and conversely the high-ignition-quality fuel is not as efficiently burned at low speeds. This would probably have been reflected in a corresponding change in the fuel economy shown in Fig. 2 if tests at low speeds had been included.

EFFECT OF FUEL VISCOSITY.

There is considerable difference of opinion among diesel technologists as to the effect of viscosity on performance. Many diesel engineers are concerned about viscosity from considerations of wear on pump and injector parts. The petroleum technical people, in addition to fears about wear, are perhaps fully as concerned about power and economy as affected by viscosity. Obviously viscosity is difficult to dissociate from other fuel properties, and it is this aspect of the viscosity question with which this paper deals.

Messrs. Rothrock and Marsh of the N.A.C.A.³ found that with a new, commercial, fuel-injection pump the rates of fuel injection showed little variation for a range of fuel viscosities from that of gasoline to that of an S.A.E. 30 lubricating oil. Le Mesurier has stated⁴ that fuel consumption appears to be quite independent of viscosity except where leakage exists in the fuel system due to badly worn injection equipment. He observed that the leakage increases rapidly with decreasing viscosity, the reciprocal of the leakage (by weight) plotted against kinematic viscosity giving a straight-line relationship except at very low viscosities.

There is evidence to indicate that, with worn injection equipment, fuels of low viscosity show a loss in power in cases where engines are equipped with throttle stops or governor stops to prevent overload. In such cases, in addition to the lower-viscosity fuels having lower heating value per gallon, the full fuel delivery simply does not reach the combustion chamber, and the net power loss is due to the combined effect. The petroleum field-engineer meets cases, particularly in tractor operations, where low-viscosity fuels produce severe power losses in worn equipment and trade may be lost simply because a competitor may have a higher-viscosity fuel.

In general, it would appear from the data in the literature, and from considerations of flow as a function of clearance and viscosity, that two broad conclusions can be reached, namely :—

(a) An increase in viscosity from 33 to 40 seconds Saybolt (2.1–4.2 centistokes) at 100° F. cuts the leakage in half.

(b) Doubling the pump clearances increases the leakage fourfold.

In other words, good mechanical condition of the pump is the cure for troubles caused by leakage rather than increase in viscosity of the fuel.

A study of fuel consumption covering a wide range of fuel viscosity has been made on a 6-cylinder antechamber-type engine having injection equipment in good condition. The results were plotted as functions of

several fuel characteristics, with the result that, by and large, the fuel consumption seemed to correlate best with heating value of the fuel, as might be expected, with viscosity having only minor influence. Fig. 3 is a plot of the data, showing the relation between fuel consumption in the 6-cylinder engine at 1500 r.p.m. and road load and heating value in B.T.U.s per U.S. gallon. Except for very low viscosity fuels, as indicated by the broken line through the solid dots, the points show a linear relationship. The low-viscosity fuels show somewhat higher consumption than might be expected from heating values. These results were obtained at 1500 r.p.m., which is in the speed range where—as previously shown for this same engine—ignition quality had but slight effect on fuel economy, and in this plot there is no evidence to indicate that the deviations from the average line are due to ignition quality differences. It may be that the accuracy of determining heating values could account for the deviations from the line, but it is unlikely that this could also account for the relatively poor economy of the very low-viscosity fuels.

EFFECT OF GRAVITY AND HEATING VALUE.

Gravity has not generally been considered an important property of a diesel fuel. However, since fuels are sold on a volume basis, and since gravity is in an approximate way a measure of the heat content of a fuel in B.T.U.s per gallon, it follows that relative gravities should be reasonably good indices of the volumetric economy obtainable from various fuels when the fuel is burned to best advantage. For fuels generally suitable for high-speed diesel engines, a decrease of 2.5° A.P.I. gravity (*i.e.*, an increase in specific gravity of 0.01 approximately) corresponds approximately to an increase of 1 per cent. in heating value, which in turn will usually be reflected in an increase of 1 per cent. in fuel economy. This, of course, does not hold for high-speed operation, where differences in cetane number of the fuels being compared may change this relationship, as has already been demonstrated in the preceding sections.

At present the trend in the U.S.A. appears to be towards volatile, highly-paraffinic fuels which necessarily have high-A.P.I. (low-specific) gravity. It may be, when the various engine manufacturers have overcome the smoking and engine-fouling troubles that have prompted the demand for lighter fuels; and when diesel engines are purchased on a basis of the fuel economy possible with one engine compared to another, rather than as compared with a correspondingly powered gasoline engine as at present, that more attention will be given by the engine-builder to fuel economy. This will probably result in a demand for fuels of higher heat content per gallon—*i.e.*, higher-specific-gravity fuels. Just how far the trend in engine speeds and the ability to use low-cetane-number fuels will permit this to extend remains to be seen.

In reviewing the various phases of engine operation which have been discussed, it is apparent that of all the fuel characteristics which seemingly influence engine power and economy, only heating value, ignition quality, and possibly viscosity are basically important. Since this is the case, it would be convenient to have as a reference chart a set of curves showing the interrelation of the important fuel properties. For this purpose,

Fig. 4 has been prepared, this chart being similar in many respects to that of Watson, Nelson, and Murphy,⁵ but expanded to include more variables. Knowing two characteristics to locate a point on this chart, the other fuel properties can be ascertained, and their importance evaluated. In this chart, heating value, B.T.U. per U.S. gallon, is shown as directly related to gravity, which is not strictly accurate, since for the same gravity hydrogen content does affect heat of combustion to a degree. A chart of this kind can be of immeasurable help in learning to appreciate the significance of the interrelated fuel properties. It is also of assistance in setting limits of fuel properties when writing specifications such that "impossible" requirements are not established as frequently happens.

In conclusion, the points which seem to be of greatest significance may be summarized as follows:—

1. Fuel viscosity *per se* is not a major factor in the power performance of high-speed diesel engines, except in instances where worn injection equipment might make it undesirable to use a low-viscosity product.

2. Assuming complete combustion, fuel volatility affects fuel economy only as it is related to heating value and ignition quality. Heating value, in terms of B.T.U. per gallon, may be closely estimated from gravity.

3. For most present-day engines having fixed injection timing, ignition quality is a major factor in determining economy in the upper speed ranges. At the lower engine speeds, heat content, as measured by B.T.U. per gallon, or as estimated from gravity, is the most important consideration in economy.

4. The principal diesel-fuel characteristics—viscosity, mid-boiling point, gravity, hydrogen content, heating value (B.T.U. per gallon), and cetane number—are very closely related. If any two of these are known for a given fuel, the others can be closely estimated from a chart such as presented in Fig. 4.

Suggested Reading.

¹ *Automotive Industries*, 1932, 67, 79

² H. N. Bassett, *Automotive Engineer*, January 1937, p. 21.

³ A. M. Rothrock and E. T. Marsh, *N.A.C.A. Report*, 1934, No. 477.

⁴ Le Mesurier, *J. Instn Pet. Tech.*, 1931, 17, 397.

⁵ *Ind. and Eng. Chem.*, 1935, 27, 1460.

⁶ *Ibid.*, 1935, 27, 152.

⁷ R. D. Best, *Nat. Petrol. News*, 1937, 29, No. 40-R-232-6.

⁸ R. F. Selden, *N.A.C.A. Report*, 1938, No. 167.

EVALUATION OF CERTAIN NORMAL ALKYLATED BENZENES AS DIESEL FUELS.

By GANN SHEEN, B.Sc., C. E. WOOD, M.Sc., F.Inst.Pet. and
F. H. GARNER, Ph.D., F.Inst.Pet.

INTRODUCTION.

THERE has been no systematic investigation of the ignition quality of pure hydrocarbons distilling within the diesel fuel range, although the octane numbers of a large number of pure hydrocarbons in the gasoline range have been determined.* The hydrocarbons investigated include paraffin hydrocarbons, unsaturated aliphatic hydrocarbons, aromatic hydrocarbons, saturated naphthene hydrocarbons, with both five and six rings, in addition to a number of unsaturated naphthene hydrocarbons and a certain number of dienes.

As regards hydrocarbons in the diesel fuel range, Boerlage and Broeze suggested the use of mixtures of cetene and mesitylene for the rating of diesel fuels.† These have more recently been replaced by cetane and α -methyl-naphthalene, and the percentage of cetane in the blend is the cetane number of the fuel. In the paper by Boerlage and Broeze, figures are quoted for blends of tetraisobutylene with a gas oil of 70 cetene number, but these five hydrocarbons appear to be the only pure hydrocarbons of which the ignition quality has been investigated.

In 1932, Ormandy,‡ pointed out the analogy between the use of gas oil for gas-works practice and gas oil used as diesel fuels, and that it was desirable to use diesel fuels which cracked readily. The thermal stability depends on the molecular structure and, as pointed out by Boerlage and Broeze, straight-chain paraffin hydrocarbons are the least stable. The molecular structure of a fuel is the deciding factor in ignition quality; aromatic rings are fairly stable, and likewise paraffin hydrocarbons with branched side-chains. Cracked diesel fuels tend to have poorer ignition quality than straight-run fuels, depending on the intensity of cracking. Dumanois § suggested the use of heptane value as a method of expressing the ignition quality of diesel fuels, and this would be determined in the standard C.F.R. gasoline engine by the procedure used in the determination of octane numbers, but expressed in percentage heptane instead of percentage octane. The fuel used was to be blended with gas oil in the ratio of 15 : 85. There is at least a general relationship between heptane values determined in this way and cetane numbers determined in the diesel engine, as paraffin hydrocarbons are satisfactory for compression-ignition engines but unsatisfactory for spark-ignition engines, whereas the reverse is the case with aromatic hydrocarbons.

In the present investigations it was decided to determine the cetane numbers of a number of hydrocarbons derived from benzene by increasing

* W. G. Lovell and J. S. Campbell, "Science of Petroleum," 4, 3004.

† *Transactions S.A.E.*, 1932, 27, 283.

‡ *J. Instn. Petrol. Tech.*, 18, 576.

§ *Compt. rend.*, 1933, 196, 1003.

the length of the paraffinic side-chain. Normal amylbenzene distills over at 204° C., and this is within the distillation range of diesel oils. The other three hydrocarbons investigated—normal hexyl, normal heptyl, and normal nonyl—also come within the distillation range of the lighter and middle fractions of diesel oil, as the normal nonylbenzene boils at 280° C.

EVALUATION OF DIESEL OIL BY ENGINE TESTS.

Le Mesurier and Stansfield in 1931 measured the delay angle on a series of fuels with the help of a Farnborough indicator, and also determined ease of starting by adjusting the temperature of both jacket and air until the temperature was sufficiently low that hesitation occurred before firing commenced.*

Boerlage and Broeze described work † in which they had carried out tests on the ignition quality of fuels of compression-ignition engines, and in this paper the original suggestion was made that cetene and mesitylene should be used, as standards, for measuring the ignition quality of fuels. Indicator diagrams (out of phase) were taken on a Miahak indicator, which proved to be sufficiently accurate for the first stages of combustion, as was shown by correlation with an optical indicator. The test engine used was an adapted Thomassen 20-h.p. engine which was run at 100–350 r.p.m. at light load. A critical compression ratio (C.C.R.) method was introduced by Pope and Murdock; ‡ these tests were conducted on a standard C.F.R. engine converted for compression-ignition operation. The engine is motored without injection of fuel at a known compression ratio under specified conditions, and fuel is then injected for three seconds. Should an audible combustion be heard at the exhaust within this time, the compression ratio is lowered and the procedure is repeated. The lowest compression ratio at which combustion occurs is the critical compression ratio. The lower the critical compression ratio, the better is the ignition quality of the fuel.

The present standard methods which have been put forward for the determination of cetane numbers are those by the Institute of Petroleum and the A.S.T.M. In I.P.T. Serial Designation FO.39.T, the ignition quality is expressed as cetane number. Two reference fuels, I.P.T. high-ignition quality (70.5 cetane number), and I.P.T. low-ignition quality (18 cetane number), are used, and it is stated that it has not been found necessary to standardize any particular engine for the determination of ignition quality, although an engine of high-compression ratio with constant spray valve opening time and steady ignition characteristics must be used. There is, however, some evidence that the cetane number of both high- and low-ignition-quality fuels may show finite differences when tested on widely different types of engines. The A.S.T.M. has published (in October 1938), for information, a proposed method of test for the ignition quality of diesel fuels, and in this method the standard C.F.R. diesel engine is used, the delay angle being fixed at 13° and the cetane number determined from the compression ratio. A high cetane secondary reference fuel made from petroleum is prescribed, but the low-cetane secondary reference is a mixture of α - and β -methyl-naphthalene.

* *J. Instn. Petrol. Tech.*, 1931, 17, 387.

† *Engineering*, 1931, 132, 603, 687 and 755.

‡ *J. Soc. aut. Engrs*, 1932, 30, 136.

In the present investigation a C.F.R. diesel engine was employed, to which the Schweitzer and Hetzel apparatus was fitted, so that in the cetane number determination the ignition delay angle could be adjusted to a constant figure of 13° crank-angle.

HYDROCARBONS USED IN THIS INVESTIGATION.

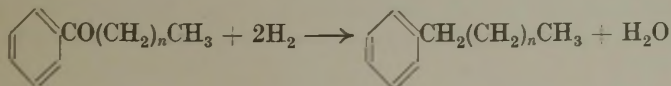
As already mentioned, very little research has been done on pure hydrocarbons within the distillation range of diesel fuels, and for this research it was decided to select compounds having properties intermediate between aromatic and paraffin hydrocarbons. Although straight-chain paraffin hydrocarbons are present in diesel fuels, the proportion is necessarily small, owing to the necessity of the diesel fuel used having a satisfactorily low pour point. From the investigations made at the Bureau of Standards it appears that substituted aromatic hydrocarbons are present in lubricating oils, but little work has been done on the isolation of individual hydrocarbons present in the diesel-oil fractions of crude petroleum.

Normal monoalkylated benzenes were the compounds chosen as most suitable for this initial investigation, compounds in which the aromatic influence is gradually diminished. A series of normal alkylated benzenes ranging from normal *n*-amyl to *n*-nonyl were prepared on which the following problems could be studied :—

- (1) The effect on ignition quality of increasing the length of a paraffin side-chain.
- (2) A comparison between the effect of ignition quality on a paraffin and aromatic nucleus, since the number of paraffinic carbon atoms in the side-chain varies from 4 to 9, as against 6 in the aromatic nucleus.
- (3) The validity of purely physical tests for evaluating the ignition quality as determined in the engine for this type of hydrocarbon.

PREPARATION OF HYDROCARBONS.

Normal monoalkylated benzenes were prepared by reducing the corresponding alkyl aryl ketones.



the ketones being obtained by acylation of benzene with acyl chlorides by means of Friedel and Crafts' reaction. Two methods were employed for their hydrogenation :—

- (1) Clemmensen's method of reduction by means of zinc amalgam and hydrochloric acid.
- (2) Catalytic hydrogenation of the ketone in alcoholic solution under a pressure slightly greater than atmospheric in the presence of palladium deposited on animal charcoal.

The following data briefly summarize the physical properties of the alkylbenzenes under consideration as determined by us on the principal hydrocarbons.

Hydrocarbon.	Boiling Pt. ° C.		Viscosity Centistokes.		Specific Gravity, 60° F.
	9 mm.	760 mm.	100° F.	210° F.	
<i>n</i> -Amylbenzene . . .	77-78	204-205	1.2260	0.6605	0.8662
<i>n</i> -Hexylbenzene . . .	93-94	226-227	1.4647	0.7527	0.8646
<i>n</i> -Heptylbenzene . . .	108-109	240-241	1.7845	0.8632	0.8637
<i>n</i> -Nonylbenzene . . .	137.5-138.5	280-281	2.4501	0.1060	0.8626

ANILINE POINT.

All these alkylbenzenes are miscible with aniline in equal volumes even at -10°C .

DETERMINATION OF THE CETANE NUMBER.

The engine tests were carried out in the Esso European Laboratories at Vauxhall by Mr. A. Prizeman.

METHOD OF RATING.

The tests were made on the C.F.R. diesel fuel-testing engine. Fixed-ignition lag method was adopted which was developed by Hetzel and Schweitzer.* Due to the uncertainty and difficult controlling of the bouncing pin, an electric magnetic unit, such as is used in the magnetic type of radio speakers, is employed in this method. A short stiff wire resting on the diaphragm transmits the motion to the armature of the unit. The current generated in the coil surrounding the armature reduces the negative voltage on the grid of a thyatron tube, thereby causing it to conduct. The current passing to the plate of the tube goes to a high-tension coil, which in turn sends a flash through the neon lamp. During ignition, the velocity of the diaphragm is high, thus the thyatron relay trips and causes the neon lamp to flash. Instead of using an ordinary protractor, the neon lamp is mounted on the fly-wheel, which has a larger scale and permits the operator to read the angles accurately and conveniently in a standing position.

During the tests, the engine was operated under the following standardized conditions :—

- (a) Engine speed, r.p.m. 900.
- (b) Jacket-water temperature, 210°F .
- (c) Air inlet temperature, 140°F .
- (d) Lubricating oil temperature, 110°F .
- (e) Injection pressure (valve opening pressure) lbs./in.², 1500.
- (f) Fuel quantity, c.c. per minute, 13.
- (g) Injection advance angle, 13 degrees.
- (h) Compression ratio varied until ignition registered at top dead centre as indicated by the neon lamp flash, i.e., delay angle fixed at 13 degrees.

* *J. Soc. aut. Engrs*, 1936, 38, 206; *Automotive Industries*, 17th August, 1935, 73, 202.

Two reference fuels, the I.P.T. high-ignition-quality and low-ignition-quality secondary reference fuels, were used to match the sample. The high standard fuel had a cetane number of 70.5 and the low standard, cetane number 18. Fuels of any cetane number between 70.5 and 18 can be matched by mixing these two reference fuels.

The cetane number of a fuel is determined by comparing its compression ratio (read from the micrometer reading) with those for various blends of the reference fuels; two blends are found which differ in compression ratio by not more than the equivalent of 8 cetane numbers, one of which has a higher and the other a lower cetane number than the sample of fuel.

Results are reproducible within ± 1 cetane number by careful operation. The following table shows the cetane numbers of the hydrocarbons and blends of the hydrocarbons with light reference fuels.

Hydrocarbon.	Cetane numbers. % by volume of hydrocarbon in high standard reference fuel.			
	100%.	60%.	50%.	20%.
<i>n</i> -Amylbenzene	—	38	42	—
<i>n</i> -Hexylbenzene	26	—	52	63
<i>n</i> -Heptylbenzene	35	—	54	64
<i>n</i> -Nonylbenzene	50	—	60	66

n-Amylbenzene could not be run straight in the engine.

The percentages by volume are converted to percentage by weight. The specific gravities of the high standard reference fuel is 0.8070 at 60° F.

Hydrocarbon.	% by weight hydrocarbon.	% by weight high standard reference fuel.	Cetane no.
(1) <i>n</i> -Amylbenzene	100	—	—
	51.8	48.2	42
	61.6	38.4	38
(2) <i>n</i> -Hexylbenzene	100	—	26
	21.1	78.9	63
	51.7	48.3	52
(3) <i>n</i> -Heptylbenzene	100	—	35
	21.1	78.9	64
	51.7	48.3	54
(4) <i>n</i> -Nonylbenzene	100	—	50
	21.1	78.9	66
	51.7	48.3	60

DISCUSSION OF RESULTS.

(1) Boerlage and Broeze * found that cetane numbers, when expressed in weight instead of volume percentage, were additive, so that cetane numbers of fuel blends showed a linear relationship. If this applies to cetane numbers of blends, the cetane number of the unblended pure hydrocarbon could be read off by extrapolation of a graph showing cetane number

* *J. Soc. aut. Engrs*, 1932, 27, 289; "Science of Petroleum," 4, 2493.

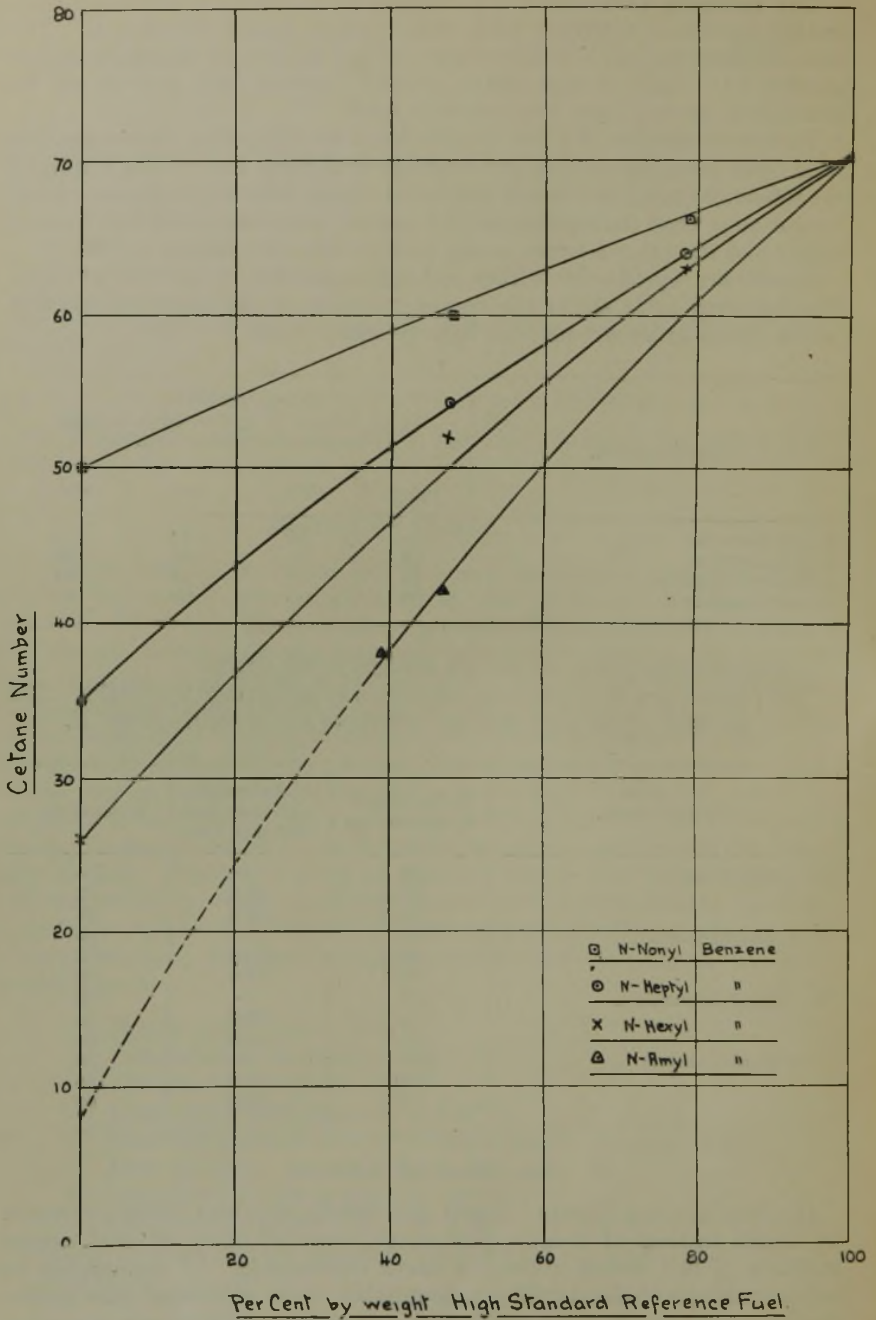


FIG. 1.

against percentage by weight of the high-ignition quality of secondary reference fuels. The experimental results, which are given in Fig. 1, show that the lines representing the cetane numbers of blends of high reference fuel and of the pure hydrocarbons are curved in all cases, with the possible exception of normal nonylbenzene; the curvature becomes greater the lower the molecular weight of the hydrocarbon.

The following table shows the blending cetane number of the four hydrocarbons calculated from the 50 per cent. point shown on Fig. 1.

<i>n</i> -Nonylbenzene	.	.	.	51
<i>n</i> -Heptylbenzene	.	.	.	39
<i>n</i> -Hexylbenzene	.	.	.	32
<i>n</i> -Amylbenzene	.	.	.	18

Fig. 2 shows actual and blending cetane numbers of the pure hydrocarbons. The actual cetane numbers are those experimentally determined for *n*-nonylbenzene, *n*-heptylbenzene, and *n*-hexylbenzene, together with that extrapolated from the blending curve shown in Fig. 1 for *n*-amylbenzene. It will be seen from Fig. 2 that the blends of high cetane reference fuel with the individual aromatic hydrocarbons investigated have cetane numbers which are always higher than would be anticipated from their percentage composition.

(2) The cetane numbers of the alkylated benzenes increase with increasing number of carbon atoms in the side-chain. Whereas amylbenzene with a cetane number of about 8 shows the poor ignition quality found in aromatic hydrocarbons, with increasing length of side-chain the cetane numbers improve quite rapidly. The cetane number of 50 for *n*-nonylbenzene is higher than would be anticipated from this hydrocarbon.

(3) Aniline point has no significance in the evaluation of this particular type of hydrocarbon, since the aniline points of all four alkylbenzenes are below -10°C .

Similarly the following table shows the cetene number calculated by Moore and Kaye's formula* from the viscosity/gravity constant, together with the cetane number as calculated from the experimental cetene number. This formula is as follows:—

$$G = 1.082A - 0.0887 + (0.776 - 0.72A)[\log \log (KV - 4)] \text{ where } G = \text{sp. gr. at } 60^{\circ}\text{F.}$$

A = modified viscosity/gravity constant.

KV = kinematic viscosity in millistokes at 100°F . Cetene number can be calculated from the following equation:—

$$A = 1.015 - 0.003N, \text{ where } N = \text{cetene number.}$$

Hydrocarbon.	Modified V.G.C.	Calculated cetene number.	Determined cetene number.
<i>n</i> -Amylbenzene	0.9933	7.3	10 †
<i>n</i> -Hexylbenzene	0.8795	43.8	30
<i>n</i> -Heptylbenzene	0.8725	47.5	40
<i>n</i> -Nonylbenzene	0.8623	50.8	57

* Moore and Kaye, *Oil Gas J.*, Nov. 15, 1934, 108.

† These figures are calculated from the relationship—70 cetane numbers are equivalent to 80 cetene numbers.

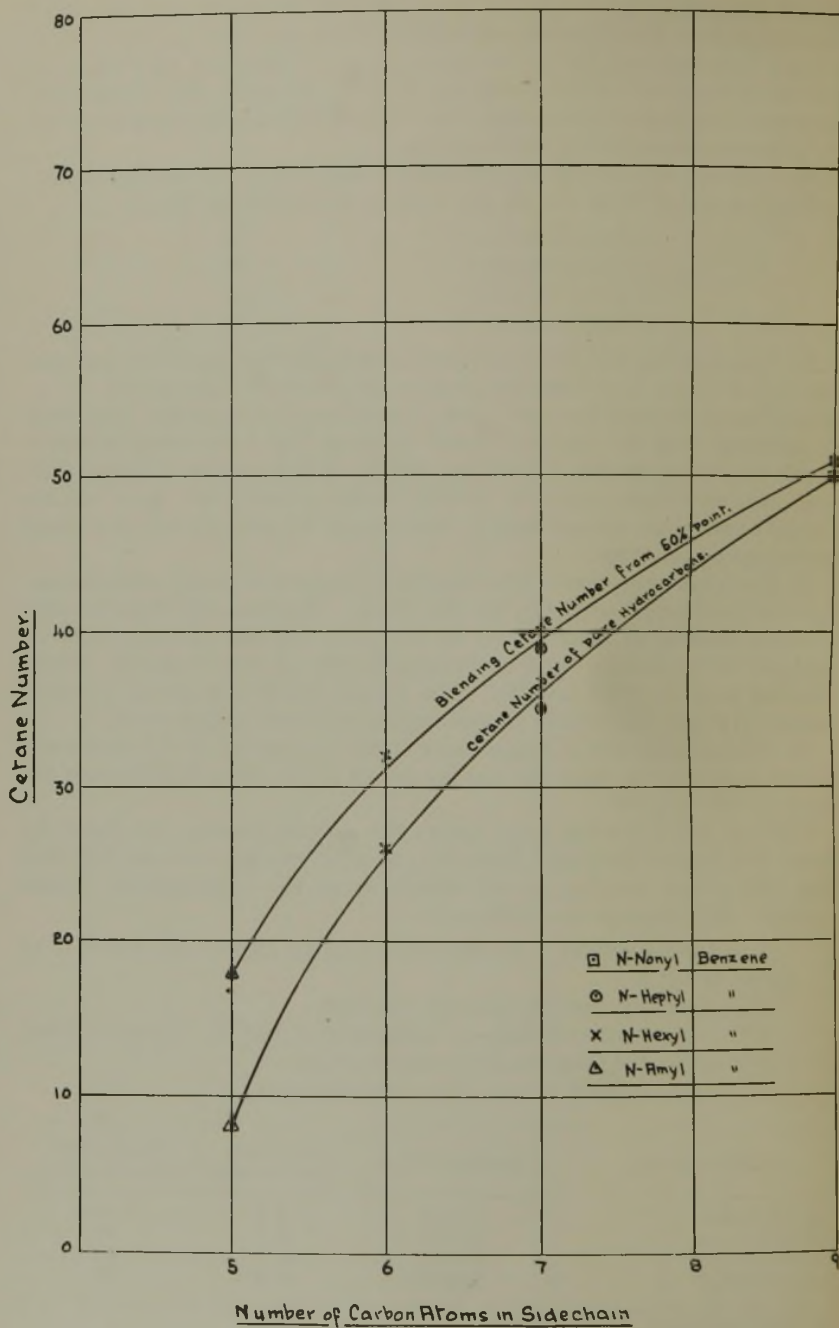


FIG. 2.

Kreulen * gave a formula for the calculation of cetene number on the aromatic, naphthenic and paraffin side-chain content as follows :—

$$\text{Cetene number} = - 0.2A + 0.1N + 0.85P$$

The calculated figures together with the determined figures are shown in the following table :—

Hydrocarbon.	Calculated cetene number.	Determined cetene number.
<i>n</i> -Amylbenzene	30.3	10
<i>n</i> -Hexylbenzene	35.1	30
<i>n</i> -Heptylbenzene	38.0	40
<i>n</i> -Nonylbenzene	45.4	57

From the above examples it will be noted that there is little agreement between the results as calculated by these two formulæ, and, furthermore, only with the Moore and Kaye formula do the calculated cetene numbers even approximately agree with the experimental determinations.

The authors wish to thank Professor A. W. Nash for his interest and for the facilities he has granted in connection with this work.

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and

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* *J. Instn. Petrol. Tech.*, 1937, 23, 253.

Morning Session—Wednesday, 24th May.

DISCUSSION.

MR. R. STANSFIELD said that the papers read at that session had all been of such high quality that any one of them would have been adequate on which to base a discussion. From the mass of material available he intended to confine his comments to Messrs. Blackwood and Cloud's paper and to that given by Messrs. Broeze and Hinze.

It would be noticed on page 689 of the former paper that a difference between fuel behaviour occurred as the engine speed was altered, low speeds being insensitive to fuel ignition quality, but high speeds demanding a high ignition quality for the best performance.

This examination of the effect of variables such as speed was very important in high-speed diesel fuel and engine research if misleading conclusions were to be avoided.

On reference to the second of the papers referred to, it would be noted that fuel consumptions were shown as improving materially with decrease of ignition quality, but this effect was well known to take place only when an engine was running at or above the smoke-point. Full rated output or overload output was, of course, a very important aspect of engine duty, but no one would contend that any engine was bought to run at its maximum possible load for more than a small fraction of its total life. In fact any discriminating engineer would make every effort to run his engines at loads not exceeding, say, 80 per cent. of maximum rating except for short emergency periods.

When the effect of ignition quality at loads other than peak values was examined, it was found that results somewhat similar to those of Blackwood and Cloud were obtained—*i.e.*, change of load altered the relative importance of ignition quality. As load fell to just below the smoke-point, but still well above the average running load for most engines, the low-ignition fuel no longer had any advantage over that of higher quality, and when low loads of considerable duration in the running life of vehicle engines were encountered, the low-ignition-quality fuels were liable to give late burning (not always definite misfiring), and this was accompanied by fuel consumptions which might reach 20 per cent. excess above fuels of more ready ignitability. Burning of this sort was not detected easily by the attendant, but might provoke a dirty condition of the engine and other troubles. It was assumed when making such comparisons that the fuels were similar in distillation characteristics, for, by special selection of samples, almost any desired comparison might be obtained, regardless of ignition quality.

Reverting again to Messrs. Broeze and Hinze's paper, the scales used for the maximum rate of pressure rise curve and the maximum pressure curve of Fig. 10, for example, suggested at first sight that there was little difference between the two effects. Closer inspection showed, however, that the alteration in maximum pressure when changing from the high to the low cetane fuel was about 13 per cent., whilst the change of rate of pressure rise was as much as 67 per cent. It was the latter alteration which affected smooth running and, often, stresses in engine parts, reducing the safety margin allowed by the engine designer. This stress effect was, further, one which must be considered solely in relation to peak output, and was much more serious than consumption figures at peak output which formed only a small percentage of any engine's life-history.

MR. E. L. HARLAND said that when considering the desirable characteristics of oil-engine fuels from a technical point of view, it might be as well to remember that the actual grades supplied to a given area were frequently determined far more by artificial considerations than by technical ones.

One was reminded of two such areas by the references made in the papers to ignition quality, and particularly by Mr. Stansfield's remarks, which stressed that fuel consumption experiments in that connection should be carried out at m.e.p.'s corresponding to those likely under actual operating conditions. The fact was, however, that they had actual knowledge of the behaviour of engines in service using fuels of widely differing ignition quality, and that information was surely at least as valuable as experimental data.

Thus throughout a large area in the Far East, owing to the prohibitive price of any fuel not passing certain customs restrictions, the vast majority of oil engines of all types and speeds had to operate on a special distillate grade which, in qualifying for

tax exemption, was inevitably of very low ignition quality, judged by Western standards. But, as in most cases where no alternative was possible, it was surprising how well the engines behaved on that fuel! Whatever else might be said, high fuel consumption was certainly not a complaint forthcoming from that country. In fact, generally-speaking, remarkably good fuel-consumption results were reported using the low-ignition-quality fuel.

By way of contrast, the other area which he had in mind also provided suppliers with an artificial problem, but the customs test could be and was met in that case by a blended diesel-fuel grade of very high ignition quality, which sold alongside a grade passing the same test but of medium ignition quality. Of the two, the latter fuel was the more favourably received by the industrial engine users, to whom both grades were often available at the same price.

Whether or not the differing ignition quality was in that instance purely incidental to the results obtained was a matter of conjecture. Such an example did, however, serve to demonstrate that high ignition quality did not necessarily mean good all-round service performance. In fact, in the experience of some operators the very opposite appeared to be true.

MR. P. DRAFER said that reference had been made in some papers and during the discussion to the relative merits of high- and low-ignition-quality (delay angle) fuels, and some attempt had been made to specify the cetane numbers of fuels suitable for high-speed engines.

It was, of course, known that a high cetane fuel (short delay angle) would give smooth running, less shock on bearings, and easy starting; but this was a matter of degree, and it might not be desirable for a fuel to have a higher cetane number than the minimum on which it could operate satisfactorily, especially if there were other desirable characteristics which went with low cetane fuels.

In this connection the following might be of interest as indicating some of the benefits obtained with low cetane fuels.

As the result of comparative tests in high-speed engines, it had been found that, in general, low cetane distillate fuels kept an engine in a clean condition, that was to say, less carbon was formed in the combustion chamber, which was to be expected from a consideration of the process of burning in a combustion chamber, in which a comparatively long delay period might enable the fuel spray to search out its air before inflammation occurred in the vicinity of the nozzle.*

Other advantages of low cetane fuels included low fuel consumption on a volumetric basis (miles per gallon) and the low pour point and absence of filter troubles referred to by Messrs. Broeze and Hinze.

It might be seen that some of these advantages were not directly attributable to the long delay angle, but nevertheless the fact remained that the crude oils which provided fuels of this type did also possess the other qualities which were desirable.

MR. L. V. WARD said that Mr. Broeze had pointed out that the reason for research into the possibility of increasing ignition quality by artificial means, at the same time keeping a low pour point, was largely with respect to aviation requirements, since very special conditions in that field of diesel-engine operation had to be met.

The normal diesel-fuel trade in the world was adequately satisfied by fuels which had no need of dope and which, it had been pointed out, gave trouble-free operation in many large areas in the world. In certain papers high ignition quality had been stressed, but he would ask: What was understood by high ignition quality and what was considered low ignition quality? Fuels as they appeared then on the world's market varied widely in ignition quality, and they all had their place in diesel-engine operation. Even high-speed diesel engines such as were used in passenger transport vehicles might be adjusted to give excellent performance on a wide range of distillate fuel. Medium-speed industrial-type engines were even more easily persuaded to consume efficiently a wide range of both distillate and blended fuel, whilst the larger slow-speed engines were quite happy on fuel which might be considered of very low ignition quality.

Specifications were a guide, and extremely necessary where such considerations as

* See Boerlage and Broeze, "*Gas and Oil Power*," January 1935.

hard carbon, sulphur content, ash, etc., were concerned, but ignition quality was one of those qualities of a fuel which, as Mr. Stansfield had stated, showed up to a different extent in different designs of engines, so that it was misleading, and he thought erroneous, to state hard-and-fast limits. C.I. engines and their fuel were complementary to each other, and they must recognize that the scientific development of the former was bound up with the qualities of the available supply of the latter. Let them not mistake ignition quality for fuel quality.

MR. A. T. WILFORD referred to the comments in Messrs. Blackwood and Cloud's paper, regarding the influence of specific gravity on fuel consumption when fuel was purchased on a gallonage basis. This matter was of considerable interest to a large user such as the London Passenger Transport Board, where careful records were kept of the miles per gallon figures obtained and any variations were subjected to close investigations. Such variations were generally found to be due to weather conditions or loadings, or a combination of the two, although at times these factors did not constitute an adequate explanation. Other things being equal, a fuel of the highest possible specific gravity would, of course, be preferred. Bench and road tests had been carried out recently with two fuels of closely similar ignition quality, but differing by 0.01 in respect of specific gravity. The bench tests, which were carried out in two different laboratories, had failed to differentiate between the fuels in respect of consumption in pints per B.H.P.H. The road tests had, however, shown a tendency for the heavier fuel to be slightly the more economical, and it was intended to follow up the matter when circumstances permitted.

He asked for further information as to the ideal fuel. He was given to understand that for some types of engines a fuel of high cetane number was less efficient than one of lower ignition quality, whilst other speakers had indicated that satisfactory results were obtainable from fuels of low cetane number. He also asked for a numerical definition of the terms "low" and "high" cetane numbers, respectively. Finally, in reference to Messrs. Broeze and Hinze's experiments he inquired as to whether there was any prospect of obtaining cheaper fuels by using materials of low ignition quality suitably doped.

MR. E. L. HARLAND said that with lower-ignition-quality fuels the user might notice increased knock or roughness and poorer startability, but after that his balance appeared to be loaded on the other side, for he gained on fuel consumption, power, and what might be termed "clean running."

One question he would like to raise in view of a previous contribution to the discussion: were they to assume that references in the various papers to ignition quality applied only where entirely distillate grades of fuel were concerned? He would not have thought this restriction to the principles put forward necessary and, in any case, it should be remembered that, in many countries overseas, the fuels normally predominating for oil-engine operation were grades containing appreciable proportions of undistilled fractions.

MESSRS. J. J. BROEZE and J. O. HINZE in reply to Mr. Stansfield's comments wrote as follows:

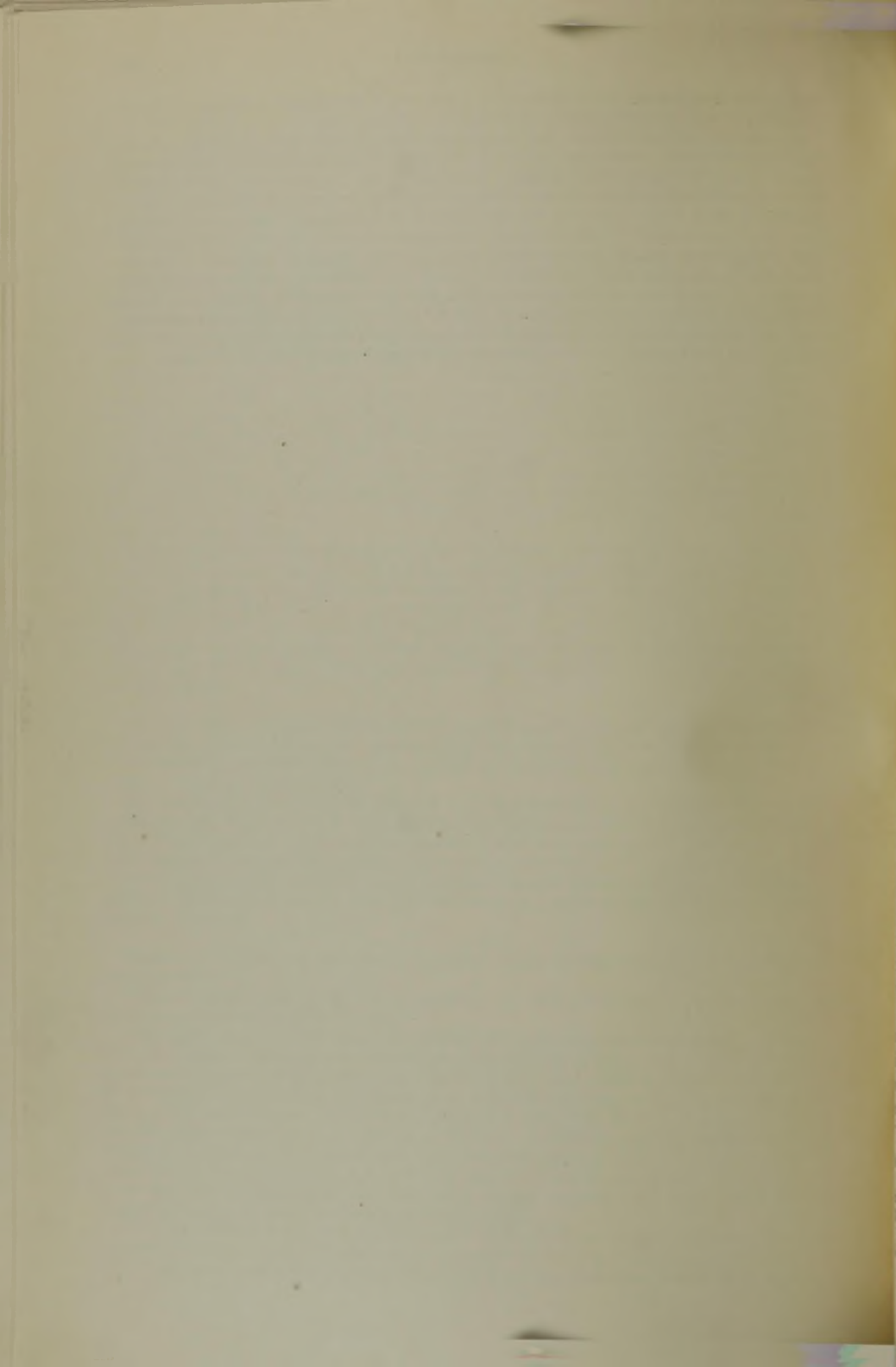
"The remarks made by Mr. R. Stansfield are very interesting and the authors agree to a certain extent with them.

They agree that the differences in specific fuel consumption which are in favour of the low ignition quality fuels, are substantially found at high loads. They do not agree that these differences are restricted to the full- and overload range; numerous tests on high speed engines of several types have shown that in many cases also at lower loads, even beyond the load corresponding with minimum fuel consumption, the low ignition quality fuel may be in favour. It will be put forward that the results given in Fig. 10 of the paper refer to tests carried out at normal running conditions of the engine (b.m.e.p. = 5.3 kg./cm.²). Only at low loads, which, however, are not of importance for high duty Diesel engines, the facts which Mr. Stansfield has mentioned in his remarks may occur.

As to the influence of the ignition quality of the fuel on smooth running and on stresses in engine parts, Mr. Stansfield has pointed out that a closer inspection of Fig. 10 shows that the alteration in maximum pressure when changing over from the

high to the low cetene fuel was about 13 per cent., whereas the change of rate of pressure rise was as much as 67 per cent.

In this respect the authors wish to put forward that the rate of pressure rise is unfortunately still considered as being the predominating factor. This is only partly true. A closer mathematical investigation of the influence of impulsive forces in vibration problems shows that when the time in which maximum load is reached is short with respect to the own period of vibration of the system (shorter than about one-fourth) the amplitude of vibration is only determined by the maximum load, independent of the fact in which way that maximum is reached. This was particularly the case with the engine referred to in Fig. 10; as the compression pressure at which the sudden pressure rise due to combustion started was about 25 atm., the difference between the low ignition quality and the high ignition quality was only 20% in favour of the latter. In fact, when running the engine on both fuels it was hardly possible to observe a difference in smoothness of running."



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Geology.

1056. Concentrations of Hydrocarbons in the Earth. E. McDermott. *Geophys.*, 1939, 4 (3), 195-209.—Investigations on the concentrations of hydrocarbons and minerals near the surface of the earth, and evidence of the presence of unsaturated hydrocarbons such as ethylene in the soil in appreciable quantities, have led to a new hypothesis for the origin and accumulation of petroleum. The main points of this hypothesis are the following. Genetically, the subsurface concentrations and the near-surface concentrations are very much the same. Oil shales are included in this category. The source materials of oil- and gas-fields are hydrocarbon gases leaking from the basement complex and from buried coal deposits. The saturated hydrocarbons result in gas-fields, whereas the unsaturateds are synthesized or polymerized to form oil which results in oil-fields. These gases migrate mainly in a vertical direction. There is no great movement of oil in the original accumulation. The formation of an oil- or gas-field depends principally on the permeability of the cap-rock and perhaps also to a more limited extent on the presence of certain catalysts such as aluminium chloride. As the permeability of shale decreases with depth of burial and in regions of deformation, the volatility of the accumulations will increase. The gases, during migration to the surface, transport quantities of the subsurface waters and the minerals dissolved in those waters.

The evidence for this hypothesis is discussed and its importance in relation to geochemical prospecting is indicated. S. E. C.

1057. The Formation of the S. Hanover Petroleum Deposits. L. Riedel. *Oel u. Kohle*, 1938, **14** (46), 963-967.—Geological evidence concerning the movement of the Hänigsen-Wathlingen salt-stock leads to the conclusion that the Nienhagen oil deposits could not have formed before the time of the *mucronaten* zone of the Senonian. This agrees with Barsch's mechanical conception of the formation of oil deposits which postulates that migration from the primary deposits first becomes possible when the salt in the neighbourhood of the salt-stock has been completely squeezed out from the parent salt-bed. In the case of the Hänigsen-Wathlingen salt-stock this event probably took place during the energetic salt movements in the Lower *mucronaten* Senonian. The importance of cracks and fissures distant from the salt-stock is pointed out. The presence of oil at a distance from the salt mass and yet in strata which extend up to it is explained by migration up these distant channels. S. E. C.

1058. Form and Tectonic Movements of the Lower Saxon Basin. G. Richter. *Oel u. Kohle*, 1938, **14** (46), 968-976.—The study of numerous new borings shows that in the south the Lower Saxon Basin has a somewhat blurred form rather than a clear boundary. In the north it is outlined by an uplifted area, the "Niederdeutsche Masse." The area in which Lower Saxon sedimentation took place has the form of a trough-shaped geosyncline within which are zones favourable to sinking (Minden, Hils, Brunswick) and zones which are more stable (particularly the Nienhagen-Hildesheim ridge). In direction and tectonic tendency these elements are only preliminary to the present structure. The great graben system, and also the lines of weakness along which salt uplift took place, are the orogenic end stages of long-reaching epirogenic demands. S. E. C.

1059. Helium Occurrences and their Accompanying Geological and Physical Conditions. A. Mayer-Gür. *Oel u. Kohle*, 1938, **14** (46), 977-983.—The world's resources of helium are reviewed. The more important occurrences are in Texas, Oklahoma, Ohio, Utah, Wyoming, Colorado, Montana, California, Alberta, Ontario, Russia, and Italy. These deposits are derived from the breakdown of radio-active minerals which are sufficiently widespread in the earth's crust to provide the quantities of helium at present known. Natural gas is of importance in that it assists or makes possible the escape of the occluded helium from the minerals. The conditions necessary for the formation of a commercial deposit of helium are a local enrichment of radio-active minerals in ridges of the basement complex or in sediments, and a suitable reservoir rock and structure for its accumulation, as well as a competent cap-rock and the presence of natural gas. A further favourable condition is the disruption, by tectonic forces, of the rocks containing the radio-active minerals. S. E. C.

1060. New Mathematical and Stereographic Net Solutions to Problem of Two Tilts— with Applications to Core Orientation. C. H. Johnson. *Bull. Amer. Ass. Petrol. Geol.*, 1939, **23**, 663-685.—A simple solution is given of the problem of determining the original dip of beds below an angular unconformity. The equations obtained for this solution are then used to construct various nets and it is shown that they are the basis of Fisher's stereographic-net solution which was recently published. Difficulties which may arise when the lower beds are overturned, either before or after secondary tilting, are discussed and a new stereographic-net solution is given which indicates at a glance when overturn has occurred.

The application of these methods to the determination of dip by the magnetic orientation of cores is discussed. S. E. C.

1061. Additions to Oil Reserves in California during 1938. H. W. Hoots. *Bull. Amer. Ass. Petrol. Geol.*, June 1939, **23** (6), 932-948.—Developments in 1938 added an estimated 253 million brls. to the state's known oil reserves. Five new fields were discovered in 1938—Wasco field, East Coalinga Eocene field, Coles Levee field, Richfield Western field and Aliso Canyon field.

New producing zones were discovered in five fields. Prolific production was found in the Vedder zone in the Greeley field. The Del Amo (Miocene) zone has been developed at Torrance. Three new zones were discovered at the western end of the Monte-

bello field. Miocene production was obtained at North-west Long Beach, and a deep zone of doubtful economic value was found in the Signal Hill area of Long Beach.

Extensions were made to the Wilmington, Rosecrans, Torrance, Potrero, Ventura Avenue and West Cat Canyon fields. Two new gas-fields were found (Willows and Potrero Hills) and the Rio Vista gas-field was extended.

The East Coalinga Eocene field is probably a stratigraphic overlap with a known thickness of 587 ft. of unusually permeable medium coarse oil sand. The Wasco field, discovered by the deepest well in the world, is probably small.

The reflection seismograph continues to be an important, almost indispensable, tool in geological exploration in this state.

The present rate of discovery of additional reserves, although keeping pace with consumption, should be improved in order to augment the decreased reserve supply. The rapidity of drilling wells in new fields and the resulting excessive production or capacity to produce is now interfering with normal exploration and the attainment of a desirable rate of discovery.

G. D. H.

1062. Foreign Oil Developments in 1938. B. B. Zavoico. *Bull. Amer. Ass. Petr. Geol.*, June 1939, **23** (6), 949-967.—There were no outstanding discoveries in the U.S.S.R. in 1938, although geological and geophysical work have revealed a number of major structural features which are ready for drilling. Some important developments took place on the Apsheron peninsula. The Maikop-Kuban district has a number of shallow, pinching-out, shoreline sand bodies. The Ural-Volga Permian basin is of considerable interest.

The Venezuelan production rose, with the western part giving 72.9% of the total. Eastern Venezuela made rapid strides during 1938 and commercial oil-fields were discovered at El Tigre and Jusepin.

In Iran the Gach Saran field has been further outlined, and at Agha Jiri promising results have been obtained. A deep gas-field has been discovered at Pazanum.

Nothing of importance happened in the Netherlands East Indies. The Roumanian production declined. Deep Meotic production was found in the Baicoi-Tintea field.

The Mexican production fell by 23%. In Iraq all the exportable oil was obtained from Kirkuk, whilst Naft Khana gave a little oil for local requirements.

All the Colombian production was from the Infantas and La Cira fields. The most important developments in Trinidad were associated with the Guapo fault zone. Drilling began in the North basin.

The Canadian production increased very markedly during 1938 due to developments of the Madison production at Turner Valley. The Egyptian production also rose during 1938.

G. D. H.

1063. Development in Southern Arkansas and Northern Louisiana in 1938. W. C. Spooner. *Bull. Amer. Ass. Petr. Geol.*, June 1939, **23** (6), 896-902.—The development in Southern Arkansas and Southern Louisiana during 1938 was primarily in search of oil and gas from the Glen Rose formation and the Smackover limestone. New producing horizons have been found in the developed Caddo Cotton Valley and Shongaloo fields of Louisiana. At Caddo the Paluxy sand yields oil from thin lenticular sands.

The present knowledge of stratigraphy indicates that future production of oil and gas from this region will be obtained principally from the Cotton Valley formation and from the Smackover limestone. The former consists of shale and interbedded sand; the latter is made up of an upper porous and oolitic member—the oil- and gas-producing member—and a lower dense non-porous member. Both these formations have shown marked lithological changes which determine in large part their suitability as reservoirs for oil and gas accumulation.

A structure map and a list of the wells drilled outside the producing fields are given.

G. D. H.

1064. Development in Rocky Mountain Region in 1938. J. M. Kirby and H. N. Hickey. *Bull. Amer. Ass. Petr. Geol.*, June 1939, **23** (6), 903-931.—There was only moderate activity in the Rocky Mountain Region during 1938. New fields were discovered at Cole Creek (Wyoming), Wilson Creek (Colorado), North Cut Bank (Montana), Big Hollow (Wyoming) and Shoshone (Wyoming). Extensions to old

oil-producing areas were made at Kevin-Sunburst (Montana), Hamilton dome (Wyoming), Lance Creek (Wyoming), Shoshone (Wyoming). Deepening or recompleting wells in proved fields gave gas and oil in the Wasatch at Hiawatha (Colorado), and oil in the Tensleep at Mahoney. Drilling in 1938 gave gas at Cut Bank 4 miles north of the main area; the Clay Basin (Utah) Dakota gas area was extended; gas was discovered at Beaver Creek (Wyoming) and Oil Springs (Wyoming). The Muskrat gas area was substantially extended.

Details of the numbers of wells drilled in the various areas are given, and the important dry holes are noted. Seven maps are included.

The gross production of oil in the Rocky Mountain region (exclusive of South-eastern New Mexico) for 1938 is estimated at 25,450,205 brls., as compared with 27,397,660 brls., in 1937.

G. D. H.

1065. Development of the Turner Valley Gas- and Oil-Field. V. Taylor. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1099, 1-16.—97% of Canada's oil output in 1938 was obtained from the Turner Valley gas- and oil-field. In 1913 light oil was found in upper Cretaceous beds; in 1922 naphtha was found in the Palaeozoic limestone. The first large crude oil producer was completed in 1936, proving crude oil on the west flank of the structure. The structure is a highly faulted, closely folded anticline underlain by a major overthrust fault. The eastern flank may be due to drag folding. To date the total productive length is almost 18 miles. The Palaeozoic limestone has two principal producing horizons. The upper is almost a pure dolomite and 75-100 ft. thick; the lower is also dolomitic and 20-120 ft. thick. Three sands above the Palaeozoic limestone give oil in small quantities, but production is sporadic.

The peak naphtha production was in 1930, after which the output fell in spite of increased gas production. All gas wells were then prorated to 40% of their open-flow capacity. In 1938 naphtha production at most wells had dropped almost to zero; separator production from cap wells averaged only 257 brls./day, and gasoline-plant recovery was 1150 brls./day.

The productive part of the structure has a closure of at least 4650 ft. with gas occupying 2500 ft. at the top. By the end of 1938 65 crude oil wells had been completed.

Although the early development was all done with cable tools, the rotary has now almost entirely displaced them. Drilling is difficult. At present the two common methods of drilling-in are by the circulation of a straight bentonite mud or a heavy crude oil.

The production methods in naphtha wells and crude oil wells are described. The present regulations give a 40-acre spacing of wells. All wells in the crude oil area are acidised at least once, and generally the treatment is beneficial. In 1937 crude oil proration was introduced.

The area of the gas cap has been accurately defined, but the oil boundary is known on one side only. The gas cap is estimated to have 340,000,000 to 540,000,000 million cu. ft. The oil productive acreage covers 3743 acres, but the probable area of the field is estimated at 15,275 acres and the possible oil reserves at 150,000,000 brls.

G. D. H.

1066. Major Areas Develop as Rice County Pools are Extended. D. Dalrymple. *Oil Gas J.*, 3.8.39, 38 (12), 32-33, 37.—This area has a potential of about 1,000,000 brls./day. The first production in West Kansas was obtained in 1923, and since 1926 development has gone on steadily. The five main areas are: Wherry pool, Silica pool, Chase district, Geneseo pool and the Bloomer-Habiger-Stumps area. Geneseo produces from the Arbuckle lime and lies on a range of buried hills. The Wherry pool yields oil from a conglomerate.

Relatively few wildcats have been drilled in East Rice County. Thousands of acres of proven land in Rice County remain to be developed, and many more are favourably located but not yet explored. Rice County lies on the south-east "nose" of the Central Kansas uplift. Most of its production is from Ordovician rocks. Oil and gas have been found in the Arbuckle lime, Lansing-Kansas City lime, conglomerate, Mississippi chat, Wilcox or Simpson sand and pre-Cambrian quartzite.

G. D. H.

1067. Seeking New Fields in Many Sections of Alberta. J. L. Irwin. *Oil Gas J.*, 17.8.39. **38** (14), 30, 31, 115.—At Steveville 150 miles east of Turner Valley a heavy gas flow with some gasoline was found. Important drilling campaigns have been planned at Pouce Coupe and Wainwright. Encouraging oil and gas discoveries have been made at Lloydminster, and gas has been encountered on the Kootenay dome 40 miles west of Calgary. The Ram River and Clearwater wells have also found gas. Five wells are being drilled at Taber, 120 miles south-east of Turner Valley.

The extreme producing wells at Turner Valley are 17 miles apart, but the bulk of the Turner Valley crude is from an area in the south, 5 miles long and 1 mile wide. The Turner Valley prospects seem quite bright.

In May a new oil refinery was opened at Calgary, and a further refinery at East Calgary is expected to be ready before the end of the year. G. D. H.

1068. New Wells Stir Interest in Sandoval Field. H. F. Simons. *Oil Gas J.*, 24.8.39, **38** (15), 35.—A Devonian lime pool has been proved near Sandoval. This underlies a Benoist-pay horizon which was drilled in 1908. The Devonian wells range 2900–3000 ft., and are good producers. The initial average production is 1248 brls./day. To date the proven area is a little over a mile long. Dry wells have been drilled between producers, and the inconsistency shown by the differences at which the pay formation has been found have made many of the operators quite cautious. The structure of the Devonian beds appears to be unpredictable at present, but it is believed that the Devonian structure will be sharper than that above. G. D. H.

1069. Five-County Campaign along Historic Wabash. H. F. Simons. *Oil Gas J.*, 31.8.39, **38** (16), 19–20.—It is uncertain whether the production from Gibson and Posey counties, Indiana, and Wabash, White and Gallatin counties, Illinois, is from several local structures or from a major structure. Two good pay zones have been discovered along the Wabash river, and there are possibilities of a third and fourth.

The Griffin field was not developed rapidly due to the lack of a pipe-line outlet and to other factors. Good saturation was found in the Cypress sand at about 2500 ft. Oil has been found on both sides of the river. G. D. H.

1070. Two Mississippi Structures are given New Exploration. *Oil Gas J.*, 31.8.39, **38** (16), 85.—The Glass dome is 7½ miles south-west of Vicksburg, and merits seismic investigation and deeper testing than it has hitherto received. At Blakely 7 miles north-east of Vicksburg seismic examination is also required. In addition to the Blakely structure there are noticeable undulations between Vicksburg and the Warren-Yazoo County line. The significance of the flexures is unknown, but they probably represent the eastward Bluff extension of a series of structural highs favourable for oil and gas accumulation beneath the thick alluvium of the Mississippi valley, or they may represent noses of a major structural high beneath the alluvium.

The Satartia structure of Yazoo County is faulted and shows signs of bitumen, but the source of such bitumen is unknown. Again geophysical examination is required, for extensive slumping has disturbed the surface geology. G. D. H.

1071. Wasson-Bennett Merging to make Largest most Active Field in Permian Basin Area. H. H. King. *Oil Wkly*, 7.8.39, **94** (9), 20–23, 26, 28.—The pending merger of the Wasson and Bennett fields into a single producing area will give the Permian basin its largest known stretch of productive acreage. Undrilled proved locations are adequate to ensure continuous drilling for a period of years.

The Wasson sector is conservatively credited with 34,000 acres and the Bennett field with 3,000. Between are at least 5,000 acres. Expansion of both fields is also probable. The output has been restricted and the ultimate recovery is expected to exceed 250,000,000 brls.

Some consider the area to be a dome with oil in the lime section, but the most popular interpretation is that of a broad anticline with north-west-south-east and north-east-south-west cross-folding. The oil- and gas-producing zones are classed as the Blaine lime or the upper middle section of what is sometimes called the San Andres. It occupies a lower section of the Permian than most lime fields in the district.

All the wells are drilled by rotary. A shale at about 1100 ft. is rather troublesome. The wells are generally subjected to multistage acid injections as well as shooting.

G. D. H.

1072. Results of Australian Drilling Discouraging. Anon. *Oil Wkly*, 21.8.39, 94 (11), 48, 50.—In the Gippsland area of Victoria scout bores have gone down to the Jurassic, showing a great thickness of Tertiary in the area, but no oil and gas was encountered or new structures located in the recent drilling. In the vicinity of Lakes Entrance three bores were completed and a little oil bailed. Operations are suspended pending consideration of a repressuring scheme.

Inconclusive tests have been drilled and small shows of oil reported in the Permian-Carboniferous Desert Basin. There are well-defined domal structures in the Tertiary of the North-west Basin where there are also Palaeozoic and Mesozoic rocks.

The logs of the wells drilled in Victoria are given in tabular form.

G. D. H.

Geophysics.

1073. The Relationship of Geophysics to Geology. F. M. Kannenstine. *Geophys.*, 1939, 4 (3), 149-154.—Geophysical prospecting was developed when the need arose for better methods of finding structural anomalies. Doubt is now being expressed as to the future success of these methods in their present form and the value of structure is being decried in favour of stratigraphic traps. It is pointed out, however, that there are probably few stratigraphic traps not associated in some way with structure and, in addition, it is probable that the most important accumulations will continue to be of a structural type. Areas in the U.S.A. where more detailed structural information is required are listed. The relative values of the various geophysical methods for this work are examined briefly and it is concluded that the reflection seismograph will remain supreme at least for the next few years.

S. E. C.

1074. On the Strategy and Tactics of Exploration for Petroleum, III. E. E. Rosaire. *Geophys.*, 1939, 4 (3), 155-166.—The application of the principles of war to exploration for petroleum is discussed in this series of articles, the principles considered in the present paper being those relating to the objective and to economy of force.

The principle of the objective in exploration is the discovery of oil under the most favourable conditions of time, place, and investment.

The principle of economy of force refers largely to the choice and sequence of tactics. These were referred to in an earlier paper and it was concluded that prospects should first be located by the cheapest appropriate method and evaluated by the successive use of appropriate methods of higher cost. The development of prospects in a particular area should not be initiated by any given method until the area has been primarily explored by the cheapest appropriate method. In the present paper the "appropriateness" of the methods is considered.

Exploration methods are divided into two major groups, structural prospecting methods and stratigraphic prospecting methods. Structural prospecting methods are further subdivided into two classes, pseudo and true, the former including profiles determined by refraction shooting, electrical, gravity, and magnetic methods. There is little justification for the general use of pseudo-structural methods on account of their limited depths of penetration and high observational errors. True structural prospecting methods are those using the reflection seismograph and the drill. The main limitations to these methods are practical rather than theoretical and often they may be charged simply to misuse. The reflection seismograph suffers, however, from the limitation that if production is not closely associated with the structure, accurate depth determinations are not sufficient.

There are five types of stratigraphic prospecting methods: magnetic, electrical, acoustical, gravitational, and chemical. The general field of usefulness for these methods is in reconnaissance; the fundamental limitations are the absence of any indications as to the depth or relief of the structure indicated.

The estimation of discovery costs is discussed and it is shown that on this basis also stratigraphic prospecting methods are better suited for reconnaissance work and that

an exploration programme should be initiated by them. Any prospects then discovered should be evaluated by the structure prospecting methods.
S. E. C.

1075. A Problem in Seismic Depth Calculation. R. F. Beers. *Geophys.*, 1939, 4 (3), 167-175.—The calculation of the depth to a reflecting surface is subject to error when reflection surveys are carried out in area of great topographical relief. The customary method of depth determination yields a result in which the structure bears the impress of the topography. A method of depth calculation which seems to overcome these difficulties has therefore been developed. The velocity function of the entire geological section is measured if possible, otherwise it is estimated. It is then distributed with respect to the portion of the section embraced in the reflection path at each station. The use of this method is simplified by preparing velocity-depth curves and time-depth curves for varying degrees of erosion. The method may also be employed to advantage in cases where there is a thick cover of sediments with an abnormal velocity, the path then being divided into two portions.
S. E. C.

1076. Determination of Density for Reduction of Gravimeter Observations. L. L. Nettleton. *Geophys.*, 1939, 4 (3), 176-183.—The density of the surface material is frequently obtained by measurements on small samples and the result used in the Bouguer correction for elevation of a station. This method is apt to introduce considerable errors into the correction and it is suggested that a more accurate measurement of density can be made with the gravimeter itself. Briefly, the method consists in making a special gravimeter traverse across a topographical feature. A series of gravity values is then calculated for each station, using the usual reductions for latitude and free air corrections but making the Bouguer correction for a number of different densities. In this manner a series of profiles can be drawn for the selected densities and the value of density used in the profile which approaches closest to a straight line across the topographical feature is the density of the surface material.
S. E. C.

1077. Terrain Corrections for Gravimeter Stations. S. Hammer. *Geophys.*, 1939, 4 (3), 184-194.—The topographic correction is divided into two parts, the Bouguer correction and the terrain correction. In order to determine the latter an adequate topographical map is necessary. A transparent terrain correction zone chart, of which an example is given, is placed on the map and the difference between the elevation of the station and the average elevation under each zone of the chart is determined. The terrain correction is then calculated for each zone by means of special tables published in this paper, and finally these corrections are then summed to give the total correction for the station. The tables are based on the formula for the gravitational attraction of a vertical hollow cylinder at a point on the axis and in the plane at one end of the cylinder. The density of the surface material has been assumed to be 2.0. For any other value of density the figures given must be multiplied by the appropriate factor.
S. E. C.

1078. On Geochemical Prospecting. I. L. Horvitz. *Geophys.*, 1939, 4 (3), 210-228.—Geochemical prospecting methods may be divided into three types. The first is the search for visible oil and gas seeps, the second is the analysis of interstitial soil air, and the third is soil analysis. It is found that soil analysis, in contrast to the analysis of interstitial soil air, yields satisfactory results with small samples and even with completely water-logged samples. Briefly, the method consists of freeing the entrained hydrocarbons from the sample of soil, removing from them substances such as carbon dioxide and ammonia, and finally determining their constituents by fractional condensation methods. These may include methane, ethane, propane, butane, and a group of heavier substances referred to as pseudo-hexane. Methane is usually of importance only in arid regions, ethane and propane are the most valuable indications, and the pseudo-hexane is useful in areas where it is impossible to obtain hand auger samples from depths of more than 2-4 ft. The results of many surveys show that the greatest concentrations of these hydrocarbons are around the edges of established production, thus producing what is known as a halo pattern. Some typical examples illustrating these points are given.

A further development of the soil analysis method is the search for oxidized and polymerized hydrocarbons in the soil. It is found that these are present in far greater proportions than the lighter hydrocarbons, thus simplifying the analytical procedure. The results obtained from the determination of these heavier hydrocarbons agree very well with those obtained from the lighter. S. E. C.

1079. A New Recording System for the Magnetometer. A. Graf. *Beitr. angew. Geophys.*, 1939, 7 (4), 357-365.—A photo-electric recording system for the magnetometer is described. This has the following advantages over the normal method of photographic recording. Readings may be obtained at any moment without waiting for a full plate to be exposed. Readings may be obtained at places distant from the instrument and there is no need to approach or disturb the instrument in order to fit new plates. Paper speed is variable. The sensitivity can be increased by the use of Merz's D.C. amplifier and multiple recording is possible. S. E. C.

1080. Comparison of the Theoretical and Practical Determinations of a Gravity Anomaly. S. v. Thyssen and F. Lubiger. *Beitr. angew. Geophys.*, 1939, 7 (4), 366-391.—In order to examine the difference between a calculated and a measured gravity anomaly the gravity effect of a small valley was utilized. The measurements were made with a Thyssen gravimeter set on a stone bridge crossing the valley. The calculation of the anomaly was carried out by three methods, the first involving the use of Helmert's formulæ, the second being Jung's two dimensional solution, and the third making use of Schlessner's reduction tables. The calculations are described in detail. It is shown that these three methods give satisfactory results which are in accordance with the gravimeter measurements. S. E. C.

1081. Gravity Anomalies Between the Aller and Steinhuder-meer Lines. R. v. Zwerger. *Oel u. Kohle*, 1938, 14 (46), 943-953.—As a result of the intensive geophysical work carried out in the last few years a number of important gravity anomalies have been discovered. Each of these is described in detail. This discovery of new lines of uplift completes the tectonic picture of the area; on the one hand they form the continuation of the hercynian axes of the subhercynian basin; on the other hand they complete the picture of the Rhenish tectonics by the discovery of a probable flat salt anticline at the west margin of the zone with predominant Rhenish strike. From the point of view of petroleum, the value of these structures is variable. Either the strata from the Lower, and perhaps the Upper, Cretaceous to the Emscher are folded so that the Lower Cretaceous reservoir rocks have an anticlinal structure, or the folding had already taken place in the Kimmeridge and the Wealden-Valendis is transgressive. Even in the latter case oil accumulation of a secondary nature is possible in the Lower Cretaceous. S. E. C.

1082. Seismic Work in the Region Between the Aller Estuary and the Weserbergland. P. Rossle. *Oel u. Kohle*, 1938, 14 (46), 954-956.—The surveys in this region were carried out by the refraction method, using fan and lineal shooting. A description is given of the results obtained, particularly of velocities in the various areas and strata. S. E. C.

1083. The Influence of the Accuracy of Scale Readings on the Usefulness of Gravimeter Measurements. A. Schlessner. *Oel u. Kohle*, 1938, 14 (46), 957-959.—The conclusions drawn from a discussion of this subject are that in the case of local surveys, a small, constant error in the scale value is of no consequence in the interpretation of gravimeter measurements. Also, in the case of regional measurements, the influence of a somewhat uncertain scale value is without great significance. S. E. C.

1084. A New Apparatus for the Rapid Estimation of the Velocity of Elastic Waves in Cores. S. v. Thyssen. *Oel u. Kohle*, 1938, 14 (46), 960-962.—An apparatus has been designed by means of which the velocity of longitudinal waves in cores of any rock can be determined in a few minutes. A piece of unprepared core is put on one of

the plates of a condenser. The ends of the core may be made flat by cutting or by a thin coating of plaster. The condenser plate is then made to vibrate at various frequencies until the natural frequency of the core is reached. At this point there will be maximum resonance in the core and this is determined by a sensitive piezo-electric indicator. The velocity of longitudinal waves in the core is then calculated from the natural frequency.

S. E. C.

1085. An Investigation of the Seismic-Electric Effect. K. H. Waters and W. Wen-Po. *Beitr. angew. Geophys.*, 1939, 7 (4), 337-346.—Experiments were made in order to discover whether the seismic-electric effect is due to changes in the resistivity of the ground. A four-electrode system was used, the current electrodes being 350-400 ft. apart and on a line passing through the shot point, and the potential electrodes on a line at right angles to this and passing through the current electrode nearest the shot point. The results obtained indicate that the effect is due to a change in resistivity of the bulk of the ground as the compression wave passes through it. The theoretical discussion is simplified by considering only the effect of a sudden discontinuity of resistivity approaching the current electrode from the shot point, the plane of the discontinuity being parallel to the line of the electrodes. This problem is solved by the Method of Images. It is shown that even with a very sharp change of resistivity the initial potential is smooth and of little use to give the exact time of the wave and further, that the potential variation is much more complicated than the corresponding ground motion. Another disadvantage of the method is that it is considerably affected by wet and thundery weather conditions.

S. E. C.

1086. On the Watson Method for the Evaluation of Geo-Electric Resistance Measurements. F. Gassmann. *Beitr. angew. Geophys.*, 1939, 7 (4), 347-349.—Watson's formulæ for apparent specific resistance are corrected and a method given for the simplification of numerical calculations.

S. E. C.

1087. The Static (Barometric) Gravimeter for Measurements on Land and Sea. Part II. H. Haalck. *Beitr. angew. Geophys.*, 1939, 7 (4), 392-417.—Part II of this series deals with the sources of errors and the influence of those errors on the measurements. After a short discussion on the theory of the source of error, individual errors are dealt with in detail. These include the effect of temperature variations, pressure variations, volume variations, variations in scale value, and the effect of frictional and capillary forces. The most important and difficult technical problem in the development of the static gravimeter was the considerable effect of temperature variations on the scale position. A detailed description is given of the means used to overcome this trouble.

S. E. C.

1088. The Static (Barometric) Gravimeter for Measurements on Land and Sea. Part III. H. Haalck. *Beitr. angew. Geophys.*, 1939, 7 (4), 418-448.—Part III of this series deals with the use of the instrument on board ship. The special conditions arising in such circumstances are discussed and the alterations necessary in the standard model are described. The effect of the irregular vibrations of the ship on the scale position is examined critically and finally the results of four series of measurements made between Bremen and Hamburg are discussed in full.

S. E. C.

Production.

1089. A Résumé of the Application of Gravel Packing to Oil Wells in California. W. A. Clark. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1079, 1-8.—Gravel packing is used to prevent sand movement with the consequent troubles of caving and wear of well fittings. The methods of gravel packing are briefly described. The extra cost due to such an operation rarely exceeds 10% of the cost of drilling the well. Zones 25 to 666 ft. in thickness have been packed at depths ranging 1100 to 6700 ft.

The cumulative production from gravel-packed wells is, as a general rule, greater than that from conventional types over the same production period. This is explained by deferred or lost production in the latter wells due to time spent in pulling and bailing. It appears that less sand is produced with the oil in gravel-packed wells than in ordinary wells. Pump repair costs were lower in the gravel-packed wells. It is desirable that the gravel size should be carefully chosen with respect to the oil sand grain size.

G. D. H.

1090. Visual Studies of the Flow of Air-Water Mixtures in a Vertical Pipe. S. Cromer and R. L. Huntingdon. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1080, 1-10.—The flow of gas-liquid mixtures in vertical pipes occurs when oil and gas are produced from a well; when water is removed from gas wells with siphon lines and when liquids are elevated by means of air or gas lift. The column used was 2 in. diam., 98 ft. long and with 2 ft. Pyrex observation sections at 14-ft. intervals. At the base was a mixing chamber with no perforated nipple or foot-piece.

If the air enters the bottom of a flow column at an extremely low rate, it will merely rise to the surface of the liquid in small bubbles. At rather higher air rates the air forms bullet-shaped slugs at the bottom, which acquire a trail of small, round air bubbles higher and gives almost a froth between the slugs still higher. At the point of maximum efficiency (37 cu. ft. air/brl.) pistons of air and water were seen 16 ft. up the column, but higher the short pistons merged to form longer ones. The air piston was at all times surrounded by an annulus of water flowing downwards. The water velocity apparently increased upwards. Maximum water flow was attained with an air-water ratio of 60.3 cu. ft./brl. Here the formation of pistons was observed higher in the column, and there was no downflow of water around the air pistons.

At still higher air rates the pistons gradually disappeared and water appeared to be travelling both as droplets suspended in the air stream and in an annular ring along the tube walls. A further increase caused the air core to carry less and less water until it became comparatively free of it, and water rippled upwards along the sides of the flow tube in the annular ring. On sufficiently increasing the air rate, the friction load produced by the air flowing through the pipe became greater than the hydrostatic head of water. This obviously prevented water from entering the pipe and a second condition of no liquid flow was reached.

G. D. H.

1091. The Economics of Overdevelopment. J. D. Gill. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1084, 1-8.—Various aspects of the economics of over-production are considered in some detail, and the arguments put forward demonstrate the complexity of the problem. It is a debatable point whether the alleged waste of money and energy in overdevelopment is more serious than the idleness of the associated and supplementary workers who might have been unemployed but for overdevelopment.

In the confusion over the nature of the ultimate control of economic endeavour, many have embraced the philosophy of control based on engineering abstractions and experiments. But this has a danger that arbitrary technology will be placed in control, because practicability requires the adoption of the tenets of one of several schools.

The Secretary of Agriculture does not seem to have learned to substitute technological control for economic control, although he has had the resources of the Federal Government and taxation to support him in an effort to make the experiment succeed. In the end the efforts to replace economics by technology only invite experiments in arbitrary control where the conservation argument is absent, and some professional economists and others have begun to think that there is no useful competition in business, and that thoroughgoing governmental regulation of business is necessary.

G. D. H.

1092. Multistage Stabilization of Crude. H. S. Gibson. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1085, 1-12.—Multistage stabilization as practised at Haft Kel is a process for preventing the greater part of the casing-head gasoline hydrocarbons from ever leaving the crude, instead of allowing them to be vaporized and then recovered from the lighter gases by the usual compression or absorption processes. The operating conditions and results at Haft Kel are described, and the

operating pressures, the efficiency, and the production system at Haft Kel are discussed. Six stages are used.

When casing-head gasoline is recovered as a separate liquid in the Iranian fields, it is blended with the crude, for the only outlet is through the refinery, and the crude oil pipe-line offers the cheapest means of transportation. It is under these conditions that the retention of the butanes and pentanes in the crude by multistage stabilization is a most attractive process, possessing as it does, the following advantages: (1) extreme simplicity, (2) low first cost, (3) easy installation, (4) practically 100% operating time efficiency, (5) no operators required, (6) no water or other services required, (7) negligible maintenance, (8) once established very little routine testing is necessary.

For reasonably efficient multistage stabilization it is essential that the flowing pressures of the wells should be relatively high, *i.e.* they should not, in general, be less than about one-third of the saturation pressure of the crude in the reservoir.

The efficiencies compare most favourably with those obtainable by the best design of absorption plant. G. D. H.

1093. Principles of Well Spacing. M. Muskat. *Petrol. Tech.*, August 1939, A.I.M.M.E., Tech. Pub. No. 1086, 1-15.—The problem of ultimate recovery and well spacing has been investigated mathematically on the basis of experiments with a uniform sand column. It is concluded that from a strictly physical point of view there is no basis for believing that the absolute ultimate recovery of oil that can be produced from a uniform and non-lenticular sand through the agency of dissolved gases will materially depend upon the number of wells used to drain the reservoir. There is, however, a definite variation of the economic ultimate recoveries that can be derived from a given reservoir with the number of wells, if we consider the economic ultimate recovery to refer to that which can be obtained with the individual well-production rates exceeding a pre-assigned minimum. For the linear system, which was treated in detail, it was found that this economic ultimate recovery will increase as the number of wells used increases. When the minimum limiting production rate is small or the sand columns are highly permeable, the economic ultimate recovery rises rapidly as the number of wells is first increased, but quickly attains values which are thereafter no longer appreciably increased by further drilling. For tight sand columns, or if the lowest production rate at which the operation of a well would still be profitable is high, one must make the well spacing fairly small in order to approach ultimate recoveries which would be obtainable in highly permeable sands or with low minimal production rates.

Although but little practical significance can be attached to the numerical results derived, because of the various assumptions underlying details of the analysis, their broad features show a close correlation with general opinion regarding the well-spacing problem that has been previously expressed in the literature. G. D. H.

1094. Specific Problems in the Chemistry of Acidising Wells. C. E. Clason. *Petrol. Engr.*, August 1939, 10 (12), 72.—Corrosion of oil-well equipment by acids used to increase production in limestone formations has been limited by (a) the use of inhibitors and (b) electrochemical methods. An extremely low viscosity acid of high penetrating value has also been developed. Water has been found the best medium for forcing the acid into the formation, as it increases the speed of placing the acid, washes the formation and dilutes the heavy spent acid salts, allowing their easier removal. Treatment is also improved by adding the penetrative medium to the washing water. In the Panhandle and parts of West Texas the dolomites contain gypsum which is first dissolved by the acid and then precipitated, resulting in plugging of the formations. Similarly magnesium carbonate is reacted on much less slowly than calcium carbonate and is liable to be loosened from the formations resulting in further plugging. Delayed action acids are accordingly used to equalize the action on the two types of carbonates and also in fast acting limestones in order to extend the action. In the latter cases penetrating acid is used first until the pressure drops, followed by the delayed action acid. Some forms of silica tend to form a gelatinous mass under the action of acid, while further pore clogging may be caused by fine needle-like crystals of acid soluble silicates mixed with colloidal silicates in the spent acids. Similarly acid treatment of very fine-grained rocks may be more harmful than beneficial. Delayed action can also be obtained by increasing the pressure. Emulsion

breaking also creates difficulties, the particular chemical chosen being best placed in the formation with the acid. Adequate examination should be made of core cuttings and full records kept of oil production before and after acidisation. C. L. G.

Crude Oil.

1095. Atlanta, Arkansas, Crude Oil. Anon. *Petrol. Engr.*, August 1939, **10** (12), 75.—A Bureau of Mines analysis has been made of a sample of crude oil from the discovery well of the Atlanta district in Columbia Country, Arkansas. The crude oil is of paraffin base and has a specific gravity of 0.813, a sulphur content of 0.49%, a carbon residue content of 0.4% and viscosity S.U. at 77° F. of 38 secs. On Hempel distillation the crude oil yielded 34.9% of total gasoline and naphtha (8.6% of light gasoline), 19.5% of kerosine distillate, 13.2% of gas-oil, 12.8% of non-viscous lub. dist., 4.5% of medium lub. dist. and 14.6% of residuum. C. L. G.

Gas.

1096. Dehydration of Natural Gas by Silica Gel. H. de Raay. *Petrol. Engr.*, August 1939, **10** (12), 45.—A description is given of a silica gel plant for the dehydration of natural gas in Mene Grande field Venezuela, removing 586.55 lb. per day of water from 8,827,500 cu. ft. of natural gas. The plant is installed between the outlet of the compression plant and the intake of the refrigeration or expansion plant, and consists of three absorbers and one heater. One absorber is used to absorb the water, while one is being dried by heated dry gas and the third cooled by cold dry gas. The absorbers consist of steel high-pressure cylinders containing two grates, one near the bottom and one half-way up the cylinder. The upper section contains successive layers of fine gravel, No. 1 quality (high sensitivity) silica gel, fine gravel, No. 2 quality silica gel and fine gravel, while the lower section contains the same layers in reverse order. The gas heater is a standard tubular heater in which cold dry gas is heated by live steam. High-pressure gas is passed from the top to the bottom of the absorber, and from thence to the refrigerating plant, until the silica gel is saturated with water. The second absorber is then used and so on. The cold dry gas is heated in the gas heater to about 165° C. and passed up into the saturated absorber. Another portion of cold dry gas is taken from the output of the refrigerating plant to cool the silica gel after the heating period. About 0.06 gal. per million cu. ft. of gasoline is lost by absorption in the silica gel, but may be recovered if the high pressure gas is returned to the wells for gas lift. The cost of the silica gel used in dehydration is given as \$0.34 per million cu. ft., the silica gel lasting three years. C. L. G.

1097. Patents on Gas. Metallgesellschaft A.-G. and W. Herbert. E.P. 507,366, 14.6.39. Appl. 25.4.38. Synthetic production of motor spirit by catalytic conversion of CO and H₂.

G. W. Johnson. E.P. 507,567, 3.6.39. Appl. 13.12.37. Manufacture of gaseous olefines, in particular of ethylene, from products obtained in the catalytic reaction of CO and H₂, by leading the products at elevated temperatures in the presence of H₂ over a hydrogenating catalyst, and then cracking and/or dehydrogenating the resulting hydrocarbons in vessels constructed of coatings of silicon, titanium or chromium steels. W. S. E. C.

Polymerization.

1098. Midget Poly Plant Uses Combined Feed. J. P. O'Donnell. *Oil Gas J.*, 24.8.39, **38** (15) 59.—A U.O.P. midget polymerization plant is in operation at a Farmer's Valley (Penn.) refinery, running on a mixture of 263.5 million cu. ft./day (in terms of vapour phase) of liquid charge—condensed overhead from the Dubbs stabilizer—, 143 million cu. ft. of gas charge—uncondensed stabilizer gas—, and 132 million cu. ft. of spent recycle gas. The installation of this plant and some changes made in the

Dubbs cracking unit have increased the gasoline yield by 9.2% and the O.N. by 0.4, when operating on gas oil and by 7.3% and 0.8 resp. when operating on naphtha. Maximum retention of olefines is obtained by deep stabilization (to 4.5/5 lb.) and by cooling the stream to the distillate receiver to 57° F. and increasing its operating pressure to 60/80 lb. The combined charge contains 23.5% olefines, being 90/95% of the processable olefines available. The yield of 10 lb. polymer gasoline per lb. of catalyst is at present 36.97 galls., but is expected to reach 70 galls. The polymer gasoline has the following properties: Gravity 67.7°; Reid V.P. 34 lb.; I.B.P. 83° F., 32% to 212° F.; E.P. 430° F. C. L. G.

1099. Patent on Polymerization. Standard Oil Development Co. E.P. 507,439, 14.6.39. Appl. 14.12.37. Manufacture of dimers and trimers of olefines by polymerization with sulphuric acid. W. S. E. C.

Refining.

1100. Vapour Recovery and Stabilization. D. Smith. *Oil Gas J.*, 24.8.39, 38 (15), 53.—A description is given of the vapour recovery and stabilization equipment at two identical refineries in Europe, built for the production of high-grade gasoline from low-grade crude oil and operated for maximum recovery of products. The operations at the refinery included hydrogenation, cracking, distillation, chemical treatment and gas processing, the gas charge to the vapour recovery unit consisting of (a) gases from cracking units, (b) gases from primary distillation unit prestabilizer, (c) gases from let-down drums at hydrogenation units and (d) recycled gases from within the gas plant itself. C. L. G.

Analysis and Testing.

1101. Some Practical Aspects of Fuel Oil Testing. B. O'Connor. *Oil Gas J.*, 7.9.39, 38 (17), 52.—A discussion is presented of the manipulative technique and practical importance of various fuel-oil testing methods. The following items are covered: sampling; Pensky-Martens flash-point; Saybolt viscosity; Conradson carbon residue; sulphur content (bomb method); water and sediment; ash content; sediment, and copper strip corrosion test at 212° F. C. L. G.

Motor Fuels.

1102. Patents on Motor Spirit. Standard Oil Development Co. E.P. 507,246, 13.6.39. Appl. 1.1.38. Improvement of anti-knock value of motor fuels by adding a di-tertiary butyl ether of ethylene glycol and a metallo-organic anti-knock agent.

F. Uhde and T. W. Pfrmann. E.P. 505,953, 19.5.39. Appl. 29.8.38. Manufacture of high-quality benzine and diesel fuel by hydrogenation of tars prepared by carbonization, consisting in separating the tars by mixing with middle oils obtained by the reduction of CO and H₂, into two components of different specific gravity. A lighter fraction together with a part of the middle oils, is hydrogenated in the gas phase and a heavier fraction is hydrogenated in the liquid phase.

W. T. Hancock. U.S.P. 2,162,715, 20.6.39. Appl. 1.9.37. And U.S.P. 2,162,717, 20.6.39. Appl. 1.11.38. Refining of cracked distillates containing gasoline by first polymerizing the vapours at 200–500° F. but below cracking temperature by passing them through an adsorptive material. The gasoline is then mixed with an independent heavier oil under pressure to keep the gasoline liquid; the pressure is then reduced and the gasoline fractions vaporized.

W. T. Hancock. U.S.P. 2,162,716, 20.6.39. Appl. 19.10.38. Refining of petroleum hydrocarbons by heating them to cracking temperature to form unvaporized residues and vaporized lighter hydrocarbons containing a cracked gasoline fraction.

The vaporized fractions are then separated from the residue and the gasoline polymerized and the vapours passed through an adsorptive substance. The gasoline is then mixed with the residue under pressure, the pressure is then reduced and the gasoline fraction vaporized.

D. S. McKittrick. U.S.P. 2,162,963, 20.6.39. Appl. 28.8.37. Process for desulphurizing hydrocarbon distillates by extraction with a solvent, *e.g.* liquid SO₂, aniline, etc.

W. C. Ault and C. A. Hochwalt. U.S.P. 2,162,992, 20.6.39. Appl. 3.3.36. Refining of cracked distillates to remove gum-forming substances, by contacting the vapour substantially free from steam, at 175–185° C. with a liquid catalyst, *e.g.* an acid of phosphorus.

M. P. Youker. U.S.P. 2,163,113, 20.6.39. Appl. 14.10.35. Conversion of hydrocarbon gases into gasoline and synthetic crude, by treating at elevated pressures and at 900–1200° F. a mixture of butane and a kerosine distillate having a carbon residue of less than 1%; 20 parts of butane by weight are admixed with 1 part of kerosine distillate.

J. R. Rose. U.S.P. 2,163,155, 20.6.39. Appl. 22.11.37. Conversion of refinery gases into motor fuel by first liquefying the gases under 500–1500 lb./sq. in. pressure and heating the resultant liquid while still under pressure to cracking temperatures (500–1500° F.). The vapours are then contacted with a polymerizing catalyst and the product cooled to 50–75° F. The uncondensed gases are vented from the system, and the pressure on the resultant liquid reduced to separate from the liquid polymer gases for recycling.

J. A. Chenicek. U.S.P. 2,163,269, 20.6.39. Appl. 28.6.37. Method of separating high anti-knock constituents of cracked gasoline from those of relative low anti-knock value by subjecting the gasoline to the solvent action of cinnamaldehyde below 25° C.

W. A. Schulze. U.S.P. 2,163,312, 20.6.39. Appl. 11.5.37. Sweetening of sour hydrocarbon oils by treatment with a solid adsorbent catalyst impregnated with a solution containing cupric and chloride ions. The reaction is carried out in the absence of air.

W. S. E. C.

See also Abstract No. 1115.

Lubricants.

1103. Patents on Lubricating Oil. Edeleanu Gesellschaft. m.b.H. E.P. 505,740, 16.5.39. Appl. 29.8.38. Solvent extraction of crude oil, residual oil, or lubricating oil using a selective solvent, *e.g.* pyridine containing 2–2.5% by volume of water. The mineral oil solution is cooled in the presence of a non-selective solvent (*e.g.* benzene, which solidifies at the temperature of treatment and/or in the presence of wax which is contained in the original oil or has been added), to temperatures at which the lubricating oil is precipitated together with the wax and/or non-selective solvent which crystallizes out.

W. S. E. C.

Asphalt and Bitumen.

1104. Soil Stabilization using Asphalt Cut-Backs as Binders. J. C. Roediger and E. W. Klinger. *Assoc. Asph. Paving Techn. Proc.*, 1939, 1–36.—The authors stress the need for suitable terminology to distinguish between the various procedures and materials employed under the general term “soil stabilization” and put forward a suggested classification. The paper then describes the procedure employed in determining suitable proportions of water and cut-back for treatment of a particular soil and gives details of construction of a soil-asphalt pavement by the road-mix method. In determining the proportions of water and cut-back, portions of direct soil are mixed in a Kitchen-Aid mixer with definite amounts of water and cut-back to

determine the amount of water necessary to obtain satisfactory distribution of the cut-back. Further mixtures are then made with amounts of water above and below this moisture content and with amounts of cut-back from nil to the amount required to cause exudation of liquid under the compacting load in the Hubbard mold. 100 grms. of each of the mixtures are placed in 2-in. molds, tamped 50 times with a No. 1 tamper and 15 times with a No. 2 tamper and subjected to 10,000 lb. pressure for 2 minutes, the specimens should then be 0.9-1.0 in. high. Four specimens are made with each mixture, two being dried to constant weight at 140° F. and one dried and one undried specimen then exposed to a water absorption test for 7 days. The stability is finally determined on each specimen by the approved Hubbard-Field procedure with the exception that the test is made at room temperature without the water-bath. The water absorption test is made by placing the specimens in flat-bottom trays containing $\frac{1}{2}$ in. of water, the trays being either tightly covered or stored in a humidity cabinet at room temperature. At intervals up to 7 days the weight of the specimen is determined after removal of surface moisture with filter paper, the increase in weight being expressed as gm. of water absorbed per 100 sq. cm. of surface exposed to water. Volumetric swell is calculated from measurements before and after the absorption test.

It is considered that these tests should indicate the proportions of cut-back and water which can be easily mixed to give a mixture showing the maximum strength after exposure to water, minimum loss in strength due to exposure, low water absorption and minimum swelling. Results obtained with typical soils and a correlation of field and laboratory results are given. Photographs showing the various stages in construction of a pavement by the road-mix method are also given.

A. O.

1105. Stabilization of Soils with Emulsified Asphalt. R. R. Thurston and B. Weetman. *Assoc. Asph. Paving Techn. Proc.*, 1939, 37-85.—This paper discusses the factors involved in the stabilization of soil by means of emulsified asphaltic bitumen, with particular reference to the U.S. Bureau of Air Commerce specifications for emulsion for stabilizing airport runways. The latter specifications include limits for viscosity, miscibility with water, specific gravity, residue on heating, settlement, sieve test, demulsibility, dehydration, and properties of original bitumen. The Bureau of Air Commerce also requires stability tests to be made on soil-emulsion mixtures, these tests necessitate the use of expensive equipment and take a fortnight to complete and the authors give details of a simple compression machine and method of test which requires only a few days. Examination of soils of varying plasticity index indicated no definite relationship between the latter or material passing 200-mesh and strength of mixtures containing 4% of bitumen; further tests showed that compression strength is independent of soil constants but is related to percentage of clay and colloids present. The demulsibility, stone coating and cement mixing tests are considered unsatisfactory for determining the suitability of emulsion for use with a given soil and a stability test is described in which the soil to be stabilized is used. No correlation was shown between dehydration value and compression strength or rate of drying of emulsion-soil mixtures. The authors state that efficient stabilization with emulsion depends on the incorporation of sufficient minute particles of bitumen to fill the interstices of the soil, but experiments indicated that emulsions containing extremely small particles are not essential. Compression strength was found to increase with increased consistency of the bitumen used, but it is thought that excessively hard bitumen may be unsatisfactory. The quantity of bitumen should be sufficient to reduce water absorption in service without reducing compression strength owing to excess bitumen.

A. O.

Special Products.

1106. Waxes from Fatty Acids. German Conversion Process. Anon. *Chem. Tr. J.*, 18.8.39, 105, 140.—A process for the production of materials similar to wax or petroleum jelly by heating of distillation residues of fatty acids in the presence of catalysts which favour the splitting off of CO₂, and then reducing the resulting

products with hydrogen, is described by the I.G. Farbenindustrie A.-G. in E.P. 506,678 of 1938. As basic materials may be used the residues from the distillation of saponification products of natural oils or from the oxidation of paraffin hydrocarbons. The carboxylic acids condense to form ketones and are then filtered or settled to remove the catalyst and finally reduced, the carbonyl or carboxyl groups being converted into hydroxyl and/or methylene or methyl groups. Hydrogenation is preferably carried out between 200° C. and 400° C. at pressures of 160 to 200 atmospheres.

The products obtained are pale, frequently colourless, consisting mainly of high molecular weight alcohols and/or hydrocarbons and are suitable as salves or agents for the protection of metal, etc., from the action of gases. They have a considerably higher melting point and a viscosity constant within a larger temperature range than natural petroleum jelly. A product obtained by the oxidation of Fischer-Tropsch paraffin wax, following by distillation, catalytic heat treatment and hydrogenation had a similar appearance to petroleum jelly, smearing well and exerting no irritant effect on the skin. Its properties were acid value 0, saponification value 0, melting point 61° C.

C. L. G.

1107. Patents on Special Products. N. V. de Bataafsche Petroleum Mij. E.P. 505,732, 16.5.39. Appl. 13.7.38. Manufacture of phenols and/or thiophenols from mixtures of these substances present in washing liquors originating from the refining of pressure distillates, by extraction treatment of the mixtures containing alkali in a quantity equivalent to the quantity of thiophenols present.

Standard Oil Development Co. E.P. 505,736, 16.5.39. Appl. 4.8.38. Production of olefine polymers of high mol. wt., by polymerizing olefines below -10° C. in the presence of a solid metal halide of the Friedel-Craft's type dissolved in CS₂.

G. W. Johnson and I.G. Farbenindustrie A.-G. E.P. 506,038, 18.5.39. Appl. 18.11.37. Manufacture of butadiene by leading tetrahydrofurane in the gaseous phase at 250—450° C. using steam as a diluent, over phosphoric acid catalyst having a weak acid reaction under the reaction conditions.

F. W. Johnson. E.P. 506,832, 6.6.39. Appl. 8.12.37. Manufacture of ethylene from saturated hydrocarbons.

W. A. Farenholtz, G. Hubbe and K. Blass. E.P. 507,521, 16.6.39. Appl. 4.5.38. Production of fatty acids by catalytic oxidation at temperatures below 120° C., of paraffin hydrocarbons which are liquid under conditions of treatment. The catalysts used are salts of metals of groups 6, 7, or 8 of the periodic system.

I.G. Farbenindustrie A.-G. E.P. 507,538, 16.6.39. Appl. 18.11.37. Manufacture of olefine oxides by the catalytic oxidation of olefines with oxygen or oxygen-containing gases using a silver catalyst activated by a metal of the platinum group.

Boots Pure Drug Co., A. D. Powell, J. C. E. Tait and Lord Wolmer. E.P. 508,125, 27.6.39. Appl. 13.4.38. Preparation of a composition for destroying pests and slugs by forming a paste of metaldehyde and a fatty compound, and baking the same at temperatures low enough to avoid substantial volatilization of the metaldehyde.

T. L. Shepherd. E.P. 508,407, 30.6.39. Appl. 8.3.38. Preparation of an insecticide by mixing 1 part by weight of salol and 3 parts by weight of thymol heated to melting temperature and then cooled. The mixture is dissolved in a solvent, e.g., terpineol or Ti-Tree oil.

W. S. E. C.

Detonation and Engines.

1108. British Diesel Engines. *Auto. Engr*, 1939, 29, 178-185.—A survey of high-speed diesel development and practice during the past year. Many detailed refinements have been introduced, and the study of rate of pressure rise in relation to ignition lag has contributed to smoother running; two-stroke developments have remained slow.

For marine propulsion the displacement of spark-ignition engines continues at an increased rate. In railway traction standard road-vehicle engines are being successfully adapted to multi-unit train arrangements. For road transport there has been a continuation of the trend towards direct injection in order to obtain the best possible fuel consumption. Taxation has hampered the development of small units for the lighter vehicles. It is estimated that 20% of the diesel fuel used by road vehicles is home-produced.

The products of twenty-two manufacturers are described, with illustrations.

K. T. A.

1109. Continental Oil Engines. *Auto. Engr*, 1939, **29**, 186-214.—A review of the trend of design and constructional practice in European countries during the past year. The products of some fifty manufacturers in ten different countries are described, with 83 illustrations. Among the many points of interest the following are, perhaps, the more outstanding: In Denmark the well-known firm of Burmeister and Wain have entered the field of small, high-speed engines with two six-cylinder direct-injection units of 55 and 90 H.P. An unusual design of cylinder head is employed, and each cylinder has its own combined fuel pump and injection valve of Bur-Wain design and manufacture. In Finland O.Y. Ares A/B produce fourteen high-speed marine units, developing from 45 to 520 H.P. All are of the low-compression, spark ignition type (Pohjanpolo patents). The system has been adapted experimentally to a Cirrus aircraft engine.

A number of French manufacturers build engines under British and German licences, but the Panhard road transport engine is unique in having dual sleeve valves. The development of the Clerget aircraft diesels is directly sponsored by the French Air Ministry. There is a fourteen-cylinder air-cooled radial of 600 H.P., weighing 2.53 lb. per H.P. The latest unit has sixteen water-cooled cylinders and develops 1600 H.P.; it is supercharged by four Rateau exhaust-turbo blowers, and a fuel consumption on transatlantic service of 0.375 lb. per H.P. hour is anticipated. The Coatalen aircraft engine has a rated maximum of 575 H.P. with a dry weight of 1100 lb.

German manufacturing programmes show the influence of type rationalization under the Four-Year Plan, and there is marked interest in the use of low cetane fuels. It is claimed that the D.W.K. railcar engine can utilize brown coal tar oil and gas-oil equally well and without modification. Petrol starting systems are used on the Famo and Kämper. Maybach, who have consistently advocated direct injection, have now adopted a pre-combustion chamber system for railcar and marine engines. Phänomen have produced a four-cylinder 60 H.P. air-cooled diesel, whilst the Krupp horizontally-opposed air-cooled engine has disappeared. Of the M.A.N. air-cell engine it is reported that complete control of combustion has been established, and a substantial reduction in the fuel consumption has been effected.

The Italian firm of Alfa-Romeo are developing V-type blower-scavenged two-stroke engines for transport applications. In Switzerland the Saurer toroidal combustion chamber remains unchanged. Sulzer high-speed marine engines are of the opposed-piston two-stroke type, but the single crankshaft has only two throws per cylinder. This is made possible by a system of rocking beams.

K. T. A.

1110. American Oil Engines. *Auto. Engr*, 1939, **29**, 215-222.—It is estimated that there are now about 39,000 American high-speed diesel engines in service; of these perhaps 31,000 are used in tractors and less than 5000 in automotive service. However, it seems likely that from now on the use of diesel engines on the road will increase very rapidly indeed.

An outstanding development in the past year has been the General Motors blower-scavenged two-stroke engine, of which some 700 are already in service. It is produced in three-, four- and six-cylinder units. Scavenge air is delivered by a three-lobed Roots blower. Combined pump and injector units in each cylinder inject fuel through a multi-hole nozzle at 20,000 lb. per sq. in.

In the more conventional types of engine the Lanova combustion chamber is widely used, as in the Buda, Dodge and Mack. Hercules continue to use their own "hot cup" turbulence chamber. The Cummins is still used in automotive service in considerably greater numbers than all other makes combined.

The well-known Caterpillar engine is built in a number of different sizes, all of the pre-combustion chamber type; the sale of this engine is now of the order of 12,000 units per year. Waukesha produce three Ricardo "Comet" type engines for road vehicles, and a range of nineteen engines of the Hesselman type. The latter are, of course, of the low-compression spark-ignition type.

K. T. A.

1111. Tables of High-Speed Oil Engines. *Auto. Engr*, 1939, **29**, 223-234.—One of the features of the annual Diesel Number of this journal is the section summarizing the specifications of diesel engines for road, rail and small marine purposes. This year data are given for 195 British and 420 Continental and American engines. The trend of automotive design in the leading countries is apparent from the following summary:

	Number of types manufactured.			
	Turbulence Chamber.	Direct Injection.	Air cell.	Pre-chamber.
Great Britain	20	11	3	—
France	11	11	—	3
Germany	27	8	6	31
Italy	5	4	3	5
U.S.A.	21	7	7	11

The specific fuel consumption of direct injection types is usually about 0.41 lb./B.H.P./hr., except in Great Britain, where the average is 0.36 lb. Other types range from 0.41 to 0.46 lb. In Great Britain 67% of the engines (all types) have a compression ratio between 14.0 and 16.5 in contrast to Germany, where 62% are between 17 and 18 to one. In the U.S.A. 49% have ratios between 14.5 and 15.5, whilst 18% are less than 13 to one.

K. T. A.

1112. Vapour Phase Cooling for Internal Combustion Engines. J. H. Wallace and R. A. Newton. *Oil Gas J.*, 7.9.39, **38** (17), 58.—A study is presented of the thermal conditions within the internal combustion engine cylinder and a description given of a new method of cooling termed vapour phase cooling, involving the use of a liquid at or near its boiling point. In tests on a typical four-cycle explosion type cylinder, the following temperatures were obtained: intake air 60° F., end of suction 155° F., end of compression 800° F., firing 4000° F., end of expansion 2588° F. and end of exhaust 1641° F. The heat of combustion is distributed as follows: brake horsepower 26%, engine friction 6%, radiator 6%, exhaust 34%, jacket water 28%. The last item is subdivided into combustion (to the head) 6%, expansion (to the walls and head) 7%, and exhaust (to walls and head) 15%. It is shown that irrespective of the average jacket-water temperature, the water in the upper jackets and heads is at boiling point, while 10/15 times the normal water flow would be required to keep the metal temperatures to within 20° F. of that of the water. High jacket temperatures reduce liner distortion (owing to the smaller temperature difference), increase the mechanical efficiency by up to 10%, but have little effect on thermal or volumetric efficiency, while they reduce moisture condensation in the cylinder with beneficial effects on corrosion and sludge formation.

The ideal jacket-water temperature is obviously near its boiling point, but this cannot be maintained with normal systems owing to evaporation loss from steam bubbles, vapour lock and the difficulty of thermostatic control under such conditions. Systems which have been tried out include (1) the use of an auxiliary condenser to separate the steam, returning the condensate to the system; (2) steam cooling in which a water level is maintained in the jackets and the steam removed and condensed. The entire jacket heat is removed through the latent heat of vaporization of the water on the jacket wall. The cooling liquid circulation is, however, insufficient to prevent the formation of steam or large steam bubbles and thus hot spots are formed.

The vapour phase cooling system which has now been developed consists essentially of a flash chamber in which the jacket water is circulated and from which steam-free water is returned by a pump to the jacket. The circulation rate is maintained at approximately 0.4 gall. per min. per B.H.P. hr. and is sufficient to maintain a temperature difference of not more than 20° F. Very little cooling takes place so that the liquid soon reaches its boiling point, any vapour formed being drawn off the flash chamber, condensed and returned. The advantages of such a system are: (1) any temperature can be maintained by the selection of suitable liquids or mixtures or by altering the pressure; (2) as the automatic control depends entirely on the latent heat of vaporization of the liquid, it is absolutely stable and automatic; (3) efficient cooling is accomplished owing to the constancy of the temperature of the water throughout the entire jacket; (4) the system is completely sealed so that losses are extremely small; (5) the radiator capacity is greatly increased as it is only used for condensing steam.

The results of practical tests indicate the improvement in the condition of the engine and of the lubricating oil after the installation of these cooling systems.

C. L. G.

1113. Present Position in the Development of Producer-Gas Propulsion. H. L. Pirie. *Instn Mech. Engrs J.*, 1939, 141 (4), 365-368.—The problems associated with the use of producer gas (from coal or a solid derivative thereof) are at present being studied by a committee appointed by interested bodies in Great Britain. The author has therefore refrained from quoting controversial matter and confined himself to a statement of the existing position. Gasoline and producer-gas engines both have thermal efficiencies of about 23 to 25%; diesel engines are about 35% efficient. Even though the calorific values of coal and oil are about 14,500 and 19,000 B.t.u. per lb., respectively, the fuel costs of the producer-gas engine are probably lower. There is about 30% loss of power compared with a gasoline engine of the same size.

Only a small number of experimental vehicles are in use in Great Britain, but in France 4436 producer-gas vehicles were in use by 1937; in the same year Germany possessed 1207, whilst a recent estimate shows that about 1500 are used in Italy. In the United Kingdom the fuels most readily available are anthracite and low-temperature coke. The special equipment of a producer-gas vehicle and the larger engine required may increase the unladen weight of a commercial vehicle by 10 cwt.; the fuel for producer gas weighs nearly four times as much as diesel oil, for a given distance. Since goods vehicles in this country are taxed on unladen weight, conversion to producer gas means an additional tax burden and may also have the effect of reducing the legal speed limit. It is concluded that the operation of vehicles on producer gas from coal presents no insurmountable technical difficulties; development in this country is not likely to be rapid in peace time unless the regulations are modified.

K. T. A.

1114. The Producer-Gas Road Vehicle. W. H. Fawke. *Instn Mech. Engrs J.*, 1939, 141 (4), 368-371.—The author, in this paper, has summarized his experience in operating a 31-seat public service vehicle on producer gas for some 36,000 miles. Numerous types of producer are available, but the cross-draught type without any refractory lining is considered to be particularly suitable because of its relatively low weight. The engine must be not less than 33½% larger in volume than the gasoline (or oil) engine to produce the same power. At the same time a compression ratio of 8:1 is desirable, together with increased turbulence. The equipment of the experimental vehicle is described in some detail. The operation of starting up from cold takes not more than five minutes. The fuel costs for 32,000 miles are summarized thus: Producer gas, £90; gasoline, £253; diesel fuel, £136. There is an additional annual charge against the gas vehicle of £30 for plant cleaning and fuelling. With a suitable anthracite fuel cylinder wear is not greater than in a gasoline or diesel engine. Conversion of existing vehicles, as was done in the case under consideration, is not so satisfactory as the provision of a new chassis with suitable engine and gearing, but the principle of gas propulsion is regarded as sound.

K. T. A.

1115. The Application of Town Gas as a Fuel for I.C. Engines. C. M. Walter, D.Sc. *Instn Mech. Engrs J.*, 1939, 141 (4), 381-386.—Since 1932 the City of Birmingham

Gas Committee has conducted comprehensive experiments to determine the possibilities of coal gas as a fuel for traction purposes. It has been found that the adaptation of existing gasoline engines results in a power loss of about 20%. The effect of increasing the compression ratio was investigated, and it has been found that by utilizing the fuel injection principle the compression ratio can be raised to 16 : 1; thermal efficiencies of a high order can then be realized.

Special storage bottles have been developed, capable of storing 330 cu. ft. of free gas at 3000 lb. per sq. in., the empty weight being 124 lb. per cylinder. From three to seven of these are mounted on the vehicle. A two-stage pressure reducer supplies gas to the air-gas mixer at slightly below atmospheric pressure.

Bench and road tests have been made, using gas of 475 B.t.u. per cu. ft. gross calorific value. When working on the Otto cycle the optimum gas consumption was 27 cu. ft. per B.H.P. hr., with a compression ratio of $6\frac{1}{2}$: 1; the power output was 85% of that obtainable on gasoline. Using a modified diesel engine, in which gas injection took place during the compression stroke, with 16 : 1 compression ratio the power output was slightly greater than with liquid fuel; the heat input was approximately the same with both fuels.

The economic aspect is analysed on the basis of a fleet of 50 vehicles, each covering 50,000 miles per annum and consuming 0.2 gallon of gasoline per mile. Road tests have indicated that the gas consumption (Otto cycle) per equivalent gallon of gasoline approximates to 265 cu. ft. It is concluded that town gas at 4d. per therm can, under certain conditions, compare favourably with gasoline. If the gas is used in high-compression engines with fuel injection, operating costs would be comparable with diesel engines.

K. T. A.

1116. New Injection System for Gas Engines. R. A. Erren. *Instn. Mech. Engrs J.*, 1939, 141 (4), 386-389.—The author has found it possible with gaseous fuels to take in a full charge of air during the suction stroke and to admit the necessary gas after the suction valve has closed. A higher volumetric efficiency is thereby achieved. Gas admission during the compression stroke is controlled by a rotary valve. Engine-test results for coal gas and hydrogen are quoted in comparison with Otto cycle performance on gas and gasoline. It is claimed that the new system yields increased power with higher thermal efficiency. Hydrogen has been used as an "accelerator" for coal-tar oils not otherwise suitable for combustion in high-speed diesel engines.

K. T. A.

1117. Problem of Anti-Knock Fuels. (1). W. Chylinski. *Przem. Naft.*, 10.3.39, 5, 129-133.—After dealing with the characteristics of the phenomenon of "knock" and the methods used for its measurement, the author proceeds to describe two theories put forward as explanations of the above phenomenon. Ricardo's theory, according to which "knock" is due to an irregularity in the gaseous combustion of the fuel, is dealt with shortly. Herstad's theory, however, based primarily on the assumption that a large percentage of the fuel is present in the dispersed liquid state, is described at length.

Herstad took as a starting-point the fact that "knock" can be reduced and even completely suppressed if the combustible mixture is heated before entering the cylinder. From this he inferred that, under ordinary conditions, part of the mixture entered and remained in the cylinder in liquid form and that combustion took place in two stages: first, combustion of the gaseous fuel, then combustion of the liquid. "Knock," according to this theory, is therefore strongly dependent on the mode of evaporation and combustion of a drop of liquid fuel under engine-temperature conditions.

Following this idea Herstad investigated qualitatively and quantitatively the phenomena of evaporation and spontaneous ignition of a liquid fuel sprayed on to a hot metal surface. It was found that, as the temperature of the metal surface rose, the time of evaporation decreased gradually until a certain minimum point was reached, after which it rapidly increased to a maximum. Further rise in temperature again decreased the time of evaporation. The minimum reached at lower temperatures, was, however, not attained again, even at temperatures where spontaneous ignition occurred. The described minima and maxima seemed to be characteristic

of all examined fuels. By means of a Time of Evaporation/Temperature diagram it is shown that fuels with high octane number exhibit bigger maxima than fuels with low octane number. The shape and form of the droplets varied at different parts of the curve. Near the minimum the droplet thrown on to the heated surface immediately took on the form of a rapidly disappearing small cloud. As the temperature was raised the droplet was increasingly clearly visible until, at the point of maximum time of evaporation it was seen to be enveloped by an insulating layer of gas. This condition was called the "transition" state of the droplet.

The droplet in the "transition" state ignited quietly and its time of burning was found to increase with rising temperature.

While examining the behaviour of petrol and its fractions, Herstad showed that droplets of higher fractions had longer times of evaporation and more pronounced "transition" periods. It was further shown that the smaller the droplet the longer the time of evaporation for a constant amount of liquid and that when the log of the amount of liquid was plotted against the log of the time of evaporation, a straight line was obtained.

A simple linear relation was also shown to exist between the molecular parachors and the maximum times of evaporation of different fuels.

With regard to the octane number a diagram is drawn with two almost identical curves: one showing the increase in octane number of a knocking fuel to which increasing amounts of benzole are added, the other giving the change of the maximum time of evaporation for these respective benzole additions.

The following conclusions are drawn: (1) The fuel exists in the cylinder in two phases, gaseous and liquid, even during the compression. (2) In the liquid phase slow-burning and fast-burning substances, with pronounced and weak "transition" periods, have to be distinguished. The latter have "knocking" properties. (3) The temperature of the cylinder walls has a decisive influence upon whether the liquid burns rapidly in a normal form or slowly in the "transition" state. (4) The kind of surface and metal are important factors because of the part played by interfacial tension. (5) The combustion phenomena depend on the mode of atomization.

E. J. W.

ERRATUM.

Abstract No. 1047 (*September Journal*, No. 191), line 19. For "pentane" read "heptane."



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INSTITUTE NOTES.

OCTOBER 1939.

EMERGENCY ARRANGEMENTS.

Owing to the premises of the Institute at the Adelphi being required for other purposes, it became necessary for the Institute to find alternative accommodation at very short notice. The Council accepted an invitation of the President (Prof. A. W. Nash), on behalf of the University of Birmingham, to accommodate the office and staff at the Department of Oil Engineering and Refining. The address of the Institute, to which all communications should be sent, is now :

The Institute of Petroleum,
C/o The University of Birmingham,
Edgbaston, BIRMINGHAM, 15.

Tel. No. : Selly Oak, 1181.

It was not possible to transfer the Institute's library to Birmingham. The books at the Adelphi have been protected and partly stored, but will not be available for consultation or borrowing.

The *Journal* will continue to be published monthly, including the Abstracts of current technical literature. In view of the fact, however, that many of the regular abstractors are either serving with H.M. Forces or are engaged on work of national importance, some temporary curtailment of the service of Abstracts may be inevitable.

The London meetings of the Institute and of the Branches in the United Kingdom are suspended for the present. It is hoped to resume these, either in London or some other convenient centre, when circumstances permit. Papers which would normally have been presented at meetings will, wherever possible, be published in the *Journal*.

THE CENTRAL REGISTER.

This Register has been compiled by the Ministry of National Service and Labour from information collected through the medium of various technical and scientific societies. Its object is to ensure that in wartime, work of national importance, for which specialist qualifications are necessary, is performed by those persons best qualified to undertake it. An explanatory circular and cards were issued in April 1939 to Fellows, Members and Associate Members of the Institute, having a registered address in the United Kingdom. Upwards of 400 members of the Institute completed the card questionnaire. These particulars have been forwarded to the Central Register, whose address is now :—

The Central Register,
Ministry of National Service and Labour,
569, Chiswick High Road, London, W.4.

Members who have not enrolled, and are desirous of doing so, should apply to the Secretary of the Institute for the necessary forms. This registration is optional and not binding, and does not debar members from subsequently joining H.M. Forces or taking up other forms of national service.

Employers have been invited to notify the Central Register of vacancies. The Central Register office will then communicate direct with registered persons whose qualifications appear suitable for the appointments vacant. It should be emphasized, however, that the Institute of Petroleum does not administer that portion of the Register relating to appointments in the petroleum industry.

Members of the Institute who become unemployed are asked to notify the Secretary, when a notification to this effect will be forwarded to the Central Register.

CANDIDATES FOR ADMISSION.

The following have applied for admission to the Institute or transfer to another grade of membership, and in accordance with the By-Laws the proposals will not be considered until the lapse of at least one month subsequent to the issue of this *Journal*, during which any Fellow, Member or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of any candidate.

The object of this information is to assist the Council in grading candidates according to the class of membership.

The names of the candidate's proposer and seconder are given in parentheses.

DUNN, Roland, Managing Director (*Holmes Mullin & Dunn, Ltd.*), 7, Howard Street, Belfast. (*E. J. Dunstan ; V. M. Farrant.*)

DYSON, Leonard Anderson Leighton, Sales Manager (*Holmes Mullin & Dunn, Ltd.*), 21, Derryrolgie Avenue, Belfast. (*E. J. Dunstan ; V. M. Farrant.*)

HANCOCK, John, M.Sc., M.Inst.Min.E., Mining Engineer (*Imperial Chemical Industries, Ltd.*), Nobel House, Stevenston, Ayrshire, Scotland. (*L. Patrick.*)

IDYLL, Clifton Purvis, B.Sc., Chemist (*Trinidad Leaseholds, Ltd.*), Pointe-a-Pierre, Trinidad, B.W.I. (*A. G. V. Berry ; H. C. H. Thomas.*)

LYTLE, John Ebert, B.S., M.Am.Soc. Mech.E., Engineer, M. W. Kellogg Co., 225, Broadway, New York City, U.S.A. (*J. W. Hyde ; A. E. Dunstan.*)

POMEROY, Ralph Gaisford, A.M.I.Mech.E., Engineer, Vacuum Oil Co. of S. Africa, Ltd., P.O. Box 1043, Johannesburg, South Africa. (*W. E. Gooday ; I. H. G. Nicholson.*)

SMITH, C. Gordon, M.Sc., Chemist, Alfred Holt & Co., Ltd., Liverpool. (*E. A. Evans ; G. H. Thornley.*)

DANGEROUS GASES.

The series of Papers on "Dangerous Gases in the Petroleum and Allied Industries," which appeared in the issues of the *Journal* for June and July 1939, have been reprinted as a book. Copies are available from the Institute office at 7s. 6d. per copy (cloth-bound).

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Honorary Secretary.

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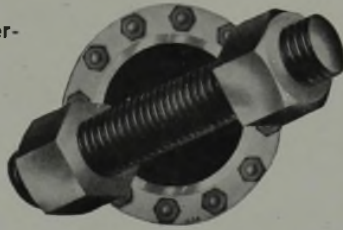
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Venezuela.—P. Bayle, Villa Proselec, MARACAIBO.

Trinidad, B.W.I.—Schlumberger Electrical Coring Methods, SAN FERNANDO.

Colombia.—H. Rappart, PUERTO-BERRIO.

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Morocco.—M. Texier, Société de Prospection Électrique, PETITJEAN.

Rumania.—A. Poirault, 18 Strada I. C. Bratianu, CAMPINA, (Prahova).

Germany.—Firma von Flotow, Schillerstrasse 36¹, HANOVER.

Dr. B. Paul, Kobenzlgasse 30, VIENNA.

Hungary.—M. Scheibli, Vadaszkürt Tür Istvan U.5, BUDAPEST.

Iraq.—L. Beaufort, QAIYARAH.

British India.—A. Couret, DIGBOI, Assam.

Burma.—L. Bordat, KHODAUNG.

Netherland East Indies.—R. Sauvage, PLADJOE, Sumatra.

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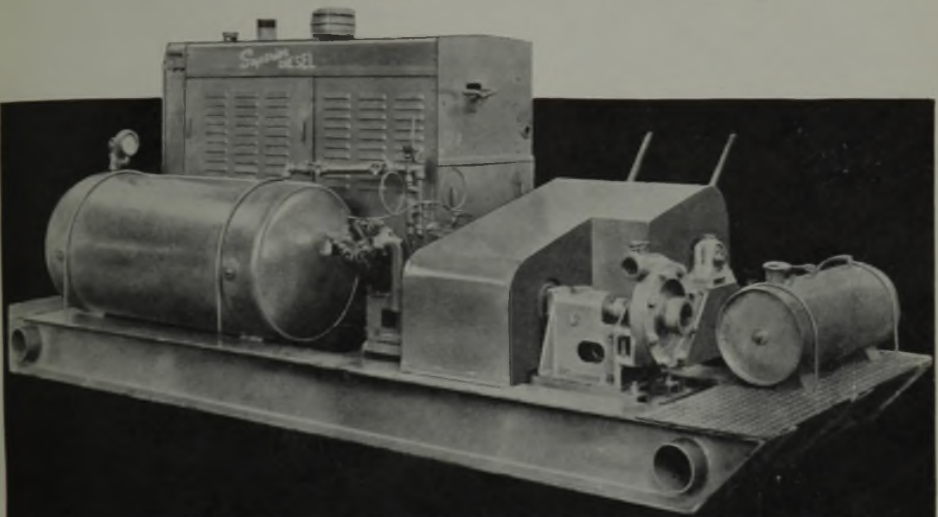
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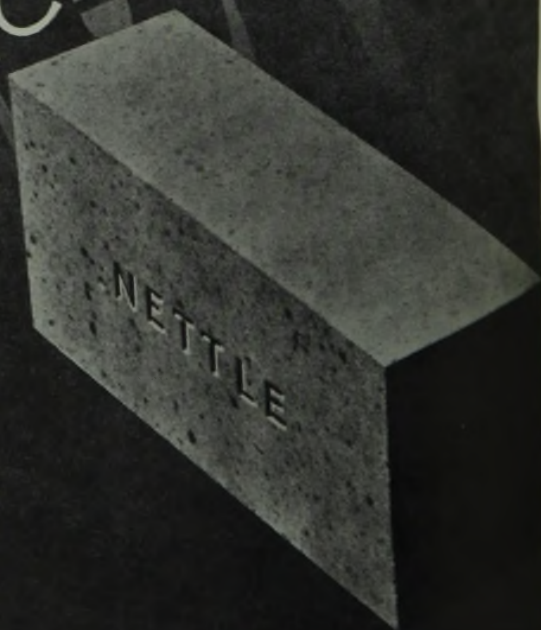
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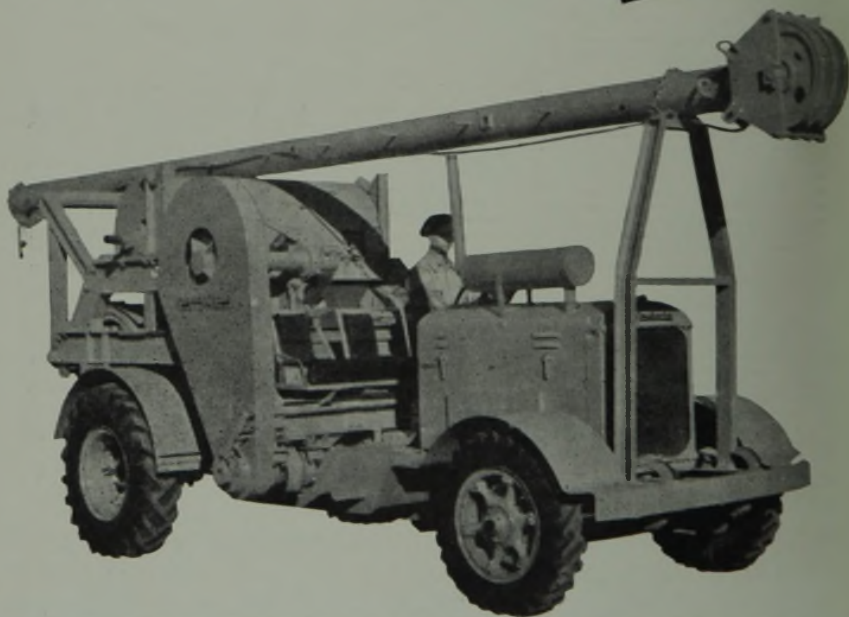
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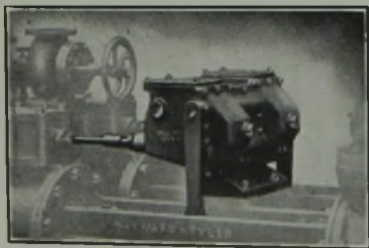
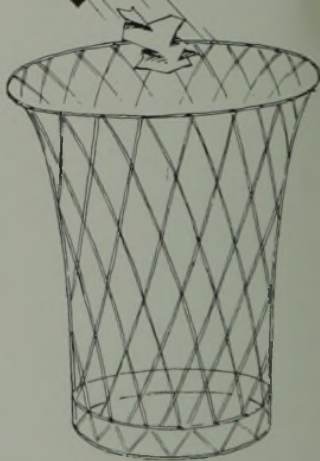
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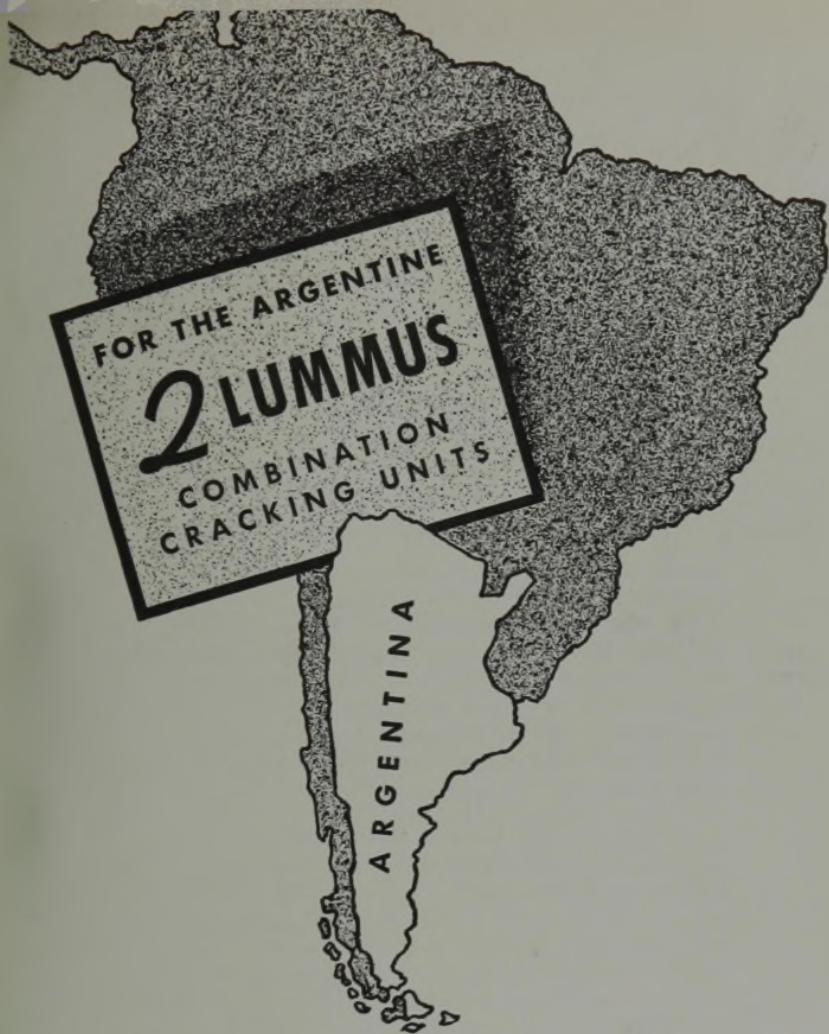
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