FUELS for diesels

It is intended in this article to put forward a scientific approach towards the formulation of workable fuel mixtures suitable for combustion in model diesel engines. This article first appeared in Mexboro' M.A.C. Magazine, to which due acknowledgment is made.

by S. J. Lobley

THE MATERIALS.—Let us first consider the materials which are commonly available.

OILS.—For general use, mineral-based motor oils can be strongly recommended, and in fact no better oil suitable for our purpose can be found to give better quality for money. The oils most suitable are those having S.A.E. ratings between 40 and 60, which are readily available in many different brands. In winter, an oil at the "thinner end" of this range is to be preferred to the thicker oils which have the higher S.A.E. rating numbers. However, this point need never cause any worry since this adjustment is seldom critical except in extreme climatic conditions which are not generally experienced in this country; nevertheless, let it be mentioned that the application of a little common sense here and there will avoid trouble: for example, the use of a summer oil in mid-winter is not a sensible arrangement. Of all the oils available on the market, I personally wouldn't hesitate to recommend the *Wakefield* range, and in this connection would add that I have found no mineral oil better suited for use as a universal oil for fuel preparation than *Castrol "Grand Prix"* which, having an S.A.E. rating of 50, falls midway between the limits already prescribed, and consequently is equally suitable for summer or winter use. Also a further point in favour of this oil is the fact that it is specifically produced to maintain adequate lubrication at higher shaft revolutions than ordinary motor oils and in this respect is obviously more suited to coping with the lubrication problems of our fast revving engines than are most other oils. In passing mineral motor-oils, it may be mentioned that whilst the author has had experience of other people's using the various multi-grade oils such as *Shell* X-100 and *B.P. "Energol"*, which are now available on the market, without any evident depreciation of performance or mechanical soundness of their engine, he cannot say whether or not these oils are to be recommended for use in diesel fuels, because they depend for their action upon viscosity stabilisers which retard the rapid falling-off of the viscosity of the oil at high temperatures (this phenomenon being responsible for rapid engine wear). Now, the solution of those oils in Ether, for chemical reasons, is likely to produce structural changes involving the molecular form of the oil, which, being so affected, may not then be subject to the stabilising influence of the additive. In addition to the use of mineral oils, vegetable base oils may also be used with advantage: castor base blends possessing lubricating properties inferior only to graphite and molybdenum disulphide preparations. On grounds of superior lubrication alone, ordinary Castor Oil B.P. cannot be bettered amongst castor base oils; unfortunately, however, this superior oil may cost up to twice the price of the alternative mineral oil. Even so, its use for high performance engines is to be strongly advised and also the owner of a baby diesel would find that treating his engine to this aristocrat of lubricators would amount to negligible extra cost. However, for engines of over 1·5 c.c. capacity its use is associated with an appreciable increase in fuel costs, and so except for competition purposes, it is more desirable in these circumstances to use a good mineral oil instead. Commercial Castor Oil, and Pratt's Racing Castor Oil may be used in place of ordinary pharmaceutical quality castor oil, and a reasonable reduction in fuel costs will result. As lubricators, they are only slightly inferior to Castor Oil B.P. and as such are to be preferred to any mineral oil.

ETHER.—The ether employed in diesel fuels is ordinary common "Ether", and on no account should it be confused with various other ethers which are entirely different chemical compounds and are quite unsuitable for our purpose. As an aid towards distinction of common "Ether" from any other ether which might be met up with, it is sufficient to say that if a small amount of "Ether" (just enough to wet) is poured on to a plate or other resilient surface, it will evaporate away completely within a few seconds, or a minute at the most; whereas another ether so treated will not readily evaporate. Common "Ether" may go under one of many different names according to its grade and intended use; any of the following names may be applied to common "Ether" — Anesthetic Ether; Commercial Ether; Methylated Ether; Di-Ethyl Ether, Ether Meth.; and Ether Solvent. Any of those forms being satisfactory for use in diesel fuels. Anesthetic Ether is the purest form of ether normally available and because of the exhaustive purification processes which it has undergone, it will be the most expensive of all the forms. Commercial Ether and Ether Solvent are considerably cheaper than Anesthetic Ether and at about four shillings per pint each, obtainable from Boots Chemists, they represent about the cheapest reliable ether that can usually be obtained. Of the two, Ether Solvent is to be preferred because it is purer than Commercial Ether, but really this is of little importance since these impurities are only slight and are neither corrosive nor incombustible. If, however, Solvent Ether is asked for, enquiry must be made that it is of a chemical form called "Di-Ethyl Ether" of boiling point 35 deg. C., because there are other entirely different varieties of ether which can also be called Solvent Ethers.

PARAFFIN.—Little need be said about paraffin except that a reliable commercial brand should be purchased. In spite of popular belief, the colour of paraffin bears no relation to its efficiency as a burning oil. The following brands may be recommended: Aladdin Pink; Fina Green; Esso Blue; Shell Royal Daylight. The calorific values (or heat content) of different products vary slightly; that of the highest calorific value contains most energy and being most suited to our purpose. However, in the absence of data on this point, it is not possible to advise the reader.

THE MIXTURE.—The simplest working mixture consists of equal parts by volume of oil, paraffin and ether. However, in order to make the most of the materials available and of the capabilities of our engine, and of our money, we must make prudent adjustment of the proportions of the mixture. Now, anyone who has run his engine on a fuel of the above-mentioned type which contains 33⅓ per cent. of oil, will appreciate that the use of this amount of oil is grossly out of proportion;

in fact, the copious amounts of unburned oil which are ejected are an indication that the engine has not only sufficient oil for lubrication purposes, but that it has also more excess oil than it can get rid of by burning. It is not, at the best of times, a desirable situation for any engine to burn its lubrication oil since this leads to rapid carbonising and loss of overall power and efficiency because of the poorer burning qualities of oil as compared with those of paraffin. It is clearly evident that an engine which ejects unburned oil must also be burning its maximum quota of oil, and, all other things being equal, it is consequently working at its lowest possible efficiency. In addition to this aspect of the problem there must be considered the absorption of power due to the pumping of the inactive non-gaseous unburned oil through the engine. Hence, it is necessary (*a*) to eliminate the excess of oil which is ejected unburned from the engine and (*b*) to minimise the amount of oil burned within the engine, leaving only sufficient for lubrication purposes. In this latter respect, however, it is impossible, due to lack of precise scientific data, to ascertain the exact amount of oil required for lubrication alone; and so, in order to err on the safe side, a small excess of oil must be included in the fuel. After much careful consideration based upon experience and experiment over several seasons, the author has come to the conclusion that on no occasion, except when running-in a new or lately dismantled engine, is an oil content of over 25 per cent. by volume ever called for, even with the most demanding engine. With regard to fully run-in engines, 20 - 22 per cent. of oil may be used with plain bearing engines, the amount varying slightly to suit individual engines and individual occasions. For ball bearing or roller bearer engines, 18 - 20 per cent. of oil need only be used. If the oil is of the castor base type, which, as already explained, possesses superior lubricating properties, then the oil content of a fuel may be reduced by a further 1 per cent., and by as much as 2 per cent. in the case of pure pharmaceutical castor oil, and still observe a generous safety margin. In arriving at these considerably reduced figures, the author has no misgivings, since even as they stand, these figures represent quite a considerable oil excess. Indeed mineral oil contents can be reduced to as low as 15 per cent. if accompanied by 1 or 2 per cent. of an oil soluble preparation of graphite or molybdenum disulphide. It is not recommended that castor base oils be treated with these additives unless they are specifically designed to be so used. Furthermore, tests on Allen-Mercury engines have indicated that the use of as little as 7 per cent. of oil, on runs of moderate duration, has proved entirely satisfactory, and, as far as could be ascertained, did not give rise to greater engine wear than is normally to be experienced, when using a fuel of greater oil content. In view of this, it would most probably be found that an oil content of 10 per cent. would be adequate to cover the most extreme circumstances. However, in the absence of unequivocal confirmation, the oil contents of fuels are best left as already recommended: that is, in the region of 20 per cent.

"Of course I'll get this lot perfected, then someone will invent compression-ignition"

After considerable use, an engine requiring a re-bore, should have the oil content of its fuel raised slightly in order (*a*) to increase the compression seal with an eye to maintaining the pumping efficiency which is of particular importance for easy starting characteristics; and (*b*) to prevent excessive wear due to the very loose piston cylinder fit. Nevertheless, more than 25 per cent. oil content need never be used.

Now let us consider the adjustment of the ether content of the mixture. Theoretically the more ether that is present in a mixture the better; however, in practice the ether content must be limited to a reasonable figure, otherwise the paraffin content will be reduced to impracticable proportions. A convenient maximum limit may be set at 45 per cent. of ether. *Note:* The use here of the term maximum is not intended to imply an upper limit which if exceeded may be detrimental to the engine; indeed not, it is intended only that the ether content of the mixture should not be allowed to become so great as to drive the paraffin content (which, after all, is the power-yielding constituent) into insignificance. Although it must at least be admitted that the liberal use of ether in excess of 55 per cent. in a mixture is most decidedly dangerous. However, to get back to the point: the upper limit of 45 per cent. which we have set ourselves, is a most desirable limit to work to, since high ether content makes for cooler running and smooths the combustion to a degree which cannot be obtained by use of dope additives alone on fuels of lesser ether content. Both these factors are of prime importance in the combustion of the fuel, and unfortunately this essential treatment of fuel formulation to obtain this desirable situation is often overlooked by the modeller who boasts masses of chemical names intended to convey knowledge of special "dynamite" additives which are claimed to lease considerable extra power, and promote hitherto unknown smoothness of running ! ! ! Whilst I do not intend to discourage the use of such additives (indeed, few fuels are properly formulated without judicious use of appropriate additives) I must nevertheless make it clear that their use can only be taken full advantage of if they are used in sensible amounts in the right place and for the right purpose. There appears to be much controversial argument associated with arriving at a suitable figure for the ether content of fuels: and clearly there exists here a topic open to considerable discussion. Bearing this in mind, the author offers his own views on the subject in an attempt to make clear his reasons for adopting them.

As has already been explained, a maximum ether content of 45 per cent. is adopted (*a*) to induce cooler running; and (*b*) to promote smoother, more complete combustion.

The necessity for cool running is on account of the increased volumetric efficiency which is to be had as a result. All that this means is that a charge of atomised fuel entering the cylinder at a high temperature expands a certain fixed amount after ignition and gives rise to a corresponding fixed amount of power available partly as shaft power. Now, if the overall temperature of the cylinder is kept lower as a result of using a high ether content fuel, then the temperature change of the charge (which on originally entering the cylinder is near the

FUELS for diesels *(continued)*

temperature of the cylinder and finally is at the same high temperature of combustion as in the first case alluded to) is greater during the compression / power strokes than in the first case and so gives rise to greater potential expansion of the exhaust gases, which, being in the same volume as those in the first-mentioned case, gives rise to greater internal driving force which emerges in the form of increased shaft power. May I refer those reluctant to believe this, to the falling off of power and revs apparent during the first few seconds of an engine run whilst the temperature of the cylinder is rapidly rising. It is a portion of this "lost power" which is reclaimed (by the use of high ether fuels) by preventing the temperature of the cylinder rising as high as it would if a low ether fuel were used. As a consequence, therefore, of observing this point, the benefits of slightly increased power availability and cooler cylinder temperatures are to be had.

As to the second advantage to be gained by the use of high ether content fuels (*i.e.*, smooth and more complete combustion), it may be argued as follows:

A constant volume of paraffin / ether vapour such as the atomised fuel charge transferred at each revolution into the cylinder, will, under the constant conditions prevailing in an engine running at constant speed, burn at a constant rate when ignited, *i.e.*, one charge will take the same time from ignition to completion of combustion as will the next charge and the next, and so on. Now the speed at which the charge burns after ignition is directly dependent upon the proportion of ether present in it; that is to say, a charge containing a smaller proportion of ether to paraffin will burn more slowly than a charge which contains a higher proportion of ether. In fact, where the proportion of ether to paraffin is small, the ether which ignites first, might conceivably be completely expended before much of the paraffin has burned. This reluctance of the paraffin to burn quickly means that unburned paraffin vapour leaves the exhaust when the charge is displaced by the income of a fresh charge via the crankcase. Thus, part of the calorific value of the fuel is lost, and escapes unharnessed. If engines were designed to run at lower revolutions, there would probably be sufficient time during the power stroke to allow for complete combustion, but since we demand ever increasing revs of our engines, we must make adequate provision for the slow burning of the paraffin to be accelerated in order that complete combustion shall occur before the charge is rapidly displaced by a fresh charge from the crankcase. This is admirably done using a fuel of high ether content. It must not be thought that ether is employed in diesel fuels solely for ignition purposes (if this were so, then only a small amount would be required); it is also essential to accelerate the smooth uniform combustion of the paraffin vapour; this fact becoming more and more important the more we expect engines to run at ever increasing speeds. It is here that we may explain a previous allusion to the wrong use of additives. The use of amyl nitrate has long been advocated as a cure for late ignition and uneven and incomplete combustion of the charge, but with the subtle proviso that we can hardly expect to "doctor" or "paint over" the basic formulation defects of a fuel by liberal use of this additive.

Use of Amyl Nitrate

It may indeed be conceded that many imperfections may be obscured by use of amyl nitrate or similarly acting additives, but in such cases little or no extra power will be in evidence, because all the additive will be employed in smoothing uneven running, rather than in providing higher revs in consequence of which more power is made available. On the other hand, addition of amyl nitrate to a carefully formulated high ether content fuel will provide a much more apparent effect, producing a smooth increase in power and considerably increased flexibility and ease of adjustment of the engine and what is more important, only a small amount of amyl nitrate need be added; never more than 3 per cent. for general purpose fuels, 2 per cent. proving entirely satisfactory in the majority of cases. To summarise this point, the use of a high ether content fuel will promote smooth complete combustion and so pave the way for the addition of judicious amounts of amyl nitrate to yield extra flexibility and appreciable power increase whereas the use of a low ether content fuel will necessitate the addition of far more amyl nitrate before a performance in any way comparable to that in the latter case, will be realised, and also will give rise to two additional undesirable situations. These are (*a*) high cost — bearing in mind that addition of amyl nitrate to the extent of only 2 per cent. to one pint of fuel costs about 1/1d, it is readily evident, therefore, that at least two shillings must be spent on amyl nitrate added to one pint of a poorly formulated fuel before it becomes anywhere nearly comparable to a high ether content fuel which contains only a little amyl nitrate; (*b*) heating troubles — of all the fuel constituents in current use, amyl nitrate and similar additives are the worst offenders as regards producing overheating problems. Thus the low ether content fuel which requires most amyl nitrate to "doctor' its basic defects will suffer from a tendency to cause much overheating of the engine which is highly undesirable for reasons already explained as well as for mechanical reasons. On the other hand, the high ether content fuel which naturally causes cooler running wili be more than able to cope with any heating tendencies induced by the small amount of amyl nitrate which may be added. To be more specific about ether content, it is strongly recommended that up to 45 per cent. of ether can be used wherever possible and it is guaranteed that its use in this proportion will give benefits in all the

For your Diary

May 14th. Cambridge Slope Soaring Rally—F/F, Multi and Single R/C. *Ivinghoe Beacon, Chiltern Hills.*
May 28th. East Lancs M.A.C. Open Contest—Open Power, Rubber, Glider. *Walton Spire, Nelson.*
June 4th. Wharfedale, C/L Rally—¼A, "A" and "B", T/R, Stunt and Combat. R.A.F. *Rufforth.*
June 10/11th. P.A.A. Scottish Festival. All P.A.A. classes, open F/F, Combat, A,B T/R, R/C. Enter to *24 Moor Rd., Ayr* by 27th. May.
June 11th. Midland Gala, Open—F/F, Chuck Glider, ¼A Power, ¼A, A, B, T/R, Stunt, Concours R/C. R.A.F. *Wellesbourne.*
June 18th. Junior Leaders Regiment R.E. C/L Rally—Combat, Stunt, Speed. *Old Park Barracks, Dover.*
June 18th. Scottish C/L Nats. *Beveridge Park, Kirkcaldy.*
July 2nd. Northern Heights Gala—All F/F classes, R/C Spot landing, Combat, Concours d'Elegance. R.A.F. *Halton.*
July 9th. West of Scotland F/F Gala—R.A.F. *Abbotsinch.*
July 23rd. Ashford C/L Rally—Combat, F.A.I. T/R. *Victoria Park, Ashford, Kent.*
August 13th. St. Albans F/F Gala—U/R Rubber, Power, Glider, ¼A Power, S/C Radio spot landing, Slope Soaring. *Chobham.*
August 13th. Rush Trophy Gala—¼A, U/R Power, U/R Glider, U/R Rubber, Combat. *Newcastle.*
August 20th. Scottish Gala and U.K. Challenge Match—*Abbotsinch.* (New Date.)
August 20th. C. H. Roberts Cup—Flying Boats. *Dartford Heath.*
August 20th. Devon Rally—Open F/F, ¼A Power, Combat. *Woodbury Common.*
August 27th. South Midland Area Gala—All Classes. *Cranfield.*
August 27th. I.R.C.M.S. Annual Aircraft R/C R.A.F. *Wellesbourne.*
September 10th. Northern Gala (new date).
September 17th. Croydon Gala—Open Rubber, Glider, Power, ¼A Power, Slope Soaring. *Chobham Common.*
September 29th. Caledonia Shield—*Lanark.*

respects mentioned. However, the formulation of fuels for such special purposes as team racing demand an adjustment of the formula. In the case cited there is call for maximum duration which necessitates a slight increase in paraffin content of the fuel and so it is necessary to reduce the ether content slightly in order to balance the mixture. These adjustments are only of the order of a few per cent. and in no circumstances should the ether content be reduced below 40 per cent. because the engine of a team race aircraft is called upon to give high performances which in the absence of a high ether content in the fuel, would cause overheating difficulties. The ether content may also be reduced below 45 per cent. quite justifiably on the grounds of economy and so 40 per cent. of ether will be satisfactory for most general purpose flying fuels, although the performance obtained will be slightly inferior to that obtained using a fuel of 45 per cent. ether content. As the ether content of fuels is reduced further from 40 to 35 per cent. a more noticeable depreciation in running qualities is observed by its use and it is doubtful if any of the advantages discussed in this article are to be had from a fuel of only 35 per cent. ether content. It is recommended, therefore, that the use of only 35 per cent. of ether in a fuel be avoided except in economy "brews", and even so in hot weather, 35 per cent. of ether is too low for even the most economic fuel that should be attempted. The author cannot commend the use of less than 35 per cent. of ether in any fuel whatsoever on grounds of overheating and possible tendency towards seizure in hot weather. Also, in passing it may be mentioned that low ether content will produce rough running and misfiring, due to difficulty experienced in getting the mixture to fire satisfactorily in addition to the obvious difficulty in starting.

The paraffin content of a fuel is determined merely as a balance, once the oil and ether percentages have been agreed upon. Let it not be thought that this is an abandoning attitude towards the fixing of the proportion of paraffin to be incorporated in a fuel. Although in the first place, paraffin is the only constituent of the fuel which is intended to burn solely as a power producing agent, it cannot perform this function efficiently unless the lubrication and combustion problems have been adequately solved first. Therefore, it must play a subordinate role in the diesel fuel and in fact constitute far less than half the volume of the total mixture. The use of Iranian gas oil is not to be recommended as a substitute for paraffin, as often is the case; because due to its higher molecular weight, it is less easily vaporised than paraffin and gives rise to incomplete and uneven combustion, which, as already explained, we are most anxious to avoid. Thus the additional lubricating properties which this burning oil possesses over and above the almost non-existent lubricating properties of paraffin do not balance the other disadvantages associated with its use, and in any case, there are divers excellent lubricants already mentioned which can be used to better effect.

Just a word on the use of additives. The use of amyl nitrate which is the only important additive in general use for diesel fuels, has by and large been adequately dealt with in the treatise referring to the use of ether.

The author considers its use in small amounts to be essential for use in any fuel intended for a modern diesel engine whether large or small. This is not necessarily the case with older engines which are intended for running at lower revs. Where the use of amyl nitrate is found desirable, amounts much less than 1 per cent. appear to have little effect. The use of 4 per cent. of amyl nitrate instead of 3 per cent. in a "hot" fuel is not justified by the slender increase in power yielded by the addition of this last percentage, as compared with the noticeable improvement evident when the additive content is raised from 2 to 3 per cent. Therefore, except for competition purposes, the use of 4 per cent. of amyl nitrate in a fuel for use in moderately long runs cannot be justified because of additional penalties incurred as a result of a tendency towards overheating. Diesels of over 2·5 c.c. capacity generally are prone to rougher running tendencies than their smaller counterparts and it is usually found that a slightly higher amount of amyl nitrate has to be used to combat this; allowances for this phenomenon being made with regard to formulae to be found overleaf. If difficulty is experienced in obtaining amyl nitrate, then amyl *nitrite* may replace it in all fuel mixtures to give comparable effects, except that about twice as much nitrite as nitrate is required. With this in mind, it will be found that its use to similar effect is slightly more expensive than the use of the nitrate, and in addition it provides an extra inactive bulk in the fuel, once its oxygen has been released.

The author, being at this time without experience of the use in fuels as an economy agent of nitrobenzene cannot recommend its use except in as much as to say that it has been reported from some circles to be satisfactory in this respect. How its presence in fuels affects the heat problem, cannot readily be assessed without experiment and it is to this end that experiments of just such a nature are to be carried out in the future.

As a final word, let it be said that no amount of effort in careful decision over fuel formula can be of use if the constituents of the fuel are not clean and free from foreign bodies.

Fuel formulae

2·5 c.c. Team Race B.B. Engine

18% Castor Oil B.P.
42% Ether
40% Paraffin
+ 2-3% Amyl Nitrate.

2·5 c.c. Duration

B.B. Engine	P.B. Engine
17% Castor Oil B.P.	19% Castor Oil B.P.
45% Ether	45% Ether
38% Paraffin	36% Paraffin
+ 3-4% Amyl Nitrate	+ 3% Amyl Nitrate

General Purpose Flying with high performance 2·5—3·5 cc.. B.B. Engines

e.g. Oliver "Tiger", P.A.W. Special, ETA 15, Rivers "Silver Streak" Frog 249 B.B. (Modified); Rivers "Silver Arrow".

18% Castrol R.	20% Castrol "Grand Prix"	20% Castrol "Grand Prix"
45% Ether	40% Ether	35% Ether
37% Paraffin	40% Paraffin	45% Paraffin
+ 2-2½% Amyl Nitrate	+2% Amyl Nitrate	+ 1-1½% Amyl Nitrate

It may well be found desirable to add a further ½% of Nitrate to fuels intended for 3.5 c.c. engines.

General Purpose Flying with ordinary 2·5—3·5 c.c. B.B. Engines.

e.g. E.D. "Racer", D.C. "Rapier", Frog 249 B.B., Frog 349 B.B.

Luxury Mix	*General Purpose*	*Economy*
17% Castrol R.	19% Castrol "Grand Prix"	19% Castrol "Grand Prix"
43% Ether	40% Ether	35% Ether
40% Paraffin	41% Paraffin	46% Paraffin
+ 2-2½% Amy Nitrate	+ 2% Amyl Nitrate	+1-1½% Amyl Nitrate

3·5 c.c. engines may require ½% more Nitrate than specified.

General Purpose Flying with 2·5 — 3·5 cc., P.B. Engines.

e.g., A.M.25, A.M.35, Frog 349 P.B., A.M.C.O. 3·5 P.B.

General Purpose	*Economy*
22% Castrol "Grand Prix"	22% Castrol "Grand Prix"
40% Ether	35% Ether
38% Paraffin	43% Paraffin
2·5 c.c. + 1½-2% Amyl Nitrate	+ 1-1½% Amyl Nitrate
3·5 c.c. + 2-2½% Amyl Nitrate	+ 1½-2% Amyl Nitrate

Mixtures for modern small diesels 0·5—1·5 c.c. P.B.

Castor Blend	*Mineral Oil Blend*
19% Castor Oil B.P.	22% Castrol "Grand Prix"
45% Ether	45% Ether
36% Paraffin	33% Paraffin
1-1½% Amyl Nitrate	1-1½% Amyl Nitrate

Mixtures for older engines.

e.g. E.D. Mk. II, E.D. "Comp—Special", Mills 0·75, Mills 1·3, E.D. "Bee", Mk. I, etc.

Castor Blend	*Mineral Oil Blend*
18% Castor Oil B.P.	21% Castor "Grand Prix"
43% Ether	43% Ether
39% Paraffin	36% Paraffin

The bee-haze of Amyl Nitrate can be avoided, however, some advantage may be obtained by its use in very small amounts.