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REPORT ON TESTS WITH R-FUELS

CONTENTS

Summary: The R fuels which have been used up to the present consisted of mixture of RCH oil with nitrates and peroxides. The R fuel R.110, which was used extensively in tests by the aero-engine industry, contained a peroxides which, compared with other substances of the same type, had the advantage of stability. But since R.110 attacked metals, this mixture was only regarded as a stop-gap, and the development was promoted of homogeneous substances with a high degree of ignitability. A suitable substance was found, and given the designation R.300, and has already been supplied to the engine industry in quantity.

In this report, the physical properties of the new R fuel are described. It is a fluid which is not dangerously inflammable, and which can be used with the usual injection equipment, it does not attack metals. Povimal and certain Buna mixtures can be used for tubing and packing.

Tests on engine showed that the new R fuel is less sensitive to changes in compression ratio and temperature than the fuel previously in use. The general conclusion, based on these tests, was that it is necessary to control the coolant and air temperatures. Tests at various excess air ratios showed that the power and consumption of the engine are independent of the type of R fuel. The injection advance angle and the volume of R fuel required are less with the new fuel than with former fuels.

The new R fuel is also an improvement, in the sense that the engine can be started without pre-heating. At low temperatures the intake air must be pre-heated, and it is suggested that an internal combustion engine be

used for starting, using the exhaust heat to pre-heat the intake air.

A) Object of the Tests

In the first tests with the R process, mixtures of Diesel oil with nitrates or nitrites were partly used (Report 394). Simultaneously, a fuel R 110 was developed, of which 1800 litres in all were delivered to the motor industry, which had entered the field as the result of the lecture on the 2nd February, 1940.

This fuel, R 110, consisted of RCH with 10% of a peroxide. The literature on the subject had made it known that Acetone peroxide among others, had been suggested for the improvement of Diesel oil *). This peroxide has practically the same effect as amyl nitrate, but has the disadvantage that only 3-4% of it is soluble in the paraffinic RCH Diesel oil. It crystallizes out at lower temperatures, so that dangerous accumulations can occur. Also, this peroxide only has a life of a few days.

Another peroxide was found which has the great advantage of being soluble up to any quantity in hydro-carbons. This substance, a fluid with a density of 1.07 and a calorific value of 6000 k.cal/kg, was given the code name Dibutin. Whereas pure Dibutin is an explosive with an effect like that of gun powder, a solution of 50% in RCH oil may be considered harmless. Dibutin is not suitable for improving Diesel oils, as, like all peroxides, it reacts with the unsaturated components of the Diesel fuel. The life of Dibutin is unlimited, and its effect even increases gradually.

The R fuel R-110, which contained 10% of Dibutin, was only intended as a stop-gap, for the setting point was unsatisfactory, and so was the behaviour with regard to metals. For instance, iron and copper were severely attacked, and extensive tests with various inhibitors provided no remedy.

The plan for increasing the ignitability of the high grade RCH oil by means of additives was abandoned, and a search was made for pure substances with a high degree of ignitability. After investigating a large number of such substances the fuel R 300 was selected, having regard to possibilities of production. The next task was to compare this fuel with R 110.

B) Physical and Chemical Properties

Table 1 shows that the new substance is a fairly heavy fluid with a high boiling point. The following facts should be noted:-

1. Density: The density of the new substance is at the upper limit customary for fuels. (diagram showing densities).

2. Calorific value. Calorific value of the new substance is comparatively low, as the following comparison shows:-
(diagram showing calorific values)

The most important calorific value of the new fuel, that relative to the volume, is about 20% below that of the previous R fuel. But as engine tests show, this is of no importance.

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*) Brooze and Hintze, S.A.E. world congress 22.5.1939 New York.

3. Viscosity R 300 - like R 110 -is more viscous than gasoline, and it can thus be used without difficulty in the usual injection devices.

(diagram showing viscosities)

It is possible to adjust the viscosity to any required value by means of additives. Plate 1 shows that with thickening there is also a flattening of the viscosity curve, so that at low temperature the behaviour is hardly affected. According to tests made so far, thickening has no effect on the cetane number and the behaviour in the engine.

4. Melting point. The previous fuel. R 110 has a setting point of -13°C which is characteristic of the paraffinic RCH oil. The new R fuel represents a considerable advance on this. The melting point of R 300 is at -45°C.

5. Boiling point. The pure substance R 300 has a boiling point, whose relative position can be seen in the following comparison:-

Gasoline	40-150°C
R 110	200-300°C
R 300	180°C

Here the boiling range of R 110 can be taken as representative of the boiling range of Diesel oils.

6. Vapour pressure. The vapour pressure of R 300 is very low, corresponding to the boiling temperature at 100°C it is still below 1/10 at. Comparison is difficult, for the vapour pressures of mixtures, such as Diesel oils, could only be determined by conventional methods (Reid). Plate 2 shows the vapour pressures.

7. Sensitivity to Water. The new R fuel absorbs small quantities of water. Its solubility is a very complicated question, and a simple presentation is impossible. The water content has surprisingly little influence on the cetane number. Thus, in one case up to 4% of water was added without the cetane number being reduced. But without doubt the other properties of the engine are unfavourably influenced.

8. Corrosion. There was considerable corrosion of copper and iron with R 110. On the other hand, R 300 hardly corrodes at all at room temperature. Iron and aluminium were not corroded at 100°C. Zinc and copper are slightly corroded at 150°C, but this can be inhibited by means of additives. The tests will be continued as soon as samples are available of the final quantity production substance.

R.300 differs essentially from the customary fuels as regards its tendency to dissolve organic substances. Thus, the binding material of the DBU hoses which are of fabric and are in general use in aero-engines, is dissolved. The ordinary oil resistant Buna is dissolved in the same way. On the other hand, Perduren 215 is stable. Since it is difficult to produce hose of this material, other rubber mixtures were successfully investigated. But there is already a satisfactory solution of the problem in the hose constructed of Povimal *). These hoses require protection against damp.

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*) Techno-Chemie Komm. Ges. Kessler & Co.
Berlin O 34, Frankfurter Allee 12:, Silberschlauch LP. Ausführung TR.

G) Engine properties **)

1. Cetane number: The customary measurement of the cetane number is limited by the comparative substances α - Methyl - naphthalene and cetane, to which the values 0 and 100 have been given. It is only possible to evaluate substances which are more ignitable than cetane by means of a new fuel. Therefore the cetane number of pure dibutin was determined in blends with different fuels and was found to be about 600. A reference mixture of cetane and dibutin was thus given the value 245, and with this extended range of measurement a value of 190 was found for R 300. As was shown elsewhere, the pressure rise of Diesel fuels is flatter, the higher their ignitability. The new R fuel is no exception to this rule, although it seems that the pressure rise of R 300 is somewhat steeper than that of R 110. But this phenomenon is unimportant, because the combustion of gasoline fuel occurs suddenly once ignition has taken place.

It must not be concluded on the basis of the cetane number that the injection advance angle with the R process will correspond. Evidently the combustion of the gasoline mixture only begins when the reaction of the R fuel has produced a certain temperature. As combustion is more sluggish the more ignitable the fuel, so the maximum point of the reaction will be longer delayed after the beginning of combustion, the higher the cetane number. This explains why the injection advance angle is not reduced in a corresponding degree to the rise in cetane number. This can be observed when the engine is idling as a pure Diesel engine, for then the injection advance angle is determined, not by the beginning of combustion, but by the moment of greatest heat development.

2. Behaviour at different temperatures of the intake air and coolant: It is of general significance in the R process to investigate the effect of various temperatures of the intake air and coolant, as in this way the sensitivity to different heat conditions of the engine is shown. It was found that the new R fuel is less sensitive than R 110, which was used previously.

For these tests, a single cylinder (DB 6001) DB 601 type engine was used on an I.G. test unit. The fuel volume was set at 9.4 hg/hour, to give a mean effective pressure of about 9 kg/cm^2. The R fuel volume was fixed at 200 mm^3/stroke, and the injection advance angle was set at the optimum value for each case. If the air temperature was now changed (plate 3) then loses in power first occurred below 60°C. The exhaust gas temperatures show that combustion is incomplete, although injection was advanced. With R 110 however, it was impossible to work below 30°C, whereas R 300 could still be used at room temperature.

A similar curve shows that the normal gasoline engine depends very little on intake air temperature, varying in this respect as the density of the air.

The tests were repeated (plate 4) and besides the temperature of the intake air, that of the coolant was also lowered. Under these conditions the falling off in power begins at 70°C, and R 110 fails at 40°C. Lower temperatures are possible with R 300. This second series of tests thus shows that the cylinder wall temperature has a considerable influence.

The problem of control consists, therefore, in keeping the cylinder wall temperature at a suitable value by controlling the volume of coolant. Also the temperature of the intake air must be regulated by pre-heating with exhaust gas. A coarse control is sufficient here to keep the temperature above a certain minimum.

) For test conditions see table 2 *) Report of Dipl.Ing.Köhler No.414

3. Behaviour at different compression ratios: Up to the present, the R process has always operated at a compression ratio of 1:8. The tests presented on plate 5 show that at higher compression ratio the injection advance angle falls considerably, so that the time in which the R fuel can mix with the fuel is reduced. Starting will also undoubtedly be improved. On the other hand, increased peak pressures and increased demands on the anti-knock value of the fuel have also to be reckoned with. In the present case, there is a falling-off in mean effective pressure and an increase in exhaust gas temperature at high compression ratios; the reason is that at high compression ratios and small ignition delays the jet is impeded by the piston at least at the end of the injection process.

As the compression ratio falls, there is a fall in mean effective pressure, as can be seen from the accompanying curve for the gasoline engine. On the other hand, in the R process the mean effective pressure falls more steeply, as combustion becomes incomplete. The injection advance angle must first be increased, and at very low compression ratios the optimum value is reached at somewhat smaller angles. This is evidently connected with the fact that at low compression ratio, injection must occur near to dead centre, that is to say, near the highest compression temperature, if ignition is to occur at all.

The superiority of R 300 can be seen in this series of tests from the fact that ignition is possible at very low compression ratios.

In plate 6 the gasoline and R processes are compared in more detail. In the R process the excess air ratio was about 40%. In order to get the same power in the gasoline process at a compression of 1:8, λ was set at 1.0, and the engine was throttled. Consumption is better in the R process, provided that at high compression ratios the ignition jet is not impeded or that at low compression ratios ignition is reliable while the last series of tests was only made at 80% load, the results shown in plate 7 were achieved at maximum power. In both processes the excess air ratio was below 1.0. Consequently, apart from the results at very low compression ratios, the consumption curves also coincide. In the latter case power fell sharply, as the rich mixture no longer ignites, and consequently the optimum power could only be reached at a greater excess air ratio. At high compression ratios it was possible to achieve a power which, surprisingly enough, was greater than that when operating on spark ignition. It is possible that with rich mixtures the complete development of the ignition jet is not so important as at very weak mixtures. Therefore it is possible to obtain good power even though the jet is impeded by the piston. At the high compression ratios the knock limit was the decisive factor in setting the ignition advance. Therefore the higher power in the R process is to be interpretted as a lesser inclination to knocking.

4. Behaviour at various powers: The R process is controlled by changing the fuel flow without throttling. The apportionment of the R fuel according to time and volume must be adapted to the various conditions. It is desirable to keep the volume of R fuel as low as possible, so that with a slightly larger, fixed volume, ignition will occur under any conditions. The injection angle must also be small, since different engine conditions will have a greater effect, the earlier injection occurs. It is fairly difficult to fix the most suitable volume of R fuel, as the golume which gives the most favourable total consumption of the engine is not identical with the volume at which there is no fall in power. Special tests are being made to clear up this question.

The series of tests described here concerned the evaluation of the various R fuels. It appears that power and consumption are independent of the type of R fuel (plate 8). At small loads there is no noticeable effect of calorific value. In regard to the required volume there was a difference only at small loads, and R 300 had showed best behaviour, for the required volume hardly rose at all. As the load decreases the injection advance angle increases somewhat. A slightly smaller angle is required with R 300.

The test was repeated on a cylinder, type Jumo 211 (plate 9). With this cylinder, the volume of R fuel required was actually less. At low loads it rose to about 20 mm^3/stroke. The injection advance angle is almost the same as with the DB 6001 cylinder.

These tests make it clear that a volume of 20 mm^3, injected 60° before top dead centre satisfies all the necessary conditions.

5. Remarks on starting: With R 110 the engine could only be started if the intake air was heated. The new R fuel permits starting without pre-heating. In order to inaugurate tests to find the lowest starting temperature, it was necessary to set up a test bed in the cold chamber. It is intended to carry out tests with the different aids, which will be necessary to make starting possible at low temperatures.

It can be stated to begin with that starting is carried out purely on the Diesel engine principle. It was not possible to establish that throttling brought about any improvement. The engine runs at first only on R fuel, the volume injected being 30-40 mm^3/stroke. The main fuel cannot be supplied until the cylinder wall temperatures have risen sufficiently. When starting a warm engine R fuel and main fuel are used together, since this considerably reduces the starting time. For starting at low temperatures, pre-heating is necessary. Glow plugs can only be used effectively in pre-combustion chambers and can only be considered where the engine has been equipped with such auxiliary chambers for other purposes, such as L'orange pressureless injection.

It appears to be more advantageous to pre-heat the whole of the intake air to at least + 20°C. The additional electrical power required is about 3 kw for a 30 litre engine, and there are no facilities for this on aircraft. But it appears possible to solve the problem by using as a starter a small internal combustion engine whose exhaust heat can be used to pre-heat the intake air.

Immediately after starting, pre-heating can be obtained from the exhaust heat of the main engine, since as stated previously it is necessary to control the air temperature for other reasons.

sgd. von Penzig.

Appended 2 tables
9 plates, 862-71.

TABLE I

	R 110	R 300
Specific Gravity @ 20°C	0,780	0,910
Boiling Point °C	200-300	180
Setting Point °C	-13	-45
Viscosity cst -30°C		5,94
20°C	2,84	1,5
50°C		0,93
99°C		0,56
Directional coefficient "m"		4,23
Calorific value k.cal/kg.	10050	6880
Air requirement kg/kg	14,2	9,33
Cetane number	150	190
Vapour pressure @ 60°C	0,10*)	
kg/cm² 80°C	0,25	0,022
" 95°C	0,41	0,043
Flash Point °C	63	78
Flame Point °C		80

TABLE II

Plate No.	Test No.	Engine	Composition of Fuel	Nozzle	1000 k.cal/h.	R - Fuel No.	mm³/stroke	Nozzle	Changed
3	8 7 41	DB 6001	CV2b+ET110+0.12pb.	1'orange 6 " 1'orange 4	95 95 108	R 110 R 300 Gaso.	20 20 20	Bosch 0.4 " -	Air temperature between 25 and 100°C
4	13	DB 6001	CV2b+ET110+0.12pb	1'orange 6 "	95 95	R 110 R 300	20 20	Bosch 0.4 "	Temperature of air and coolant between 20 and 100°C
5	20 19 34	DB 6001	ET110+0.12pb	1'orange 6 " 1'orange 4	91 91 111	R 110 R 300 Gaso.	20 20 -	Bosch 0.4 " -	Compression ratio between 1:5.5 and 1:11
7	35 36	DB 6001	ET110+0.12pb	1'orange 4 1'orange 6	- -	Otto R 300	- Measured	- Bosch 0.4	Compression ratio between 1:5.5 and 1:11 max.power.
8	4	DB 6001	CV2b+ET.110 + 0.12 pb.	1'orange 6 "	- -	R 110 R 300	Measured "	Bosch 0.4 "	Air excess between 0.8 and 2.3
9	72 82	Jumo 211	C_2	Bosch Z 45°	- -	R 110 R 300	Mesurod "	Bosch 0.4 "	Air excess between 0.7 and 2.2

Bosch pintle 45° = 2313/4
Bosch 0.4 = closed nozzle with 0.4 hole = 3311
1'orange 6 = open 6-hole nozzle = 2029/7
1'orange 4 = open 4-hole nozzle = 2029/B

Unless otherwise indicated, temperature of coolant and intake air = 80°C, compression stage 1:8. R Fuel nozzle always beside fuel nozzle.