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Nitro-paraffins as fuels.

Synopsis. When engines are operated at high altitudes or under water, then in addition to the fuel the oxygen necessary for combustion has also to be supplied. For this purpose free oxygen or suitable compounds thereof such as N_2O or H_2O_2 can be used. It is shown that the nitro-paraffins, which formerly were produced in small quantities only, have a high efficiency. This is demonstrated by comparing the heats of mixing, the weight and volume charges, the combustion temperatures and other factors. The anti-knock value of the nitro-paraffins is equivalent to about 70 O.No; thus they cannot be considered for high power gasoline engines unless suitable anti-knock additives are found. Lead tetraethyl and iron carbonyl are not effective.

The cetane number is about 15; thus they cannot be used in Diesel engines with jet injection. Their property to ignite on surfaces of 500° - 600° renders them suitable for use in ante-chamber machines. The tests showed a considerable improvement in performance and consumption as compared to hydrocarbons.

Nitro-paraffins are suitable as altitude fuels for TL power units. The ready inflammability mentioned can be utilised for igniting the TL power units, using nitro-paraffins as starting material.

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The suggestion to investigate the nitro-paraffins more thoroughly came from Dr. Roth. The nitro-derivatives of hydrocarbons were placed at our disposal by Dr.v.Schickh (Z.K. - Laboratory Z). Dr. Dimroth, D.Chem.Grünwald, Dipl.Ing.Köhler, Dipl.Ing.Witschakowski and D.Chem.Worliczek also assisted in carrying out the experiments.

Nitro-paraffins as fuels:

A) Introduction.

The output of a combustion engine depends on the supply of oxygen and thus for aero-engines depends on the efficiency of the blower. It seems desirable to supply at least temporarily more oxygen to the engine than under normal conditions; thus it would be possible either to aim at a higher performance or to reach greater altitudes.

It is thus necessary to carry oxygen either as such or in the form of a chemical compound e.g. N_2O. The air sucked in by the blower is then enriched with oxygen or oxygen carriers. At this point the fundamental principle has to be observed that in an operation with increased oxygen content the combustion temperatures increase and thus the maximum output of the engine that is obtainable is limited in so far as waste gases are not admixed. N_2O on the other hand brings along a nitrogen ballast and contains 36 per cent oxygen by weight.

Whilst oxygen, N_2O and H_2O_2 contribute oxygen exclusively to normal fuels, certain fuels exist which themselves contain part of the oxygen required for the combustion. Such fuels are the nitro-paraffins and nitro aromatic compounds. As in these fuels a whole molecule of oxygen is present, the contribution to the total amount of oxygen required is considerable and moreover the smaller the molecule the greater is the contribution. In the maximum case, i.e. for nitromethane, half of the oxygen required for the combustion of the carbon and hydrogen is present in the molecule (numerical table 1).

Numerical Table 1.

		Density Kg/lt.	B. pt. °C	Inherent O_2 %
Nitromethane	CH_3NO_2	1,15	102	57
Nitroethane	$C_2H_5NO_2$	1,06	114	31
Nitropropane	$C_3H_7NO_2$	1,02	118...131	21
Nitrobutane	$C_4H_9NO_2$	0,97	138...159	16
Nitrobenzene	$C_6H_5NO_2$	1,20	211	14

The nitro-paraffins which here interest us most, are liquids which boil at 100° to 130° C and which have a specific gravity of about 1. They are liquids even at very low temperatures with the remarkable exception of the first member of the series, viz nitromethane which solidifies at -29°C.

The smaller the molecule the worse is the solubility in the hydrocarbons, so that nitromethane and nitroethane can be mixed with ethers but not with benzene derivatives. Nitropropane and -butane are miscible with gasoline but not with the higher boiling Diesel oil.

Nitro-paraffins at room temperature take up 0.5 water. They behave like weak acids. The pH values of the saturated aqueous solution are given in the following table.

Table 2

Tetranitromethane	pH - 2,5
Nitromethane	- 3,5
Nitroethane	- 4,6
1 Nitropropane	- 4,8
2 Nitropropane	- 4,7
Nitrobutane	- 4,8

From this table it can be seen that the smaller the molecule the lower the pH values. For the sake of comparison a solution of tetra-nitromethane was made and this showed the lowest pH value. It was expected and was confirmed by experiment that metals are attacked. V2A, nickel-plated brass, aluminium, copper and iron, were found to behave best; Elektron showed up much less favourably. It appears that the water content of the material is of considerable importance so that an improvement is to be expected as a result of drying.

On testing rubber and plastic materials in gasoline, certain variations in behaviour were observed as regards swelling capacity and solubility in gasoline. Synthetic rubber types of satisfactory behaviour were found to exist. Of the plastic materials useful ones are Igamide, Oppanol, cellulose and fibre. Storing lacquers, e.g. Luphen H are stable; further suitable lacquers are those based on Igamide and Oppanol.

A separate report is made on the corrosion tests.

Nitro-paraffins - chiefly nitroethane - are at present prepared by the kilo in the Ludwigshafen works only in a small-scale plant of the Z.K. Laboratory Z (Dr.v.Schickh). A semi-scale apparatus will be set up within the scope of the PSV programme. As starting materials gaseous paraffins and dilute nitric acid, as obtained by absorption of nitrous gases in water, are used.

B) The efficiency of oxygen carriers and nitro-fuels.

For the efficiency of the engine the calorific value of the mixture is decisive, i.e. the energy which is contained in unit volume of the mixture of, say, stoichiometric proportions. If we now compare the following fuels amongst themselves we find: (x)

(x) see also the big numerical table at the end of the report.

Numerical Table 3

(Neglecting volume of the fuels)

	Calorific value kcal/kg	Air/Fuel ratio kg/kg	Calorific value of the mixture kcal/m^3
Heptane	10530	15,2	822
Methanol	4650	6,5	860
Heptane + 3 N_2O	4800	5,6	944
Heptane + 2 N_2O	5810	7,3	900
Heptane + 1 O_2	7980	10,5	886
Nitropropane	4960	5,2	1012

The calorific value of the mixture for heptane, which here represents gasoline, can be raised by about 15% if N_2O is admixed with the air in a proportion of about 1.5 times the weight of the fuel, i.e. 3 Mol N_2O/Mol fuel (x)

At the same time the amount of heat liberated in the form of heat of decomposition amounts to 20,000 kcal/kg-Mol.N_2O. The oxygen of the N_2O is liberated only on decomposition, which takes place during combustion. N_2O then behaves as a mixture of nitrogen and oxygen that contains 36% oxygen.

As a result of the small air/fuel ratio methanol has - in spite of poor miscibility - a very good calorific value for the mixture. The highest calorific values for mixtures are obtained with nitropropane. They are 23% over that of heptane and are larger even than the values obtained with heptane when N_2O is used.

The calorific values for mixtures are calculated in table 3. The assumption is made that in comparison with the air the fuels have a negligible volume, which is the case in practice if they are present in the liquid state.

The increase in volume, and thus the increase in the number of molecules as a result of the combustion is represented in Table 4, the volume of the fuel again being neglected.

Table 4

(Neglecting volume of fuel)

	A Calorific value of the mixture kcal/cu.m.	B Volume increase %
Heptane	822	7,6
Methanol	860	21,0
Heptane + 3 N_2O	944	10,3
Heptane + 2 N_2O	900	9,9
Heptane + 1 O_2	886	8,0
Nitropropane	1012	18,2

(x) In the report GK.019, current No.1217/43 of the BMW, 330 kg/h is given as the fuel consumption with GM-1 added at the rate of 150 gm/sec with the enrichment equipment switched on; the fuel consumption with the additional injection of C 3 into the suction pipe is geven as 410 kg/h, i.e. an average of 100 gm/sec.

The volume increase is greatest for methanol, but even in the case of nitropropane it is considerably greater than that for heptane and heptane + N_2O.

In Tables 3 and 4 it is assumed that the fuel reaches the closed combustion space without vaporising. Hence on the one hand it does not occupy any volume, and on the other hand the influence of the heat of vaporisation upon the density is not appreciable. In practice however this applies only to Diesel engines, to gasoline engines with injection after closing the inlet valve, and to combustion chambers of the TL power unit.

In the usual gasoline engine, part of the fuel always evaporates so that the initial volume increases and therefore the calorific value for the mixture decreases.

Table 5

Volume of the fuel evaluated as vapour.

	A Calorific value of the mixture kcal/cu.m.	B Volume increase %
Heptane	807	5,6
Methanol	754	6,1
Heptane + 3 N_2O	925	8,4
Heptane + 2 N_2O	962	7,7
Heptane + 1 O_2	870	5,9
Nitropropane	960	11,9

In Table 5 the calorific values of the mixtures and the volume increase figures are calculated with the assumption that the fuel evaporates completely. We notice that all values and especially that of methanol, are considerably smaller than those in Table 4. The actual conditions which exist in gasoline engines are difficult to express mathematically, as the degree of vaporisation depends entirely on the amount of heat supplied by pre-warming either the air or the suction-pump. At the same time the temperatures of the mixtures which are influenced by the vaporisation, also play an important part.

In Table 6 the mixture temperatures are indicated, which occur under stoichiometric conditions if the heat required for vaporisation is taken from the air. As a result of the higher densities the data on the calorific value of the mixtures and the volume increases are considerably altered. For nitropropane the values could unfortunately not be given, because the data on the heat of vaporisation for this substance is not available. For heptane 86 kcals/kg, for N_2O 45 kcals/kg, were calculated.

Table 6

	Temp. of the mixture °C	A Calorific value of mixture Kcal/cu.m.	B Volume increase	Heat of vapor - isation kcal/kg	Air/Fuel Ratio kg/kg
Heptane	- 9	880	15	86	5,3
Methanol	-10	930	29	290	6,4
Heptane + $3N_2O$	-32	1135	30		
Heptane + $2N_2O$	-23	1110	25		
Heptane + 1 O_2	-17	1080	19		

The extra output actually obtained with N_2O is considerably higher. The above figures are valid only for constant pressures (735 mm Hg). In actual fact the boost pressure increases with the density, which for N_2O increases as a result of cooling; this phenomenon is emphasized by the fact that in practical application the fuel required for enrichment is injected before the blower; thus as a result of cooling the density in the blower is increased. If in accordance with figures in Table 6 about 50% extra output is expected, then in practice 70% is obtained, as the boost pressure increases by about 20%.

The values were calculated assuming that the temperature does not effect the specific heat of the air and taking the latter as 0.235. The initial temperature was fixed at 15°C. The vapour pressures of heptane and N_2O are so great that complete evaporation can take place. For methanol only 14% of the fuel is volatile; then a temperature of -10°C is reached and as a result of decrease in vapour pressure further evaporation cannot take place.

Investigations to date have shown how the energy content of mixtures of equal volumes and pressures varies. A further means of comparison can be effected by means of the energy changes which take place in a given mass of air. These values, denoted as calorific values in air are compiled in Table 7.

Table 7

	Air/Fuel Ratio kg/kg.	Calorific value kcal/kg	Calorific values in air			
			kcal/mol air	kcal/cu.m.	Kcal/kg air	
Heptane	15,2	10530	20150	822	694	100
Methanol	6,5	4650	20800	860	725	105
Heptane + $3N_2O$	5,6	4800	24000	1006	850	123
Heptane + $2N_2O$	7,3	6340	22950	940	792	115
Heptane + 1 O_2	10,4	7980	22100	906	764	110
Nitropropane	5,8	4960	24740	1012	854	123

It is remarkable that using N_2O and nitropropane about 1¼ times as much heat can be derived from the same quantity of air, than with heptane. A smaller energy change takes place if oxygen is used although the quantity of oxygen is the same as that present in N_2O; this is due to the heat of decomposition, i.e. the amount of heat liberated in the decomposition of N_2O. This amounts to 20.000 kcal/kg.mol. Nitropropane reaches higher calorific values in air than heptane + $3N_2O$. It must be equivalent therefore to an addition of 150 gm/sec GM-1.

A further survey can be obtained finally by comparing the weights and volumes, which have to be expanded to produce 1000 kcals.

Table 8

	Calorific value kcal/kg.	Expenditure g/1000 kcal	Calorific value kcal/lit.	Expenditure cum.m.1000 kcal	Densities
Heptane	10530	95	7690	130	0,69
Methanol	4650	215	3675	272	0,79
Heptane + $3N_2O$	4800	208	4400	227	0,92
Heptane + $2N_2O$	6340	158	5480	183	0,87
Heptane + 1 O_2	7980	125	6080	165	0,76
Nitropropane	4960	202	5010	200	1,02

The most unfavourable results are obtained with methanol. Nitropropane lies between heptane + 2 and + $3N_2O$. Naturally the weight of the container is neglected here. For the usual fuels this amounts to about 10 to 15 kg/100 litres, for N_2O about 15 to 25 kg/100 litres and for liquid oxygen it was estimated to be from 15 to 25 kg/100 litres.

As these figures are only approximately valid and as one would have to find a suitable protection for the container, e.g. in the case of nitropropane; and as further, using N_2O, not only the container but the complete distribution equipment would have to be included in the calculation, one should dispense with the idea of making these comparisons by considering these weights. However one can estimate that the equipment for nitropropane is roughly the same weight as that with N_2O.

The combustion temperatures as a general rule increase with mixture or air calorific values.

Table 9

	Calorific value in air kcal/kg air	Combustion Temperature. °C
Heptane	694	2400
Methanol	725	2330
Heptane + $3N_2O$	850	2610
Heptane + $2N_2O$	792	2540
Heptane + 1 O_2	764	2530
Nitropropane	854	2600

The values contained in Tables 1 to 9 are collected with further data in Table 15. Some characteristic data are illustrated on plates 1 to 3 and here nitro-paraffins are compared with the normal paraffins. Values for heptane used with N_2O are also given. Finally single values for nitro-benzene, heptane + 1 O_2 and methanol are given.

Especially informative is the dependence of the combustion temperature on the calorific value in air as shown on plate 3.

C.) Ignition behaviour of the nitro-paraffins on hot surfaces.

When engines are operated with methanol, pre-ignition takes place at very much lower temperatures of the glowing surfaces than when gasoline is used. To explain this fact clouds of fuel were blown against an electrically heated wire spiral. Unfortunately no method was found to render the decomposition of methanol more difficult; it was found however that the decomposition of nitro-paraffins takes place at very much lower temperatures (cf.Kurzbericht No.385).

Clouds of gasoline are easily ignited by high tension sparks; however they ignite on hot surfaces only when the temperature of these is 700°. Nitro-paraffins on the other hand do not ignite very easily by sparking, as volatile fractions are absent; however they ignite on hot plates even when these are only dull red. This gives us an opportunity for inducing combustion without the application of high tension sparks.

This method will possibly find application in the TL power unit, where ignition of a cold mixture has to be effected at great heights at low pressures and is therefore difficult.

Electric sparks operate unreliably and are undesirable as special precautions have to be taken for the insulation of high tension units at high altitudes. With glow plugs this is not the case and with suitable developments these can be made reliable even for low current strengths. It is proposed to develop an auxiliary apparatus on those lines.

The temperatures required for the ignition of mixtures are summarised in the following Table:

Table 10

-	Ignition temperature Temperature of the coil °C	Krupp ignition value °C
Benzene	780	662
Heptane	730	245
R 300	720	178
Methanol	620	560
Nitrobenzene	600	538
Nitrobutane	580	398
Nitropropane	560	411
Nitroethane	480	449
Nitromethane	450	450

It is evident from this that the ignition temperature of methanol is more than 100° lower than that of the two hydrocarbons and of R 300. However, it is not very suitable for ignition on hot surfaces. As was shown in the "Ring" process methanol dissociates more easily than the hydrocarbons when it is injected into hot air, but it burns away relatively slowly. The combustion velocity of methanol is evidently smaller than the velocity of flow in the apparatus so that no flame results.

Nitrobenzene ignites still more readily than methanol. The ignition temperatures of the nitro-paraffins are considerably lower still; in some cases they are lower by more than 100°. They appear suitable for the purpose of starting the TL power units.

For the given values from the Krupp-ignition-tester, the velocity of the combustion is not so important as in the tests with the rapidly moving mixture clouds; the evaluation therefore is in some ways a very different one.

D) Behaviour of the nitro-paraffins in the engine.

The knock-rating determination of the nitro-paraffins gave some difficulty as the carburettor of the usual test engine was unsuitable for substances of such low calorific values. An I.G. test-engine was therefore modified so that it was suitable for injection. The values which the engine supplied with this equipment differ very little from the usual octane numbers; in the present case where it was mainly a question of comparison, this has no significance.

As nitromethane and nitroethane are immiscible with hydrocarbons, tests were carried out with nitropropane. The technical, fairly pure product, was called S_3. It represents the mixture of the two homologues of nitro-propane. It had an octane number of about 72. The following surprising phenomenon was observed which up to the present was not known: when S_3 was mixed with gasolines like I.G.9 and VT.702, it gave values for the mixture which were lower than those of the components (Plate 4). The lowest values were obtained at about 30% S.With ET.110 and with benzene this phenomenon was not observed. A uniform decrease of the octane number with growing S_3 addition occurred in this case. Nitrobenzene could be estimated only in a mixture, as violent pre-ignitions took place using this substance alone. It was noted that the antiknock value of VT.702 deteriorates when nitrobenzene up to about 50% is added; after this however it improves noticeably. Several rough tests with nitroethane and nitrobutane showed that these substances behaved similarly to nitropropane.

Knock tests gave the following individual octane numbers:

Table 11

	without Pb.	+ 0,12 Pb.
Nitromethane	-	73,3
Nitroethane	-	59,5
1-Nitropropane	71,5	70,0
2-Nitropropane	67,5	66,0
1-Nitrobutane	70,5	66,0
2-Nitrobutane	70,5	68,0

It appears that the octane numbers lie round about 70, and that lead addition deteriorates rather than improves these. This is not surprising as the course of the reactions for these substances is very different from that of the hydrocarbons.

One can assume that substances can be found here also which exert a similar influence upon the nitro-paraffins as lead tetraethyl does on the hydrocarbons. The following rough tests show that lead has no effect even when a mixture of S_3 with the lead sensitive ET.110 is employed.

Table 12

	Motor octane No.
S_3 + ET 110 (50:50)	75
" " + 0,12% Pb $(C_2H_5)_4$	71,3
" " + 0,40% Fe $(CO)_5$	69,5
" " + 6% Methyl aniline	72,0

It is hoped that by means of further experiments it will be possible to render nitro-paraffins suitable for use in gasoline engines as high altitude or maximum output fuels.

One determination of the cetane number gave:

Table 13

Nitromethane	C. No	10
Nitroethane	"	15
1-Nitropropane	"	14
2-Nitropropane	"	16
1-Nitrobutane	"	15
2-Nitrobutane	"	14

Nitro-paraffins in general have bad cetane numbers, which lie at about 15. On Plate 5 is illustrated the behaviour of S_2 and S_3 when mixed with different hydrocarbons and R 300. Corresponding to the remarkable behaviour of the octane number for mixtures (cf. Plate 4), no pronounced increase in the ignition tendency was noted for mixtures as compared to components in connection with the cetane number.

Mixtures with Diesel oils of higher cetane No. cannot be made up because nitro-paraffins are immiscible with paraffinic oils of high molecular weight, as has been mentioned previously. It is remarkable that S_2 and S_3, which behave very similarly, do increase the ignition tendency of R 300 not inconsiderably. The blending values of R 300, that is the apparent ignitability of R 300 in these mixtures, assuming S_2 and S_3 unaltered with a cetane No. of 15, is also shown.

It has been found for hydrocarbons that the greater the cetane No. the smaller the beneficial effect of additives; on the other hand for nitro-paraffins it was observed that the inflammable R 300 is considerably improved. Apparently this is a characteristic of the nitro-fuels; as the results on Plate 5 show, the more ignitable a substance is, the more favourably the addition of tetra-nitro-methane influences the cetane number.

E) Diesel engine test with nitro-propane.

As sufficient material was not available to carry out the test in a larger engine with unmixed S_3, a mixture with a hydrocarbon had to be examined.

Nitropropane unfortunately is immiscible with the high boiling hydrocarbons which are generally used as Diesel fuels so that the experiments on the Diesel engine had to be carried out with a mixture of gasoline I.G.9 in the ratio 50:50. Plate 6 shows that with this mixture an extra output of more than 20% was achieved, although from the calorific values in air an increase of only 10% was expected.

This is obviously accounted for by a more favourable course of the combustion, brought about by such good mixing of oxygen and fuel as cannot be obtained even with very good atomisation. On Plate 7 the effective pressures obtained are plotted against the consumption in cm^3/HP against fuel consumption in gm/HP and finally in kcal/HP.

This indicates that up to the maximum output of the hydrocarbon fuel the nitropropane-gasoline mixture has a consumption which is 20% higher by weight, but is somewhat lower volumetrically. If the combustion is more favourable then the amount of heat used is less.

The unfavourable cetane No. of the nitro-paraffins shows that under the conditions under which the cetane No. is obtained, namely direct injection, the nitro-paraffins are not suitable for use in Diesel engines. The experience gained on the ready inflammability of the nitro-paraffins on hot surfaces suggested experiments to be carried out on a Diesel engine with an ante-chamber.

On account of the limited quantity that was available, at first only rough tests could be made. They show clearly however that S_3 did not behave like a hydrocarbon which has a cetane No. of 15 to 22 but behaves even more favourably than a gas oil of cetane No.45.

The diagram shows that the ignition lag of S_3 is about the same as that of the Diesel oil with a cetane No.45, but that the increase in pressure is more rapid. As a result of the oxygen present in the fuel the combustion takes place very much more rapidly, This was effected with 5% less heat consumption. The engine ran as smoothly with S_3 as with Diesel fuel of cetane No.45. The engine knocked slightly with cetane No.22 and strongly with cetane No.15, which at direct injection is equivalent to S_3 with respect to the ignition lag.

F) Closed circuit operation with Nitro-fuels.

By closed circuit operation one understands a procedure where oxygen and fuel only are led into the engine which is completely cut off from the atmosphere and the waste gases resulting from the combustion are led back to the engine again after cooling to be used in the process. For this process which is important for submarine use of Diesel engines, N_2O and oxygen in liquid form cannot be employed on account of the long storage time. The comparison of the consumption for 1000 kcal, as illustrated in fig.14, is carried out with compressed oxygen.

Table 14.

Fuel	Fuel gm.	Oxygen gm.	Bottle gm.	Total gm.	
Heptane	95,0	335	4200	4630	100
N-Butane	181	295	3700	4176	90
N-Propane	202	272	3400	3874	84
N-Ethane	254	244	3100	3598	78
N-Methane	397	156	2100	2653	57
N-Benzene	172	261	3300	3733	87

For storing oxygen a container of 1 cu.metre capacity was employed, which for an operational pressure of 400 atmospheres and with a safety factor of 2 is estimated to weigh 6½ tons. From the values given it can be seen that for nitropropane 16% of the weight can be saved. It has been shown in a Diesel engine test that, in comparison with Diesel fuel, a certain saving can be effected in the consumption.

Using nitro-paraffins in submarines would mean saving oxygen and increasing the range. They can however be applied only to a limited extent in practice, because the nitrogen evolved gives rise to a trail of bubbles.

	Formula	Mol. Wgt.	F.Pt.& B.pt. °C	Densities g/cm.3	Air required kg/kg	Mol. air per Mol Fuel	Mol. waste gas per Mol Fuel	Volume Increase with	without
								consideration of the vol. of fuel %	%
Methane	CH_4	16	-184-161	0,655	17,20	9,50	9,50	10,53	0,00
Ethane	C_2H_6	30	-172- 93	0,122	16,10	16,70	18,20	9,00	2,80
Propane	C_3H_8	44	-190- 45	0,535	15,66	23,80	25,80	8,40	4,00
Butane	C_4H_{10}	58	-135+ 1	0,600	15,45	29,80	32,50	7,90	4,70
Methanol	CH_2OH	32	- 98 65	0,790	6,46	7,15	8,65	21,00	6,13
Heptane	C_7H_{16}	100	- 97+ 98	0,688	15,18	52,40	56,40	7,64	5,62
$+\frac{1}{2}N_2O$	$C_7H_{16}+\frac{1}{2}N_2O$	122	-	0,747	12,15	51,20	55,90	8,20	6,08
$+ 1\ N_2O$	$C_7H_{16}+N_2O$	144	-	0,794	10,05	50,00	55,50	8,80	6,70
$+ 2\ N_2O$	$C_7H_{16}+2N_2O$	188	-	0,865	7,34	47,70	54,60	9,90	7,70
$+ 3\ N_2O$	$C_7H_{16}+3N_2O$	232	-	0,918	5,64	45,25	53,80	10,30	8,44
$+ \frac{1}{2}\ O_2$	$C_7H_{16}+\frac{1}{2}O_2$	116	-	0,728	12,48	50,00	54,50	7,93	5,83
$+ 1\ O_2$	$C_7H_{16}+ 1\ O_2$	132	-	0,762	10,44	47,60	52,60	8,00	5,84
Propane	C_3H_8	44	-190- 45	0,560	15,66	23,80	25,82	8,40	4,00
Propanol	C_3H_7OH	60	-127	0,804	10,33	21,40	23,95	11,90	6,90
N Propane	$C_3H_7NO_2$	$89\frac{1}{2}$	←60 132 120	1,006 0,989	5,17	17,85	21,10	18,20	11,90
$P + 1\ N_2O$	$C_3H_8+NO_2$	88	-	0,767	7,06	21,45	24,95	11,14	6,39
$P + 2\ N_2O$	$C_3H_8+2N_2O$	132	-	0,876	4,18	21,05	24,08	14,25	9,05
$P + 4\ N_2O$	$C_3H_8+4N_2O$	220	-	0,988	1,88	18,30	22,30	21,85	15,50
N-Methane	CH_3NO_2	61	→29 102	-1.130	1.64	3,57	5,82	63,00	27,40
N-Ethane	$C_2H_5NO_2$	75	←60 114	1.050	4,13	10,70	13,50	26,00	15,00
N-Propane	$C_3H_7NO_2$	$89\frac{1}{2}$	←60 132 120	1,006 0,989	5.80	17,85	21,10	18,20	11,90
N-Butane	$C_4H_8NO_2$	$103\frac{1}{2}$	←60 158 138	0,965 0,968	7,01	25,00	28,80	15,20	10,80
N-Benzene	$C_6H_5NO_2$	123	9 221	1,200	7,00	29,75	32,50	9,25	5,70

	Calorific Value Hu			Expenditure		Calorific Value of mixture		Calorific values in air			Combustion Temp °C
	kcal/gm mol.	kcal/kg	kcal/l	gm/10^3 kcal	cm^3/10^3 kcal	with consideration of volume of fuel kcal/cu.m.	without	kcal/Mol & Air	kcal/cu.m. Air	kcal/kg Air	
Methane	187,4	11 700	7660	85,4	130,6	808	730	19.700	808	680	2250
Ethane	337,6	11.200	13750	89,3	72,7	827	780	20.200	827	696	2380
Propane	485,8	11.000	5900	91,0	170,0	835	802	20 400	835	702	2410
Butane	632,1	10.900	6540	91,7	153,0	840	814	21 200	868	731	2425
Methanol	148,8	4 650	3675	215,0	272,0	860	754	20.800	860	725	2330
Heptane	105,3	10 530	7690	95,0	130,0	822	807	20 150	822	694	2400
+ $\frac{1}{2}N_2O$	106,3	8 710	6500	115,0	154,0	841	827	20.750	850	717	2430
+ 1 N_2O	107,3	7 450	5940	134,0	168,0	861	845	21 450	879	742	2460
+ 2 N_2O	109,3	5 810	5110	172,0	195,6	900	882	22 950	940	792	2540
+ 3 N_2O	111,3	4 800	4400	208,4	227,0	944	925	24 000	1006	850	2610
+ $\frac{1}{2}$ O_2	105,3	7 280	5590	137,0	176,0	854	836	21 050	862	728	2460
+ 1 O_2	105,3	7 980	6080	125,3	165,0	886	870	22 100	906	764	2530
Propane	485,8	11 040	5900	91,0	170,0	835	802	20 400	835	704	2410
Propanol	437,0	7 280	5860	137,0	171,0	835	798	20.400	835	704	2350
N Propane	441,6	4 960	5010	202,0	200,0	1012	960	24.700	1012	854	2600
P + 1 N_2O	508,8	5 740	4410	174,0	227,0	923	884	23 600	965	814	2560
P + 2 N_2O	526,0	3.980	3490	251,0	287,0	1020	977	27 600	1130	9530	2730
P + 4 N_2O	566,0	2.570	2540	389,0	394,0	1265	1200	39.600	1620	1370	3090
N-Methane	154,0	2,520	2900	397,0	345,0	1765	1380	43.100	1765	1490	3070
N-Ethane	295,0	3.940	4190	254,0	239,0	1130	1030	27.600	1130	952	2690
N-Propane	441,6	4.960	5010	202,0	200.0	1012	960	24,700	1012	854	2600
N-Butane	589,6	5.700	5520	175,5	181,0	966	928	23.500	966	815	2580
N-Benzene	715,0	5.810	6970	172,0	144,0	983	952	24 000	984	830	2740

Plate 1.

Properties of Nitro-fuels.

Plate 2.

Properties of Nitro-fuels.

Plate 3.

Combustion temperature, plotted against calorific value in air kcal/cu.m.

Plate 4.

Knock-ratings of mixtures of S_3 and Nitro-Benzene.

Plate 5.

Improvement of oils by means of O_2 Carriers.

Plate 6.

Nitro propane as Diesel fuel
(Jet injection in the I.G. Diesel test engine)

Plate 7.

Diesel engine test.
(Jet injection in the I.G. Diesel test engine)