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PROPELLANT COMPOSITIONS

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This invention relates to novel propellant compositions. More particularly, this invention relates to propellant compositions having reduced ignition delay characteristics.

Initial fuel ignition in rocket motors and jet engines, when hypergolic propellants are employed, is brought about upon contact of an oxidizer and a fuel. When non-hypergolic propellants are employed, smooth ignition is accomplished in many combustion devices by the initial use of hypergolic or pyrophoric mixtures. One method of initiating combustion is by injecting the hypergol into the combustion chamber where it is to react with either of the main propellants. Of necessity, this hypergolic reaction must be very rapid so that reliable and safe ignition may be accomplished before an explosive mixture of the main propellants has filled the combustion chamber.

It is, therefore, an object of this invention to provide novel fuel compositions. Another object of this invention is to provide fuel compositions which have a lower ignition delay characteristic upon contact with an oxidizer. It is also an object of this invention to provide propellants which are spontaneously combustible. Another object is to provide fuels and propellants which ignite smoothly in the combustion chamber, minimizing danger of explosion. It is also an object to provide fuels for rocket, jet, and ramjet engines having improved ignition characteristics. Still other objects of the invention will be apparent from the discussion which follows.

The above and other objects of this invention are accomplished by providing a composition of matter comprising compounds having the general formula R_xM, wherein R is selected from the group consisting of hydrogen, halogen atoms, and hydrocarbon groups having from 1 to about 12 carbon atoms and wherein at least one R is a hydrocarbon group; m is a metal selected from the class consisting of groups I–A, II–A, II–B, III–A, IV–B, IV–A, and V–A of the periodic table of elements; and x is the valence of M, and wherein said composition contains at least two different metals in the form of said compounds, and wherein the amount of each of said compounds varies from about 0.1 weight percent to about 99.9 weight percent, based on the total weight of said composition. An example of the above composition is triethylboron containing 5 weight percent triethylaluminum. Such a fuel composition, when contacted with liquid oxygen in a combustion chamber, ignites within about 1 millisecond after contact and burns smoothly thereafter.

The hydrocarbon groups which make up a part of the metal-containing compounds of this invention can be alkyl, aryl, arylkyl, and alkaryl groups and can be either straight chain, branch chain, or cyclic.

The halogen atoms included in the compounds employed in the compositions of this invention are chlorine, bromine, fluorine, and iodine.

Non-limiting examples of organic-alkali metal compounds that are used in the compositions of this invention include methyllithium, ethyllithium, propyllithium, butyllithium, isobutyllithium, n-amyllithium, cyclohexyllithium, dodecyllithium, phenyllithium, alpha-napthyllithium, methylsodium, ethylsodium, propylsodium, butylsodium, cyclohexylsodium, octylsodium, dodecylsodium, phenylsodium, naphthylsodium, triphenylmethylsodium, methylpotassium, ethylpotassium, amylpotassium, dodecylpotassium, phenylpotassium, naphthylpotassium, ethyl rubidium, butylrubidium, phenylrubidium, dodecylrubidium, diphenylmethylrubidium, ethylcesium, butylcesium, octylcesium, dodecylcesium, phenylcesium, naphthylcesium, etc.

Non-limiting examples of group II–A metal-organic compounds include dimethylberyllium, dibutylberyllium, didodecylberyllium, dinaphthylberyllium, methylberyliumhydride, phenylberylliumhydride, methylberylliumchloride, ethylberylliumbromide, etc.

Non-limiting examples of group II–B metal-organic compounds include dimethylzinc, diisobutylzinc, ethyl-n-propylzinc, didodecylzinc, methylphenylzinc, ethylnaphthylzinc, methylzinchydride, ethylzincchloride, propylzincbromide, dimethylcadmium, diethylcadmium, octylbutylcadmium, didodecylcadmium, diphenylcadmium, naphthylmethylcadmium, ethylcadmiumhydride, phenylcadmiumhydride, methylcadmiumfluoride, naphthylcadmiumiodide, etc.

Non-limiting examples of group III–A metal-organic compounds include dimethylethylborine, triethylborine, tri-n-propylborine, tri-i-butylborine, tri-n-butylborine, tri-t-butylborine, tri-i-amylborine, trioctylborine, tridodecylborine, diphenylmethylborine, naphthyldiethylborine, tri-alpha-naphthylborine, phenylborinedichloride, dimethylborinebromide, dimethylborineiodide, methylborinedifluoride, dimethylborinefluoride, naphthylborinedioidide, dimethyldiborane, tetramethyldiborane, triethyldiborane, didodecyldiborane, trimethylaluminum, triethylaluminum, tri-n-propylaluminum, tributylaluminum, methyldiethylaluminum, ethyldibutylaluminum, trioctylaluminum, tridodecylaluminum, triphenylaluminum, trinaphthylaluminum, dimethylaluminumhydride, ethylmethylaluminumhydride, dioctylaluminumhydride, octaylaluminumdihydride, naphthylaluminumdihydride, dimethylaluminiumfluoride, methylaluminumdichloride, diethylaluminumiodide, cyclohexylaluminumdiiodide, diphenylaluminumbromide, trimethylgallium, methyldiethylgallium, diethylbutylgallium, trioctylgallium, triododecylgallium, trinaphthylgallium, dimethylgalliumhydride, ethylgalliumdihydride, dodecylgalliumdihydride, dimethylgalliumchloride, diethylgalliumchloride, dibutylgalliumbromide, dodecylgalliumdiiodide, trimethylindium, tributylindium, diethyldodecylindium, dimethylindiumhydride, dodecylindiumdihydride, dimethylindiumchloride, octylindiumdifluoride, naphthylindiumdibromide, trimethylthallium, triethylthallium, methyldidodecylthallium, naphthyldibutylthallium, dimethylthalliumhydride, naphthlythalliumdihydride, dimethylthalliumchloride, octylthalliumdibromide, etc.

Non-limiting examples of group IV–A metal-organic compounds include tetramethylgermanium, dimethyldiethylgermanium, diphenyldiethylgermanium, tetradodecylgermanium, naphthyltriethylgermanium, ethylgermaniumtrihydride, dipropylgermaniumdihydride, tridodecylgermaniumdihydride, dioctylgermaniumdifluoride, triododecylgumaniumiodide, diphenylgenanium difluoride, etc.

A non-limiting example of a group IV–B metal-organic compound is diphenyl-bis-cycylphenyldieniyltitanium.

Non-limiting examples of group V–A metal-organic compounds include trimethylarsine, methyldiethylarsine, tributylarsine, cyclohexyldiethylarsine, trioctylarsine, tridodecylarsine, naphthyldiethylarsine, tetraethyldiarsine, tetraethyldiarsyl, dimethylarsenichydride, ethylarsenicdihydride, diphenylarsenichydride, dimethylarsenicchloride, diethylarsenicfluoride, phenylarsenicdibromide, trimethylstibine, methyldiethylstibine, tributylstibine, cyclohexylstibine, trioctylstibine, tridodecylstibine, naphthyldiethylstibine, dimethylantimonyhydride, ethylantimonydihydride, diphenylantimonyhydride, dimethylantimonychloride, diethylantimonyfluoride, phenylantimonydibromide, trimethylbismuth, triethylbismuth, tridodecylbismuth, triphenylbismuth, trinaphthylbismuth, dimethylbismuthhydride, ethylbismuthdihydride, didodecylbismuthhydride, dimethylbismuthhydride, ethylbismuthdihydride, diphenylbismuthhydride, dimethylbismuthchloride, diethylbismuthfluoride, phenylbismuthdibromide, etc.

It is found that when the compositions contain at least two different metals in the form of compounds having the general formula R_xM the ignition delay, defined as the time elapsing from the moment of contact of the fuel with an oxidizer to the moment of ignition, is lower than the calculated ignition delay, based on the concentration of the various components of the mixture and the known ignition delay period for the pure individual compounds. A great reduction in the ignition delay characteristic is found upon mixing boron-organic compounds with other metal-organic compounds of the class disclosed hereinabove. Fuel compositions containing boron-organic compounds, therefore, constitute a preferred embodiment of this invention. An additional advantage resulting from the use of fuels containing boron is that the boron oxide residue is less adherent to the surfaces of combustion and thrust chambers and can be readily removed because of its water solubility.

The ignition delay determinations were measured by noting the time between the contacting of the propellants, namely, the fuel and oxidizer, and the time of ignition in an unconfined combustion zone. One or the other of the propellants was given a substantial lead (in most cases, the first propellant was the oxidizer), and the second propellant was then admitted. The fuel passed a photocell very near the impingement point of the two propellants. The start of ignition was noted as an evolution of visible light, also registered on a photocell. These signals were recorded on an oscillograph which made measurements to ±1 millisecond. Ignition delays have also been determined in small motors in which the propellants are contacted. The ignition point is then also evidenced by a rise in chamber pressure. The measurements were made at an ambient pressure equivalent to substantially 715 mm. of mercury.

As stated hereinabove, the amount of each metal-organic compound in the composition can vary from about 0.1 to about 99.9 weight percent since such compositions exhibit ignition delay periods lower than that expected from a knowledge of the ignition delay periods of the individual components in the pure state and the weight percent of the components in the composition. It is found, for example, that the ignition delay period upon contacting liquid oxygen with triethylboron is substantially 111 milliseconds, and the ignition delay upon contacting liquid oxygen with triethylaluminum is 9 milliseconds.

The following table illustrates the ignition delay characteristics of a composition of boron-organic compounds and aluminum-organic compounds. The ignition delay of the system is determined as described above. Liquid oxygen is first admitted to the combustion zone, followed by the admission of the fuel which contacts the liquid oxygen.

TABLE I

Comp. No.	Triethylboron, Wt. Percent	Triethylaluminum, Wt. Percent	Ignition Delay, Milliseconds, Calculated	Ignition Delay, Milliseconds, of Mixture
1	100			111
2	99.9	0.1	111	100
3	99	1	110	5
4	97.2	2.8	108	~1
5	95	5	106	1
6	50	50	59	2
7	10	90	9	8
8	1	99	~9	~8
9	0.1	99.9	~9	<9
10		100		9

From the above table it is seen that a great reduction in the ignition delay characteristics of a fuel is obtained when two different metals in the form of metal-organic compounds are present, as compared with the sum of the ignition delay characteristics of the individual components multiplied by the weight percent of that component in the composition. The maximum reduction in ignition delay of the triethylboron-triethylaluminum system is observed with Composition No. 5 in Table I, namely, 95 weight percent triethylboron (TEB) and 5 weight percent triethylaluminum (TEA). The calculated ignition delay period is 106 milliseconds, whereas the observed ignition delay is only one millisecond. This is a reduction of 99.9% in the ignition delay.

The values given in Table I hold true for values of the ratios of oxidizer-to-fuel given in terms of multiples of the stoichiometric weight ratio value of from about 0.1 to about 30. The values in Table I represent an average obtained from about 50 determinations for the individual fuel formulations. The fuels exhibit a reduction in ignition delay when employed with nitrogen tetroxide and other oxidizers discussed below.

Other fuel compositions which exhibit an ignition delay period which is lower than that calculated from a knowledge of the weight percent composition and the ignition delay period for the pure components, when employed with liquid oxygen, nitrogen tetroxide, and the other oxidizers discussed in this writing, are given in Table II below.

TABLE II

Composition No.	Component	Weight Percent
1	Methyllithium	0.1
	Methylsodium	99.9
2	Butyllithium	0.5
	Ethylpotassium	99.5
3	Alpha-naphthyllithium	1
	Ethyl rubidium	99
4	Octylcesium	5
	Amylpotassium	95
5	Butylsodium	50
	Phenylrubidium	50
6	Ethylsodium	0.1
	Dibutylberyllium	99.9
7	Butylrubidium	99.9
	Methylberylliumchloride	0.1
8	Dodecylcesium	99
	Dinaphthylberyllium	1
9	Cyclohexylsodium	50
	Dimethylberyllium	50
10	Propyllithium	0.1
	Dimethylzinc	99.9
11	Ethylsodium	1
	Ethyl-n-propylzinc	99
12	Octylsodium	99
	Methylzinchydride	1
13	Phenylrubidium	95
	Methylcadmiumfluorid	5
14	Phenylpotassium	99.9
	Propylzincbromide	0.1
15	Isobutyllithium	0.1
	Dimethylethylborine	99.9
16	Ethylsodium	0.5
	Triethylborine	99.5
17	Octylsodium	1
	Trioctylborine	99
18	Amylpotassium	99
	Tri-alpha-naphthylborine	1
19	Ethylrubidium	99.9
	Tetramethylidiborane	0.1

TABLE II—Continued

Composition No.	Component	Weight Percent
20	Butylsodium	50
	Ethylpotassium	49.5
	Methylborinedifluoride	0.5
21	Naphthylpotassium	5
	Triethylborine	45
	Tri-alpha-naphthylborine	50
22	Ethylpotassium	90
	Butyllithium	5
	Diphenylmethylborine	5
	Dodecyllithium	20
	Octylsodium	30
	Triethylborine	50
24	Butylsodium	99.9
	Trimethylindium	0.1
25	Ethylpotassium	99
	Naphthylaluminumdihydride	1
26	Phenylpotassium	99
	Dimethylgalliumfluoride	1
27	Dodecylpotassium	50
	Trioctylaluminum	50
28	Phenyllithium	5
	Triethylaluminum	95
29	Triphenylmethylsodium	1
	Tributylaluminum	99
30	Phenylcesium	0.1
	Trioctylaluminum	99.9
31	Ethylpotassium	99.9
	Diphenylgermaniumdifluoride	0.1
32	Octylsodium	99
	Ethylgermaniumtrihydride	1
33	Methyllithium	1
	Tetramethylgermanium	99
34	Phenylrubidium	99.9
	Tetradodecylgermanium	0.1
35	Dodecyllithium	99.9
	Trimethylarsine	0.1
36	Butylsodium	99
	Ethylarsenicdihydride	1
37	Phenylrubidium	0.1
	Tributylstibine	99.9
38	Methylpotassium	0.1
	Trimethylstibine	99.9
39	Cyclohexylsodium	95
	Diphenylbismuthhydride	5
40	Ethylpotassium	50
	Diphenyl-biscyclophenyldieniyl-titanium	50
41	Dibutylberyllium	99.9
	Phenylcadmiumhydride	0.1
42	Didodecylberyllium	99
	Dimethylzinc	1
43	Phenylberyllium	0.1
	Ethyl-n-propylzinc	99.9
44	Ethylzincchloride	99
	Methylberylliumchloride	1
45	Dimethylberyllium	99
	Triethylborine	1
46	Dibutylberyllium	1
	Tri-n-butylborine	99
47	Dimethylberyllium	1
	Triethylaluminum	99
48	Didodecylberyllium	99
	Tridodecylaluminum	1
49	Didodecylberyllium	99
	Tetradodecylgermanium	1
50	Methylberylliumchloride	1
	Dimethyldiethylgermanium	99
51	Dibutylberyllium	99
	Trimethylarsine	1
52	Dinaphthylberyllium	1
	Triethylbismuth	99
53	Dimethylzinc	99.9
	Triethylborine	0.1
54	Ethyl-n-propylzinc	99
	Dimethylborinebromide	1
55	Didodecylzinc	5
	Tri-n-butylborine	95
56	Diisobutylzinc	95
	Tridodecylborine	5
57	Dimethylzinc	99
	Naphthaldiethylborine	1
58	Diisobutylzinc	99.9
	Phenylborinedichloride	0.1
59	Diethylcadmium	50
	Triethylborine	50
60	Triethylborine	99.9
	Trimethylaluminum	0.1
61	Tri-n-propylborine	10
	Triethylborine	89
	Dimethylaluminumhydride	1
62	Dimethylborinebromide	1
	Tri-i-butylborine	4
	Triethylaluminum	90
	Diethylaluminumiodide	5
63	Tridodecylborine	5
	Tri-n-butylborine	90
	Tributylaluminum	4
	Octylaluminumdihydride	1
64	Dimethylethylborine	0.5
	Diphenylmethylborine	0.5
	Methyldiethylaluminum	90
	Methyldiethylgallium	9
65	Triethylborine	0.1
	Trioctylaluminum	99
	Trimethylindium	0.9

Composition No.	Component	Weight Percent
66	Triethylborine	99
	Dimethyldiethylgermanium	1
67	Diphenylmethylborine	1
	Tetramethylgermanium	99
68	Triethylborine	99
	Methyldiethylarsine	0.5
	Trioctylstibine	0.5
69	Tridodecylborine	1
	Triethylbismuth	90
	Phenylantimonydibromide	9
70	Triethylaluminum	80
	Ethylmethylaluminumhydride	10
	Diethylbutylgallium	9
	Dimethyldiethylgermanium	0.5
	Dipropylgermaniumdihydride	0.5
71	Tri-n-propylaluminum	99
	Methyldiethylgallium	0.5
	Dimethylindiumhydride	0.5
72	Triethylaluminum	99
	Methyldiethylarsine	0.5
	Ethylantimonydihydride	0.5
73	Tridodecylaluminum	0.1
	Trimethylgallium	0.1
	Triethylthallium	0.1
	Diphenyldiethylgermanium	0.1
	Trimethylarsine	0.1
	Tributylstibine	99.5
74	Tetramethylgermanium	1
	Trimethylarsine	1
	Trioctylstibine	1
75	Trimethylbismuth	97
	Naphthylcesium	90
	Tributylstibine	5
	Triethylbismuth	4
	Dimethylbismuthchloride	1

The oxidizers with which the fuels of this invention exhibit reduced ignition delay periods include liquid oxygen, nitrogen tetroxide, hydrogen peroxide, chlorine trifluoride, bromine pentafluoride, white fuming nitric acid, red fuming nitric acid, liquid fluorine, liquid fluorine and liquid oxygen mixtures of from about 5 to about 95 mole percent fluorine in oxygen, perchlorofluoride having the general formula $FClO_3$, and nitrogen trifluoride, mixed oxides of nitrogen, as well as other oxidizers known to those skilled in the art.

The amount of oxidizer employed with the fuel is given in terms of the stoichiometric ratio of oxidizer-to-fuel. The stoichiometric value of the ratio is defined as that value of the weight ratio when the oxidizer and fuel are used in stoichiometrical portions for complete oxidization of the fuel. The oxidizer-to-fuel weight ratio can vary from about 0.1 of the stoichiometric ratio value to about 30 times the stoichiometric ratio value for ignition purposes. When, however, the metal-organic compounds are employed as components of improved hydrocarbon fuel mixtures, the oxidizer-to-fuel ratio varies from about 0.5 to about two times the stoichiometric ratio value. For better engine performance with respect to thrust and range, however, oxidizer-to-fuel weight ratios equivalent to from about 0.6 to about 1 of the stoichiometric value are preferred.

Liquid oxygen is found to perform well when employed as the oxidizer with the fuels of this invention. Therefore, the use of liquid oxygen constitutes a preferred embodiment of this invention.

The performance of the compositions of this invention as rocket fuels was investigated by operating stationary rocket motors using the fuels together with a suitable oxidizer. The rocket engine employed in the tests had a throat area of 0.132 square inch. The ratio of the cross sectional area of the nozzle exit-to-throat cross sectional area was 1:1. The ratio of the cross sectional area of the combustion chamber-to-the cross sectional area of the throat was 2.0:1. The motor was operated at a combustion chamber pressure of 500 p.s.i.a. and an exit nozzle pressure of substantially 13.6 p.s.i.a. The fuel composition and oxidizer were fed through separate conduits from individual storage containers to the combustion chamber where the stream of fuel composition and the stream of oxidizer contacted each other upon emerging from orifices in an injector plate. The fuel and oxidizer ignited upon contact, producing gaseous products as a

result of the spontaneous combustion of the components of the two streams. The gaseous products were ejected from the combustion chamber through the throat area and then out into the atmosphere through the exit nozzle. The ejection of the reaction product gases from the combustion chamber produces a thrust which is measured by means of a load cell mounted forward of the motor. The fuel composition and the oxidizer were metered into the motor so that the amount reacting within any particular period of time was known.

In instances where the fuel compositions do not make completely fluid solutions, a solvent is used which also serves as a fuel. Non-limiting examples of solvents used include benzene, chloroform, and hydrocarbon fuels of the type discussed below.

Non-limiting illustrative examples of the operation of rocket motors described above employing the fuel compositions of this invention are given below.

Example I

The rocket motor described above is operated on fuel composition No. 2 of Table I, using liquid oxygen as the oxidizer. The oxidizer-to-fuel weight ratio is equivalent to the stoichiometric value. The ignition of the fuel in the engine is smooth and the engine operates satisfactorily.

Example II

The above rocket motor is operated with fuel No. 9 of Table I, together with a liquid oxygen-fluorine mixture in the weight ratio of 95:5, oxygen-to-fluorine. The ratio of oxidizer-to-fuel is substantially 0.6 of the stoichiometric ratio value. A smooth ignition and satisfactory operation is observed.

Example III

The above rocket motor is operated on fuel No. 3 of Table I, with liquid oxygen as the oxidizer. The oxidizer-to-fuel weight ratio is 0.1 of the stoichiometric ratio value. Improved ignition and satisfactory operation is observed.

Example IV

The above rocket motor is operated on fuel No. 8 of Table I, together with liquid oxygen. The oxidizer-to-fuel weight ratio is 30 times the stoichiometric ratio value. Improved ignition and satisfactory operation is observed.

Example V

The procedure of Example IV is repeated employing composition No. 4 of Table I as the fuel and nitrogen tetroxide as the oxidizer. The oxidizer-to-fuel weight ratio is substantially 0.8 of the stoichiometric ratio value. Smooth ignition and efficient operation is observed.

Example VI

The procedure of Example IV is repeated employing fuel No. 5 of Table I, together with liquid oxygen as the oxidizer. The oxidizer-to-fuel weight ratio is ten times the stoichiometric value. Smooth ignition and satisfactory operation are observed.

Example VII

The above rocket engine is operated on fuel No. 16 of Table II, together with liquid oxygen in proportions equivalent to the stoichiometric values of the oxidizer and fuel. Smooth ignition and satisfactory operation are observed.

Example VIII

The rocket motor described above is operated on fuel No. 55 of Table II, with a liquid oxygen-fluorine weight percent mixture of 76-to-24, oxygen-to-fluorine, as the oxidizer. The oxidizer-to-fuel weight ratio is 0.6 of the stoichiometric ratio value. Smooth ignition and satisfactory operation are observed.

Example IX

The above rocket motor is operated on fuel No. 71 of Table II, together with hydrogen peroxide as the oxidizer. The oxidizer-to-fuel weight ratio is equivalent to 0.7 of the stoichiometric ratio value. Improved ignition and satisfactory operation are observed.

Example X

Improved ignition and satisfactory operation are observed when the above rocket motor is operated on fuel No. 73 of Table II, together with nitrogen tetroxide as the oxidizer. The oxidizer-to-fuel ratio is 30 times the stoichiometric ratio value.

Example XI

The procedure of Example X is repeated with the modification that fuel No. 69 of Table II is employed, together with white fuming nitric acid as the oxidizer. The oxidizer and fuel are employed in proportions equivalent to the stoichiometric values for complete combustion of the fuel. Improved ignition and satisfactory operation are observed.

Example XII

The procedure of Example X is repeated employing fuel No. 10 of Table II, together with liquid oxygen as the oxidizer. The oxidizer-to-fuel weight ratio is equivalent to the stoichiometric value. Smooth ignition and satisfactory operation are observed.

In like manner, improved ignition and satisfactory operation of the rocket motor are observed when the other fuels of Tables I and II are employed with the oxidizers specified hereinabove.

When a flight rocket is operated on the composition No. 5 of Table I, together with liquid oxygen as the fuel in proportions such that the oxidizer-to-fuel ratio is equivalent to the stoichiometric ratio value, satisfactory flight performance is observed.

In like manner, satisfactory performance is observed when flight rockets are operated on fuel compositions of Tables I and II, together with liquid oxygen and the other oxidizers specified hereinabove.

The compositions of this invention are employed not only as primary fuels but also as additives to other hydrocarbon fuels having boiling points within the range of from about 87° F. to about 600° F. For example, the combustion characteristics of solene is improved by the addition of from about 1 to about 99 weight percent of the compositions described hereinabove, including those given in Table I. Solene is a hydrocarbon fuel having an initial boiling point (IBP) of about 90° F. and a final boiling point (FBP) of about 406° F. It is composed of 20.8 weight percent thermal distilate, 21.5 weight percent catalytic distillate, 26.4 weight percent virgin naphtha, and 1.3 weight percent butane. A specific example of a hydrocarbon fuel is solene containing 1 weight percent of composition No. 3 of Table I. Another fuel that is improved by the additions of the compositions described hereinabove is indolene. Indolene has an initial boiling point of substantially 94° F. and a final boiling point of substantially 390° F. Indolene is a brand of straight-run catalytically cracked and polymeric blending stocks containing 10 weight percent of polymeric components, 40 weight percent catalytically cracked heavy naphtha, 35 weight percent virgin light naphtha, 5 weight percent butane, and 10 weight percent pentane. A specific example employing indolene fuel is a composition containing 99 weight percent of composition No. 5 of Table I and 1 weight percent indolene.

Non-limiting illustrative examples of fuel compositions of this invention employing a hydrocarbon fuel as one of the components are given in Table III below.

TABLE III

Comp. No.	Components	Weight Percent
1	Composition No. 3 of Table I	1
	JP-4	99
2	Composition No. 5 of Table I	5
	RP-1	95
3	Composition No. 8 of Table I	25
	Fuel A[a]	75
4	Composition No. 2 of Table I	75
	Benzene	25
5	Composition No. 9 of Table I	50
	Kerosene	50
6	Composition No. 48 of Table II	60
	$CHCl_3$	15
	Benzene	25
7	Composition No. 23 of Table II	15
	Fuel B[b]	85

[a] Fuel A is a hydrocarbon fuel having an IBP of 87° F, a FBP of 600° F., with an aromatic content of 25 vol. percent max., and an olefin content of 10 vol. percent max.

[b] Fuel B is a hydrocarbon fuel having an IBP of 400° F., a FBP of 600° F., a flash point of 190° F., with an aromatic content of 5 vol. percent max., and an olefin content of 1 vol. percent max.

The JP–4 fuel is a hydrocarbon fuel having an IBP of about 144° F., a FBP of about 487° F., an aromatic content of about 11.3 vol. percent and a bromine number of about 1.59.

The fuel designated as RP–1 has an IBP of about 350° F. and an FBP of about 525° F., a flash point of about 110° F., an aromatic content of 5 vol. percent max., and an olefin content of 1 vol. percent max.

Non-limiting illustrative examples of the use of fuels of the type shown in Table III are given in the following examples.

Example XIII

A jet engine is operated on JP–4 fuel containing 1 weight percent of composition No. 3 of Table I. Good ignition and satisfactory operation of the engine are observed.

Example XIV

A ramjet engine is operated on composition No. 2 of Table III. Satisfactory operation is observed.

Example XV

A space rocket vehicle is powered by composition No. 2 of Table III, together with liquid oxygen as the oxidizer. Satisfactory operation is observed.

In like manner, satisfactory operation is observed when jet engines, ramjets, or space flight vehicles employ hydrocarbon fuels having an IBP in the range of from about 87° F. to about 400° F. and a FBP of from about 450° F. to about 600° F., together with the compositions of Tables I and II for propulsion purposes.

Example XVI

A rocket motor having a regeneratively-cooled thrust chamber and rated at 100,000 pounds thrust was operated on a combination of RP–1 fuel and liquid oxygen in stoichiometric proportions. The liquid oxygen was admitted first to the combustion chamber. A hypergol consisting of a mixture of 96 weight percent triethylborine and 4 weight percent triethylaluminum was next admitted to the combustion chamber preceding the fuel, where it contacted the liquid oxygen and ignition occurred. While the hypergol and the liquid oxygen burned, RP-1 fuel was admitted from a pressurized tank to the combustion chamber where it ignited smoothly and satisfactory operation of the motor thereafter was observed.

Equally good results are obtained when the procedure of Example XVI is repeated employing a hypergol consisting of a mixture of 85 weight percent triethylborine and 15 weight percent triethylaluminum. Likewise, smooth ignition is obtained when combustion in a rocket motor is initiated by the use of one of the fuel compositions of Tables I and II with liquid oxygen, as well as with other compositions of the types described hereinabove with a suitable oxidizer and a hydrocarbon fuel having an IBP of from about 87° F. to about 400° F. and an FBP from about 450° F. to about 600° F. is fed to the combustion chamber while the hypergol and the oxidizer are undergoing combustion. Thus, the method of Example XVI is used to initiate ignition of any of the hydrocarbon fuels discussed above.

By the use of a hypergol consisting of a fuel composition containing compounds having the general formula R_xM, as described hereinabove, wherein the composition contains at least two different metals in the form of these compounds, smooth ignition is accomplished. This method provides a reliability factor in the start up of engines which minimizes the danger of forming an explosive mixture in the combustion chamber prior to ignition.

From the discussion and examples given hereinabove, it is seen that novel fuel compositions have been provided. A word of caution with respect to the preparation and use of these compositions may be in order. Many of the organo-metallic compounds, as well as the fuel formulations, are highly explosive, and explosions may occur even when it is believed that all safety precautions have been observed. It is, therefore, advisable to treat all fuel compositions as highly explosive and dangerous materials for handling purposes.

While the compositions and method of this invention have been described in some detail, with the use of specific illustrative examples, it is to be understood that the examples were used by way of illustration only and not by way of limitation. It is not intended that the spirit or scope of this invention be limited except as indicated in the appended claims.

We claim:

1. A method of effecting combustion in a reaction chamber with a minimum of ignition delay between a fuel composition and an oxidizer for combusting said fuel composition, the method comprising contacting in said reaction chamber said oxidizer with said fuel composition, said fuel composition comprising a boron compound having the formula R_3B and from one to about 99 weight percent, based on the total weight of the composition, and an aluminum compound having the formula R_3Al, and wherein each R is an alkyl hydrocarbon group having from one to about 12 carbon atoms.

2. A method of effecting combustion in a reaction chamber with a minimum of ignition delay between a fuel composition and an oxidizer for combusting said fuel composition, the method comprising contacting in said reaction chamber said oxidizer with said fuel composition, said fuel composition consisting essentially of a boron compound having the formula R_3B and from one to about 99 weight percent, based on the total weight of the composition, and an aluminum compound having the formula R_3Al, and wherein each R is an alkyl hydrocarbon group having from one to about 12 carbon atoms.

3. A method of effecting combustion in a reaction chamber with a minimum of ignition delay between a fuel composition and an oxidizer for combusting said fuel composition, the method comprising contacting in said reaction chamber said oxidizer with said fuel composition, said fuel composition consisting essentially of from one to 99 weight percent triethylaluminum and from 99 to one weight percent triethylboron based on the combined weight of said triethylaluminum and said triethylboron.

4. A method of initiating combustion in a reaction chamber with a minimum of ignition delay between a hydrocarbon fuel boiling within the range of 90° F. to about 600° F. and an oxidizer for combusting said fuel, the method comprising first contacting in said reaction chamber said oxidizer with a composition comprising a boron compound having the formula R_3B and from one to about 99 weight percent, based on the total weight of the composition, and an aluminum compound having the formula R_3Al, and wherein each R is an alkyl hydrocarbon group having from one to about 12 carbon atoms, whereby said oxidizer and said composition provide

hypergolic ignition in said chamber, and thereafter contacting said oxidizer with said hydrocarbon fuel.

5. A method of initiating combustion in a reaction chamber with a minimum of ignition delay between a hydrocarbon fuel boiling within the range of 90° F. to about 600° F. and an oxidizer for combusting said fuel, the method comprising first contacting in said reaction chamber said oxidizer with a composition consisting essentially of a boron compound having the formula R_3B and from one to about 99 weight percent, based on the total weight of the composition, and an aluminum compound having the formula R_3Al, and wherein each R is an alkyl hydrocarbon group having from one to about 12 carbon atoms, whereby said oxidizer and said combustion provide hypergolic ignition in said chamber, and thereafter contacting said oxidizer with said hydrocarbon fuel.

6. The method of producing thrust comprising supplying to a combustion chamber a hydrocarbon fuel boiling in the range of from about 90° F. to about 600° F. and an oxidizer for combusting said fuel, said hydrocarbon fuel containing from about 1 to about 99 weight percent of a composition comprising a boron compound having the formula R_3B and from one to about 99 weight percent, based on the total weight of the composition, and an aluminum compound having the formula R_3Al, and wherein each R is an alkyl hydrocarbon group having one to about 12 carbon atoms, and combusting said fuel in said chamber.

7. The method of producing thrust comprising supplying to a combustion chamber a hydrocarbon fuel boiling in the range of from about 90° F. to about 600° F. and an oxidizer for combusting said fuel, said hydrocarbon fuel containing from about 1 to about 99 weight percent

of a composition consisting essentially of from one to 99 weight percent triethylaluminum and from 99 to one weight percent triethylboron based on the combined weight of said triethylaluminum and said triethylboron, and combusting said fuel in said chamber.

8. The method of claim 7 wherein said boron compound is triethylboron and said aluminum compound is triethylaluminum.

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