

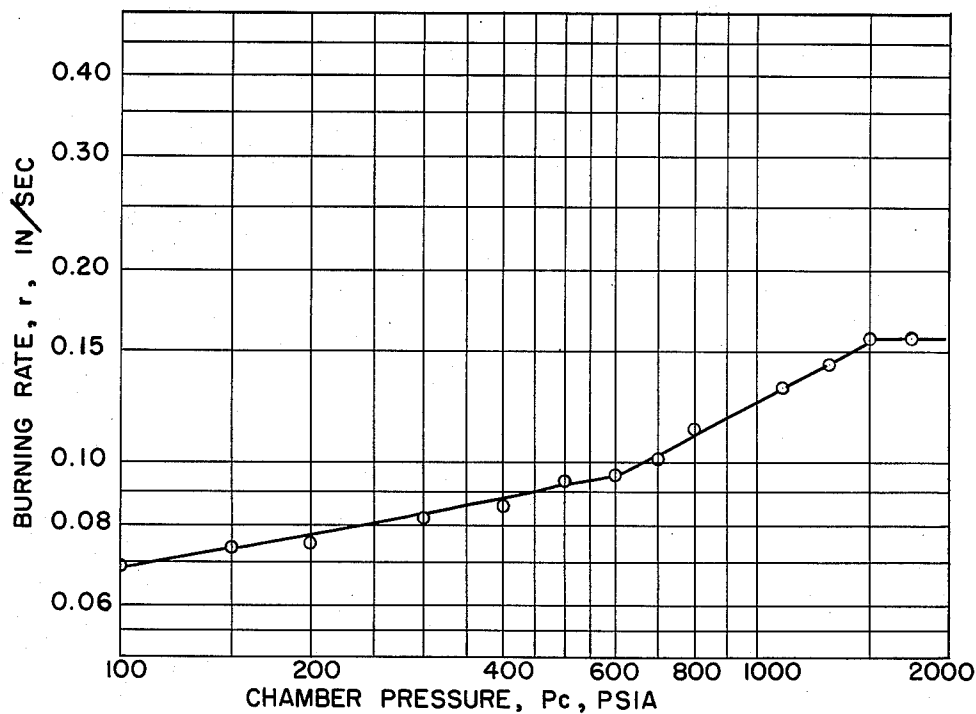
April 24, 1962

J. PHILIPSON

3,031,347

SLOW BURNING SOLID COMPOSITE PROPELLANT

Filed Feb. 5, 1951



INVENTOR.
JOSEPH PHILIPSON

BY
D. Gordon Angus
ATTORNEY

1

3,031,347

SLOW BURNING SOLID COMPOSITE PROPELLANT

Joseph Philipson, Temple City, Calif., assignor, by mesne assignments, to Aerojet-General Corporation, Cincinnati, Ohio, a corporation of Ohio

Filed Feb. 5, 1951, Ser. No. 209,507

12 Claims. (Cl. 149-48)

This invention relates to jet propulsion and more particularly to solid propellant materials useful in rocket or jet propulsion motors.

The principal object of my invention is to provide a solid propellant charge capable of burning at an unusually slow burning rate.

A further object is to produce such a slow burning propellant which burns in a substantially smokeless manner.

A further related object is to produce such a slow burning and smokeless propellant capable of developing a satisfactory specific impulse preferably above 200 lbs. sec./lb. when burned at 1000 p.s.i.

In the operation of certain types of rocket motors, a solid propellant charge or grain is burned within the chamber to generate a large volume of gas under pressure. The gas escapes in the form of a high velocity jet through the exhaust nozzle, producing the reaction force.

A solid propellant commonly comprises a fuel having mixed with it the oxidizer required for its combustion. Many solid propellant charges heretofore known burn at a higher rate than is often desired for long burning charges such as are frequently required in motors for jet assisted take-off or for sustaining flight. In some cases it might be possible to approximate the performance of such a slow burning charge by use of previously known propellants; but this would normally require resort to some special technique such as a substantial lowering of the specific impulse of the propellant or employing a complex grain configuration. Disadvantages of employing such special techniques are that the resulting intricate structure of the grain or charge often requires an unduly great increase in the weight of the chamber; furthermore, the grain so produced is generally structurally weak.

One factor by which the burning rate of the propellant can be affected is the coarseness of the oxidizer particles. The coarser the particle of oxidizer the slower will be the burning rate. Increasing the coarseness of the oxidizer, however, should not be allowed to interfere with the castability of a cast propellant; and the oxidizer cannot be coarsened to the point where the oxidizer will settle out in the liquid mixture before polymerization has taken place.

A slow burning propellant according to my invention is defined as one having a burning rate not exceeding 0.15 of an inch per second at 1000 p.s.i. chamber pressure. Furthermore, when the log burning rate is plotted against the log chamber pressure the slope n of the curve, determined by the equation

$$r = CP_c^n$$

(in which r = the linear burning rate in inches/sec.

C = a constant

P_c = the chamber pressure in p.s.i.)

shall be equal to or less than 0.5. A typical curve for a satisfactory propellant is shown in the graph.

According to my invention, I provide a smokeless propellant charge that conforms to the above requirements by compounding the propellants with fuels which are capable of supplying a portion of the oxygen required for the oxidation of the carbon and hydrogen atoms in the finished propellant charge; and as oxidizer, substances that yield their oxygen at a relatively slow rate and furthermore form no solid oxidation products.

2

In accordance with my invention, I provide a solid propellant material which can be made into a solid grain or charge of conventional size and shape, without any unusual configurations, and possessed of good physical characteristics of strength, consistency and the like.

I have accomplished my invention by the discovery of particular qualities and characteristics of the components of the propellant. One of the requirements which I have discovered is that the fuel in the propellant should be one which contains reduced oxygen atoms in the molecule; and by the term "reduced oxygen," I mean oxygen atoms included in the molecule which are linked directly only to a carbon or a hydrogen atom. The use of a fuel component having reduced oxygen in the molecule decreases the amount of oxidizer which would otherwise have to be added to the fuel to oxidize the carbon and hydrogen atoms to the proper degree.

A second criterion is that the oxygen in the fuel must be the equivalent of at least one-fifth of the weight of the combined carbon and hydrogen in the fuel.

A third, and somewhat related requirement is that the oxygen in the propellant charge must be sufficient to burn all of the carbon in the charge to CO and to convert at least one-third of all the hydrogen in the propellant to water. The amount of oxygen cannot be permitted to be substantially less than this critical amount for if less oxygen than this be present there will result carbon in the discharge which would produce undesirable smoke.

A fourth requirement of the propellant is that no oxidizer should be used in it which forms any solid particles during combustion, for such solid particles would form the undesirable smoke. This requirement excludes metallic salts as oxidizers.

A fifth requirement is that the oxidizers which are used must be limited to the group consisting of cellulose nitrate, nitroguanidine, guanidine nitrate, ammonium nitrate, ammonium perchlorate, and mixtures of any of these; with the added proviso that if ammonium perchlorate be used as the oxidizer, it cannot be allowed to exceed about 60% by weight of the propellant mixture. Thus, if ammonium perchlorate be selected as the oxidizer, and if more than the 60% oxidizer be desired for the propellant, the excess must be made up by one or more of the other of the five named oxidizers.

A sixth requirement is that the fuel component of the propellant must amount to at least 15% by weight of the finished propellant itself.

The fuel component of the propellant should furthermore be a monomer which polymerizes by addition polymerization, that is, polymerization without the formation of any by-products such as water.

Examples of unsaturated monomers useful in the practice of my invention are unsaturated polyesters, comprising the condensation product of an alcohol and an organic carboxylic acid, lower alkyl alkenoates such as methyl acrylate, methyl methacrylate, n-butyl acrylate, diethylene glycol diacrylate, and butanediol-1,3-diacrylate; lower alkenyl alkenoates such as diallyl maleate, and diallyl fumarate; lower alkenyl alkanooates such as vinyl acetate; lower alkenyl phthalates such as diallyl phthalate; phenyl substituted alkenes such as styrene; as well as other unsaturated compounds, such as diallyl diglycollate and diethylene glycol bis-(allyl carbonate).

The polyesters that may be used in the practice of this invention are the condensation products obtained by reacting a polyhydric alcohol, a saturated dicarboxylic acid and an unsaturated dicarboxylic acid. These resins have been described in detail in copending application of Joseph Philipson, Serial No. 200,881, filed December 14, 1950, now Patent No. 2,941,976, issued June 21, 1960, and assigned to the same assignee as the present application.

3

Some specific examples of large numbers of polyester resins that are suitable for this purpose are as follows:

A condensation product made by reacting 4 moles of sebacic acid, one mole of maleic anhydride and 5 moles of propylene glycol. This resin will hereafter be referred to as resin A.

A condensation product made by reacting 7 moles of adipic acid, 3 moles of maleic anhydride and 11 moles of diethylene glycol or ethylene glycol. This resin will hereafter be referred to as resin B.

A condensation product formed by reacting 7 moles of adipic acid, 3 moles of maleic anhydride and 12 moles of diethylene glycol. This resin will be referred to hereafter as resin C.

A condensation product formed by reacting 1 mole of diethylene glycol, 0.9 mole of adipic acid and 0.1 mole maleic anhydride. This resin will be referred to hereafter as resin D.

A condensation product formed by reacting 1 mole polypropylene glycol (425 molecular weight), 0.9 mole adipic acid and 0.1 mole maleic anhydride. This resin will be referred to hereafter as resin E.

A condensation product formed by reacting 1 mole polypropylene glycol (425 molecular weight), 0.8 mole adipic acid and 0.2 mole maleic anhydride. This resin will hereafter be referred to as resin F.

A condensation product formed by reacting 1 mole polyethylene glycol (300 molecular weight), 0.9 mole adipic acid, and 0.1 mole maleic anhydride. This resin will hereafter be designated as resin G.

A condensation product formed by reacting 1 mole polyethylene glycol (300 molecular weight), 0.8 mole adipic acid, and 0.2 mole maleic anhydride. This resin will hereafter be referred to as resin H.

A condensation product formed by reacting 8 moles of adipic acid, 2 moles of maleic anhydride and 10.5 moles of diethylene glycol. This resin will hereafter be referred to as resin I.

A condensation product formed by reacting 8 moles of adipic acid, 2 moles maleic anhydride and 12 moles of diethylene glycol. This reaction will hereafter be referred to as resin J.

A condensation product formed by reacting 10 moles of diethylene glycol, 4.5 moles adipic acid, 4.5 moles of azelaic acid and 1 mole maleic anhydride. This resin will hereafter be referred to as resin K.

The condensation process by which the above polyesters are formed is briefly as follows: The ingredients comprising the saturated dicarboxylic acid, the saturated diol and the unsaturated dicarboxylic acid are mixed together and heated to a temperature of approximately 140° C. until the water formed by the reaction is substantially driven off. This process is carried out in an atmosphere of inert gas such as nitrogen, carbon dioxide, helium, etc. When the water has been substantially removed the reaction product may then be subjected to higher temperatures not exceeding 250° C. The preferred temperature range for the final stage of the condensation is between 200 and 230° C. The condensation is continued until the polyester has reached a desired degree of polymerization as determined either by an acid number or by measuring the viscosity of the polyester. The preferred degree of polymerization of the application described above is between 5 and 100. The resulting product is generally a viscous liquid which when cooled may be stored until it is ready to be copolymerized.

All of these resins are capable of copolymerizing with a vinyl or diallyl type of compound such as methyl acrylate, methyl methacrylate, styrene, vinyl acetate, diethylene glycol-bis-(allyl carbonate), diallyl maleate, diallyl fumarate, diallyl diglycolate.

The oxidizers contemplated by this invention should be capable of burning without the formation of appreciable solid particles, and they should be characterized by a relatively slow rate at which they give up their oxygen.

4

Among the oxidizers which meet these requirements are nitrates, perchlorates of non-metallic basic materials, and nitro compounds containing sufficient oxygen, which form no solid oxidation products on combustion.

Examples of this class of substances are cellulose nitrate, guanidine nitrate, nitro guanidine, ammonium nitrate, and ammonium perchlorate. While ammonium perchlorate is normally regarded as a fairly slow burning oxidizer for most propellant compositions, its use in propellant compositions heretofore compounded resulted in burning rates faster than the maximum burning rate for slow burning propellants according to the present invention, which by definition is 0.15 in./sec. at 1000 p.s.i. chamber pressure. But ammonium perchlorate may be used in limited quantities or it may be mixed with others of the above-listed oxidizers to produce a propellant having the required slow burning rate. To avoid high burning rates, the amount of ammonium perchlorate to be used in any case should not exceed a maximum of about 60% by weight based on the weight of the propellant. If additional oxidizer is then required it should be one of the slower burning oxidizer substances mentioned above such as ammonium nitrate, guanidine nitrate or nitroguanidine.

The following formulations set forth examples of propellant combinations which fall within the scope of this invention and will burn at the desired rate:

Example 1

	Percent by weight	
Ammonium perchlorate.....		40
Cellulose nitrate.....		8
Ammonium nitrate.....		20
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	32
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

This mixture had a burning rate of .115 in./sec. at 1000 p.s.i.

Example 2

	Percent by weight	
Ammonium perchlorate.....		40
Cellulose nitrate.....		9
Ammonium nitrate.....		15
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	36
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

This mixture had a burning rate of .115 in./sec. at 1000 p.s.i.

Example 3

	Percent by weight	
Ammonium perchlorate.....		35
Ammonium nitrate.....		10
Guanidine nitrate.....		10
Cellulose nitrate.....		9
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	36
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

This mixture had a burning rate of .127 in./sec. at 1000 p.s.i.

Example 4

	Percent by weight	
Ammonium perchlorate.....		60
Cellulose nitrate.....		7
Nitro guanidine.....		15
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	28
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

5

This mixture had a burning rate of .15 in./sec. at 1000 p.s.i.

Example 5

	Percent by weight	
Ammonium perchlorate.....	50	
Ammonium nitrate.....	5	
Guanidine nitrate.....	5	
Cellulose nitrate.....	8	
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	32
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

This mixture had a burning rate of .134 in./sec. at 1000 p.s.i.

Example 6

	Percent by weight	
Ammonium perchlorate.....	57	
Ammonium nitrate.....	15	
Cellulose nitrate.....	5.5	
Fuel:		
Diethylene glycol bis-(allyl carbonate).....	45	22.5
Methyl acrylate.....	50	
Methyl methacrylate.....	5	

This mixture had a burning rate of .125 in./sec. at 1000 p.s.i.

Example 7

	Percent by weight	
Ammonium perchlorate.....	50	
Nitro guanidine.....	15	
Fuel:		
Resin C.....	40	35
Styrene.....	10	
Methylacrylate.....	50	

Example 8

	Percent by weight	
Ammonium perchlorate.....	50	
Cellulose nitrate.....	5	
Guanidine nitrate.....	5	
Nitro guanidine.....	5	
Fuel:		
Resin C.....	40	35
Styrene.....	10	
Methylacrylate.....	50	

Example 9

	Percent by weight	
Ammonium perchlorate.....	50	
Nitro guanidine.....	15	
Fuel:		
Resin A.....	40	35
n-Butyl acrylate.....	60	

Example 10

	Percent by weight	
Ammonium perchlorate.....	50	
Cellulose nitrate.....	5	
Guanidine nitrate.....	5	
Nitro guanidine.....	5	
Fuel:		
Resin A.....	40	35
n-Butyl acrylate.....	60	

The manner in which the above propellants are formed is by copolymerizing the ingredients shown above. The solution is polymerized by the use of heat and/or polymerization catalysts in a manner that is well known in the art. The temperatures in which copolymerization takes place is generally in the range between 20° C. to 100° C.

The catalysts which are normally employed are the

6

organic peroxides or peresters such as tertiary butyl hydroperoxide, 1-hydroxycyclohexyl hydroperoxide-1, methyl ethyl ketone peroxide, benzoyl peroxide, cumene hydroperoxide, lauryl peroxide, methyl amyl ketone peroxide, etc. Examples of the organic peresters are t-butyl perbenzoate, di-t-butyl diperphthalate, etc. When a catalyst is used it is generally employed in amounts ranging between 0.5% to 2.0% by weight based on the weight of the substances to be polymerized. The normal amount usually employed is about 1% by weight. Copolymerization is continued until the sample taken from the polymerized batch shows the desired tensile strength.

The propellants according to my invention are capable of developing thrust for an extended period of time since the rate at which the oxidizers give off their oxygen is relatively slow. In addition the incorporation with the above type oxidizers of fuels with reduced oxygen in an amount equal to or greater than one-fifth the weight of the carbon and the hydrogen atoms in the fuel, results in propellants which burn with a linear rate of not more than 0.15 in./sec. Without the presence of reduced oxygen in the resins the propellant charges containing the above oxidizers possibly would not burn at all, and if they did burn, solid carbon (smoke) would be present in the exhaust gases.

My invention has made possible a series of propellant charges which are useful where a reasonable amount of thrust is to be applied over an extended period of time, such as, for example, in jet assisted take-off, sustaining rockets or aircraft devices.

I claim:

1. A solid, slow burning, propellant composition consisting of a cured intimate mixture of a solid, non-metallic, inorganic oxidizing salt selected from the group consisting of ammonium perchlorate, ammonium nitrate, and mixtures thereof, in an amount of from about 72% to 45% by weight of the total propellant formulation; from about 5% to 22% by weight of an oxygen rich additive selected from the group consisting of guanidine nitrate, nitro guanidine, cellulose nitrate, and mixtures thereof; and from about 23% to 36% by weight of a polymerized resin fuel comprising the addition polymerization product of monomer selected from the group consisting of unsaturated polyester resins consisting of the condensation product of saturated polyhydroxy alcohol and polybasic carboxylic acid, a mixture of phenyl substituted lower alkene and an unsaturated polyester resin consisting of the condensation product of saturated polyhydroxy alcohol and polybasic carboxylic acid, lower alkyl esters of lower alkenoic acids, diethylene glycol bis-(allyl carbonate), lower alkenyl esters of lower alkenoic acids, lower alkenyl esters of lower alkanolic acids, lower alkenyl phthalates, diallyl diglycolate, and mixtures thereof, provided that the amount of ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

2. A slow burning solid propellant composition comprising a cured intimate mixture of about 40% by weight based on the weight of the total propellant of ammonium perchlorate, 8% by weight based on the weight of the total propellant of cellulose nitrate, 20% by weight based on the weight of the total propellant of ammonium nitrate, 32% by weight based on the weight of the total propellant of a polymerized fuel comprising 45% by weight based on the weight of the total fuel of diethylene glycol bis-(allyl carbonate), 50% by weight based on the weight of the total fuel of methyl acrylate, and 5% by weight based on the weight of the total fuel of methyl methacrylate.

3. A slow burning solid propellant composition comprising a cured intimate mixture of about 35% by weight based on the weight of the total propellant of ammonium perchlorate, 10% by weight based on the weight of the total propellant of guanidine nitrate; 10% by weight

based on the weight of the total propellant of ammonium nitrate, 9% by weight based on the weight of the total propellant of cellulose nitrate, and 36% by weight based on the weight of the total propellant of a polymerized fuel comprising 45% by weight based on the weight of the total fuel of diethylene glycol bis-(allyl carbonate), 50% by weight based on the weight of the total fuel of methyl acrylate and 5% by weight based on the weight of the total fuel of methyl methacrylate.

4. A slow burning solid propellant composition comprising a cured intimate mixture of about 50% by weight based on the weight of the total propellant of ammonium perchlorate, 7% by weight based on the weight of the total propellant of cellulose nitrate, 15% by weight based on the weight of the total propellant of nitro guanidine, 28% by weight of a polymerized fuel comprising 45% by weight based on the weight of the total fuel of diethylene glycol bis-(allyl carbonate), 50% by weight based on the weight of the total fuel of methyl acrylate, and 5% by weight based on the weight of the total fuel of methyl methacrylate.

5. A slow burning solid propellant composition comprising a cured intimate mixture of about 50% by weight based on the weight of the total propellant of ammonium perchlorate, 5% by weight based on the weight of the total propellant of cellulose nitrate, 5% by weight based on the weight of the total propellant of guanidine nitrate, 5% by weight based on the weight of the total propellant of nitro guanidine, and 35% by weight based on the weight of the total propellant of a polymerized fuel comprising 50% by weight based on the weight of the total fuel of methylacrylate, 10% by weight based on the weight of the total fuel of styrene, and 40% by weight based on the weight of the total fuel of a condensation product obtained by reacting 7 moles of adipic acid, 3 moles of maleic anhydride and 12 moles of diethylene glycol.

6. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of from about 45% to 72%, by weight, of solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof; from about 5% to 22%, by weight, of a mixture of guanidine nitrate and cellulose nitrate; and from about 23% to 36%, by weight, of the total propellant composition of the addition polymerization product of a mixture of diethylene glycol bis-(allyl carbonate) and lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

7. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of from about 45% to 72%, by weight, of a solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof; from about 5% to 22%, by weight, of a mixture of nitro guanidine and cellulose nitrate; and from about 23% to 36%, by weight, of the total propellant composition of the addition polymerization product of a mixture of diethylene glycol bis-(allyl carbonate) and lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

8. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of from about 45% to 72%, by weight, of a solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof; from about 5% to 22%, by weight, of nitro guanidine; and from about 23% to 36%, by weight, of the total propellant composition of an unsaturated polyester resin consisting of the condensation product of saturated polyhydric alcohol and polybasic carboxylic

acid heteropolymerized with a mixture of phenyl substituted lower alkene and lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

9. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of from about 45% to 72%, by weight, of a solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof; from about 5% to 22%, by weight, of a mixture of cellulose nitrate, guanidine nitrate and nitro guanidine; and from about 23% to 36%, by weight, of the total propellant composition of an unsaturated polyester resin consisting of the condensation product of saturated polyhydric alcohol and polybasic carboxylic acid heteropolymerized with a mixture of phenyl substituted lower alkene and lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

10. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of a solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof in an amount of from about 72% to 45%, by weight; from about 5% to 22%, by weight of nitro guanidine; and from about 23% to 36%, by weight, of the total propellant composition of unsaturated polyester resin consisting of the condensation product of saturated polyhydric alcohol and polybasic carboxylic acid heteropolymerized with lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

11. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of a solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof in an amount of from about 72% to 45%, by weight; from about 5% to 22%, by weight, of a mixture of cellulose nitrate, guanidine nitrate and nitro guanidine; and from about 23% to 36%, by weight, of the total propellant composition of unsaturated polyester resin consisting of the condensation product of saturated polyhydric alcohol and polybasic carboxylic acid heteropolymerized with lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

12. A solid, slow burning, propellant composition consisting essentially of a cured intimate mixture of from about 45% to 72%, by weight, of solid non-metallic inorganic oxidizing salt selected from the group consisting of ammonium nitrate, ammonium perchlorate, and mixtures thereof; from about 5% to 22%, by weight, of cellulose nitrate; and from about 23% to 36%, by weight, of the total propellant composition of the addition polymerization product of a mixture of diethylene glycol bis-(allyl carbonate) and lower alkyl ester of lower alkenoic acid, provided that the ammonium perchlorate present in said propellant composition shall in no event exceed 60% by weight of the total propellant composition.

References Cited in the file of this patent

UNITED STATES PATENTS

2,155,499	Lawson	Apr. 25, 1939
2,165,263	Holm	July 11, 1939
2,187,866	Spurlin et al.	Jan. 23, 1940

(Other references on following page)

UNITED STATES PATENTS

2,255,313 Ellis ----- Sept. 9, 1941
 2,388,319 Fuller ----- Nov. 6, 1945
 2,416,639 Pearsall ----- Feb. 25, 1947
 2,443,613 Fuller ----- June 22, 1948
 2,443,735 Kropa ----- June 22, 1948
 2,472,963 Singleton et al. ----- June 14, 1949
 2,479,470 Carr ----- Aug. 16, 1949
 2,479,828 Geckler ----- Aug. 23, 1949

FOREIGN PATENTS

248,089 Great Britain ----- Mar. 1, 1926
 579,057 Great Britain ----- July 22, 1946

OTHER REFERENCES

- McLarren: Rocket Engine Fuels, Automotive and Aviation Industries, Aug. 15, 1946, pp. 20-23 incl. and p. 76.
 5 Wheeler et al.: Solid and Liquid Propellants, Journal of The Institute of Fuel, June 1947, No. 114, pp. 137-152 incl.
 Hackh's Chemical Dictionary, 3rd edit., The Blakiston Co., Philadelphia, Pa., pp. 178, 575.
 10 Bebie: Manual of Explosives, Military Pyrotechnics and Chemical Warfare Agents, The MacMillan Co., N.Y. (1943), pp. 43, 106-108.