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GAS-PRODUCING CHARGE

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This invention relates to the production of smokeless powders and more particularly to the production of smokeless powders having peculiarly desirable ballistics for applications in jet-actuated devices.

It is well known that there is a definite and direct relationship between the pressure at which a smokeless powder propellant burns and its burning rate. This relationship may be mathematically expressed as $r=cP^n$ or as $\log r=n \log P+\log c$, where r is the burning rate, P is the pressure at which the burning rate is measured, and c and n are constants characteristic of a given propellant. Thus, when a plot of log r against log P is made for the conventional propellant, a straight line of slope n is obtained showing an increase in burning rate for each increase in pressure. Such a relationship is not disadvantageous in the conventional gun propellant and in fact is used to advantage in progressive powders where it is highly desirable to generate increased pressures after the projectile or shot charge has begun to move along the barrel. However, this relationship presents a serious problem in formulation of propellants for jet-actuated devices since once the desired operating pressure is reached, totally different considerations obtain.

It is highly desirable, once the operating pressure of a jet-actuated device is reached, that the pressure generated by the burning propellant be maintained as nearly contant as possible. Accordingly, if this result is to be attained, the slope n of the line representing the pressure-burning rate relationship of the particular propellant must desirably approach zero in the zone of useful rocket pressure. In the prior art rocket powders, in all of which the slope n has a value of 0.7 or over, any fracturing or slivering of the propellant charge leads to a pressure build-up because of an increase in linear burning rate resulting from the increase in pressure due to the increase in burning surface. The higher the n value of the particular powder, the higher will be the pressure rise encountered. Therefore, the results of such a fracturing or slivering vary from a highly undesirable thrust fluctuation, with consequent aberration in ballistics, to actual failure of the jet device if, with a propellant of high n value, the pressure build-up is excessive. Even unusual roughness of the charge causes serious changes in burning pressure and burning rate in the presently available rocket propellants and have been found to build up to an aberration of 5% or more in ballistics. Consequently, with the propellants now available, there is very little allowable tolerance in manufacture of charges and nozzles for jet devices. A propellant having a very low n value within the range of useful rocket pressures, however, would allow for considerable tolerances without appreciable deviation from the specified ballistics.

A second serious problem confronting producers of propellants for jet-actuated devices is the diminution of the temperature coefficient of equilibrium pressure at the desired operating pressure or pressure range. The temperature coefficient of equilibrium pressure is a measure of the pressure variation to be expected on account of temperature variation alone, using a given propellant. It is obtained by firing identical samples of propellant under identical conditions except for changes in temperature and pressure. The coefficient may be expressed as

$$\frac{\Delta P}{\overline{P}\Delta t}$$

where ΔP is the experimental difference in pressure under conditions of equilibrium burning due to the temperature change Δt; and $\overline{P}$ is the mean of the low temperature and high temperature pressures.

The advantage of having a low temperature coefficient of equilibrium pressure is obvious. If the coefficient is low, the jet-actuated device may be designed for an unusually low range of service pressure over the wide temperature range ordinarily specified for such devices in field use. Since existing propellants generally have temperature coefficients of equilibrium pressure of about 0.8%/° C. or more, service pressure may change by 100% or more in going from the lowest expected temperature to the highest expected temperature. It is therefore highly desirable to lower the temperature coefficient of equilibrium pressure below that of existing rocket propellants and thereby hold variation in service pressures due to temperature change to a minimum. If the coefficient could be lowered from 0.8%/° C. to 0.4%/° C. or less, service pressure variation would be diminished by at least one-half.

As a result of the advantages set forth above for a propellant having a low n value and a low temperature coefficient of equilibrium pressure, the combination of those two ballistic characteristics would allow additionally for important economies in the inert weight of jet-actuated devices. This is clearly seen if the equation is examined which relates the ratio between the mass of propellant (m) and the mass of the jet device without propellant (M), the gas velocity of the burning propellant (V), and the highest theoretically obtainable velocity of the jet device ($V_{max.}$) as follows:

$$V_{max.}=2.303V \log_{10}\left(1+\frac{m}{M}\right)$$

With propellants now available, the highest ratio of m/M has been about 1, where mass of propellant and mass of jet device are about equal. If it is possible, by use of a new propellant which will not build up excessive pressures, to decrease M by 10% and increase the amount of propellant to give the same total initial weight, $V_{max.}$ would be increased by a factor

$$\frac{\log_{10}\left(1+\frac{1.1}{0.9}\right)}{\log_{10}\left(1+\frac{1}{1}\right)}$$

of about 1.15. This would be a 15% improvement.

In my copending application Serial No. 492,802, filed March 7, 1955, of which the present application is a continuation-in-part, gas-producing compositions are disclosed and claimed which are characterized by the desirably low n value and/or the desirably low temperature coefficient of equilibrium pressure. Such gas-producing compositions can be produced by uniformly incorporating in a single- or double-base smokeless powder composition an amount, not exceeding 10%, of at least one material selected from the group consisting of lead, lead oxides, inorganic lead compounds and aliphatic compounds of lead. However, it is essential to obtaining these effects that the finished composition be characterized by a heat of explosion of not more than 900 calories per gram. If the smokeless powder to which one of these ballistic modifiers is added is a single-base powder, it should preferably comprise from 85–95% of nitrocellulose and from 5–15% of nonvolatile, nonexplosive plasticizer. If the propellant used is a multiple-base formula, it should preferably comprise from 40–85% of nitrocellulose, from 10–35% of explosive liquid nitric ester and from 5–30% of a substantially nonvolatile, nonexplosive plasticizer. Up to and including 10% of one or more of the ballistic modifiers selected from the group consisting of lead and the inorganic and aliphatic compounds of

lead may be employed without adversely affecting the ballistics of the gas-producing compositions of the invention. However, it is preferred to employ only sufficient of the additive to effect the desired modification in ballistics. In most cases, it has been found that 2% of the various additives based on the weight of the smokeless powder employed is ample. While lead powder, lead oxide, and lead stearate are the preferred modifiers, a substantial effect has been obtained from the incorporation of lead or any inorganic or aliphatic compound of lead.

Gas-producing compositions characterized by a low *n* value and a low temperature coefficient of equilibrium pressure have proved greatly advantageous in jet and rocket applications. Actually, the only difficulty which has been encountered lies in the fact that each specific formulation of smokeless powder and ballistic modifier has been characterized by a specific burning rate at specific pressures and that the plateau area of low *n* value wherein a substantially constant burning rate and pressure are obtained is a peculiar characteristic of a given composition. Consequently, in order to obtain either a higher rate of burning in a particular pressure region of low *n* value or to move the region of low *n* value to a higher pressure range, it has been necessary to design a specific charge formula. Such a procedure obviously requires a considerable amount of experimentation in order to obtain the desired ballistics even though the desired increase in burning rate or shift in the region of low *n* value may be small.

The object of the present invention, therefore, is a gas-producing composition which is characterized by a low *n* value.

Another object of the invention is a gas-producing composition which is characterized by both a low *n* value and by a low temperature coefficient of equilibrium pressure.

A further object of the invention is such a gas-producing composition in which the burning rate is substantially increased in a region of low *n* value within the range of useful rocket pressures.

An additional object of the invention is a means by which the burning rate of a gas-producing composition having a low *n* value and a low temperature coefficient of equilibrium pressure in the range of useful rocket pressure can be substantially increased without inordinately increasing the *n* value.

Generally described, the present invention is a gas-producing composition comprising a smokeless powder having uniformly incorporated therein an amount not exceeding 10% of at least one material of the group consisting of lead, the oxides of lead, the inorganic compounds of lead and the aliphatic compounds of lead, and an amount of finely-divided carbon not substantially exceeding the amount of lead or compound of lead; said gas-producing composition having a heat of explosion of not more than 900 calories per gram.

The burning rates in the plateau or low *n* value region in useful rocket pressure ranges of powders modified by incorporation of lead or lead compounds have generally ranged from about 0.20 to 0.35 inch/sec. By the addition to compositions thus modified of finely-divided carbon in amounts not substantially exceeding the amount of lead and/or lead compound employed, it is possible to increase plateau burning rates in the range of useful rocket pressure far above the plateau burning rates of the same compositions to which no carbon has been added. It has been found that a preferred range of carbon addition exists for each ballistic modifier chosen from the group consisting of lead and compounds of lead. Within this range, the plateau burning rate is strongly dependent on the carbon concentration and at optimum concentration, *n* values of between 0.0 and 0.2 are readily obtained. In fact, negative *n* values are often obtained. Furthermore, there is also an optimum carbon content which will give the maximum burning rate attainable while still retaining an acceptably low slope in the desired pressure ranges. Carbon concentrations which achieve these preferred and optimum conditions are naturally functions of each particular basic formula of gas-producing composition. Generally, carbon concentrations of 1% or less and lead or lead compound concentrations of 5% or less are preferred. In all cases, however, the amount of carbon must not exceed the amount of lead and/or lead compound employed. The upper limit of lead and/or lead compound ballistic modifier is 10%. Lead stearate is the preferred ballistic modifier.

While the finely-divided carbon may vary in particle size, the smaller particle sizes are most effective. The greatest increase in plateau burning rate which has been obtained has been with a carbon black having an average particle size of 0.01 or less micron.

Having generally described the invention, the following examples are presented for purposes of illustration.

In Table I, ballistics are shown for gas-producing compositions having the general formula:

Nitrocellulose (12.6% N)	58.5
Nitroglycerin	27.5
Triacetin	7.5–10.0
Ethyl centralite	1.0– 4.0
Lead stearate	1.0– 6.0
Carbon ("Excello," 0.03 micron)	0.2– 1.0

Table I

VARIATIONS IN BALLISTICS WITH CONCENTRATIONS OF LEAD STEARATE AND CARBON BLACK

Ex.	Composition						Interpolated burning rate			Graphical *n*		Temp. coeff. of equilibrium pressure (percent/° C.)	Heat of exp. (cal./g.)
	12.6% N	NG	TA	EC	C.B. (added)	PbStr. (nominal)	Pressure (p.s.i.)	At 25° C. (in./sec.)	At 50° C. (in./sec.)	Pressure interval (p.s.i.)	*n*		
1	58.5	27.0	8.5	4.0	None	2.0	500	0.15	0.16	300– 570	0.58	0.5	793
							1,000	0.19	0.22	570– 840	0.18		
							1,500	0.25	0.28	840–2,250	0.66		
							2,000	0.31	0.34	2,250–4,000	1.09		
							2,500	0.37	0.43				
2	58.5	27.0	8.5	4.0	0.35	2.0	500	0.23	0.25	300–1,400	0.67	0.4	778
							1,000	0.37	0.40	1,400–3,000	0.17		
							1,500	0.47	0.50	3,000–4,000	0.50		
							2,000	0.49	0.53				
							2,500	0.51	0.55				
3	58.5	27.0	8.5	4.0	0.5	2.0	500	0.22	0.23	300–1,500	0.71	0.4	772
							1,000	0.36	0.38	1,500–4,000	0.21		
							1,500	0.48	0.51	4,000–4,600	0.52		
							2,000	0.51	0.54				
							2,500	0.53	0.57				
4	58.5	27.0	8.5	4.0	0.75	2.0	500	0.21	0.24	320–1,000	0.61	0.7	762
							1,000	0.32	0.36	1,000–4,000	0.39		

Table I—Continued

VARIATIONS IN BALLISTICS WITH CONCENTRATIONS OF LEAD STEARATE AND CARBON BLACK

Ex.	Composition						Interpolated burning rate			Graphical n		Temp. coeff. of equilibrium pressure (percent/° C.)	Heat of exp. (cal./g.)
	12.6% N	NG	TA	EC	C.B. (added)	PbStr. (nominal)	Pressure (p.s.i.)	At 25° C. (in./sec.)	At 50° C. (in./sec.)	Pressure interval (p.s.i.)	n		
							1,500	0.38	0.42				
							2,000	0.42	0.47				
							2,500	0.46	0.52				
5	58.5	27.0	8.5	4.0	1.5	2.0	500	0.20	0.22	300–1,150	0.64	0.6	734
							1,000	0.32	0.36	1,150–2,100	0.52		
							1,500	0.40	0.45	2,100–4,000	0.34		
							2,000	0.47	0.52				
							2,500	0.51	0.56				
6	58.5	27.0	8.5	4.0	2.0	2.0	500						
							1,000	0.33	0.35	700–1,400	0.33	0.4	715
							1,500	0.38	0.43	1,400–4,000	0.52		
							2,000	0.44	0.49				
							2,500	0.50	0.55				
7	58.5	27.0	8.5	3.0	None	3.0	500	0.19	0.20	150–315	1.02	0.3	797
							1,000	0.19	0.21	315–520	0.32		
							1,500	0.25	0.29	520–840	0.34		
							2,000	0.31	0.35	840–2,450	0.72		
							2,500	0.37	0.42	2,450–4,000	1.02		
8	58.5	27.0	8.5	3.0	0.35	3.0	500	0.25	0.26	300–1,300	0.71	0.2	782
							1,000	0.42	0.44	1,300–2,800	0.00		
							1,500	0.51	0.54	2,800–4,200	0.63		
							2,000	0.51	0.54				
							2,500	0.51	0.54				
9	58.5	27.0	8.5	3.0	0.5	3.0	500	0.26	0.29	300–500	0.83	0.4	776
							1,000	0.40	0.42	500–1,650	0.60		
							1,500	0.50	0.54	1,650–3,900	0.08		
							2,000	0.55	0.58	3,900–5,000	0.94		
							2,500	0.56	0.59				
10	58.5	27.0	8.5	3.0	0.75	3.0	500	0.26	0.28	300–900	0.68	0.2	766
							1,000	0.41	0.43	900–1,700	0.52		
							1,500	0.51	0.54	1,700–4,000	0.19		
							2,000	0.56	0.59				
							2,500	0.59	0.62				
11	58.5	27.0	8.5	3.0	1.0	3.0	500	0.26	0.28	340–530	0.73	0.4	756
							1,000	0.38	0.42	530–1,900	0.56		
							1,500	0.48	0.53	1,900–4,000	0.24		
							2,000	0.56	0.61				
							2,500	0.59	0.64				
12	58.5	27.0	8.5	2.0	None	4.0	500	0.16	0.18	100–300	1.0	0.7	801
							1,000	0.18	0.21	300–860	0.0		
							1,500	0.25	0.28	860–2,500	0.78		
							2,000	0.31	0.35	2,500–4,000	0.90		
							2,500	0.37	0.43				
13	58.5	27.0	8.5	2.0	0.1	4.0	500	0.22	0.24	200–470	0.47	0.3	797
							1,000	0.18	0.20	470–980	−0.36		
							1,500	0.24	0.28	980–4,000	0.78		
							2,000	0.31	0.35				
							2,500	0.36	0.42				
14	58.5	27.0	8.5	2.0	0.2	4.0	500	0.24	0.25	300–500	0.56	0.3	792
							1,000	0.24	0.26	500–1,100	0.0		
							1,500	0.28	0.30	1,100–1,500	0.54		
							2,000	0.35	0.38	1,500–4,000	0.78		
							2,500	0.41	0.45				
15	58.5	27.0	8.5	2.0	0.25	4.0	500	0.26	0.29	310–520	0.42	0.4	791
							1,000	0.25	0.28	520–1,275	−0.08		
							1,500	0.28	0.32	1,275–4,000	0.74		
							2,000	0.35	0.40				
							2,500	0.51	0.46				
16	58.5	27.0	8.5	2.0	0.3	4.0	500	0.26	0.28	330–540	0.58	0.4	789
							1,000	0.30	0.33	540–1,500	0.0		
							1,500	0.30	0.33	1,500–4,000	0.66		
							2,000	0.36	0.40				
							2,500	0.42	0.47				
17	58.5	27.0	8.5	2.0	0.35	4.0	500	0.24	0.27	300–900	0.70	0.4	786
							1,000	0.38	0.41	900–2,000	0.09		
							1,500	0.40	0.43	2,000–4,000	0.60		
							2,000	0.41	0.44				
							2,500	0.45	0.49				
18	58.5	27.0	8.5	2.0	0.4	4.0	500	0.27	0.29	300–860	0.58	0.2	785
							1,000	0.38	0.42	860–2,400	0.16		
							1,500	0.41	0.45	2,400–4,000	0.58		
							2,000	0.43	0.47				
							2,500	0.45	0.48				
19	58.5	27.0	8.5	2.0	0.5	4.0	500	0.26	0.28	300–1,075	0.60	0.3	780
							1,000	0.39	0.42	1,075–2,900	0.17		
							1,500	0.43	0.48	2,900–4,000	0.55		
							2,000	0.46	0.50				
							2,500	0.48	0.52				
20	58.5	27.0	8.5	2.0	0.75	4.0	500	0.26	0.29	300–1,500	0.58	0.3	770
							1,000	0.39	0.42	1,500–4,000	0.25		
							1,500	0.50	0.53	4,000–5,000	0.68		
							2,000	0.54	0.57				
							2,500	0.57	0.60				
21	58.5	27.0	8.5	2.0	1.0	4.0	500	0.28	0.30	260–1,300	0.58	0.4	760
							1,000	0.42	0.45	1,300–2,000	0.38		
							1,500	0.51	0.55	2,000–4,000	0.21		
							2,000	0.58	0.64	4,000–5,000	0.48		
							2,500	0.62	0.66				
22	58.5	27.0	7.5	1.0	0.5	6.0	500	0.28	0.30	360–720	0.58	0.4	777
							1,000	0.36	0.39	720–2,250	0.14		
							1,500	0.38	0.41	2,250–4,500	0.78		
							2,000	0.40	0.43				
							2,500	0.43	0.47				
23	58.5	27.0	7.5	1.0	0.75	6.0	500	0.27	0.29	270–1,300	0.58	0.3	767
							1,000	0.41	0.44	1,300–3,000	0.15		
							1,500	0.49	0.52	3,000–4,000	0.50		
							2,000	0.51	0.54				
							2,500	0.53	0.56				

In Table II, ballistics are shown for gas-producing compositions formed by adding 0.5% of carbon having varying particle size to the following basic composition:

Nitrocellulose (12.6% N)	58.5
Nitroglycerin	27.0
Triacetin	8.5
Ethyl centralite	2.0
Lead stearate	4.0

centage of various ballistic modifiers selected from the group consisting of lead, the inorganic compounds of lead and the aliphatic compounds of lead. The following basic formula was employed:

	Percent
Nitrocellulose (12.6% N)	58.5.
Nitroglycerin	27.0.
Triacetin	8.5.
Ethyl centralite	2.0.
Ballistic modifier	(As indicated).
Carbon black ("Excello," 0.03 micron)	0.0–0.5.

Table II

BALLISTIC EFFECTS OF FINELY DIVIDED CARBONS OF VARIOUS PARTICLE SIZE

Ex.	Type of carbon	Particle size of carbon black	Interpolated burning rate			Graphical n		Temp. coeff. of equilibrium pressure (Percent/° C.)	Heat of exp. (cal./g.)
			Pressure (p.s.i.)	Rate at 25° C. (in./sec.)	Rate at 50° C. (in./sec.)	Pressure interval (p.s.i.)	n		
24	None		500	0.16	0.18	100– 300	1.0	0.7	801
			1,000	0.18	0.21	300– 860	0.0		
			1,500	0.25	0.28	860–2,500	0.78		
			2,000	0.31	0.35	2,500–4,000	0.90		
			2,500	0.37	0.43				
25	Carbon black "Excello"	0.03 micron—(average)	500	0.28	0.30	300– 700	0.78	0.2	780
			1,000	0.44	0.46	700–1,300	0.52		
			1,500	0.52	0.54	1,300–3,000	0.00		
			2,000	0.52	0.54	3,000–4,000	0.69		
			2,500	0.52	0.54				
26	Carbon black Neo Spectra Mark I.	0.01 micron—(average)	500	0.33	0.35	300– 740	0.60	0.3	780
			1,000	0.45	0.48	740–2,000	0.34		
			1,500	0.52	0.55	2,000–4,000	0.14		
			2,000	0.58	0.60				
			2,500	0.59	0.62				
27	Lamp black	Data not available. Believed similar to "Excello" Carbon Black.	500	0.29	0.33	250– 780	0.78	0.2	780
			1,000	0.45	0.48	780–1,500	0.32		
			1,500	0.52	0.55	1,500–2,650	−0.44		
			2,000	0.46	0.49	2,650–4,000	0.73		
			2,500	0.42	0.44				
28	Animal black	Less than 44 microns [1]	500	0.22	0.25	300– 700	0.42	0.2	780
			1,000	0.24	0.26	700–1,225	−0.19		
			1,500	0.27	0.31	1,225–2,900	0.78		
			2,000	0.34	0.38	2,900–4,000	1.0		
			2,500	0.40	0.45				
29	Acetylene black	0.05 micron—(average)	500	0.26	0.28	350– 520	0.95	0.2	780
			1,000	0.40	0.42	520–1,225	0.57		
			1,500	0.46	0.48	1,225–2,500	0.0		
			2,000	0.46	0.48	2,500–4,000	0.68		
			2,500	0.46	0.50				
30	Colloidal graphite ("Aquadag")	1.0 micron—(average)	500	0.25	0.26	300– 800	0.80	0.2	780
			1,000	0.40	0.42	800–1,750	0.40		
			1,500	0.46	0.49	1,750–3,000	−0.11		
			2,000	0.48	0.51	3,000–4,000	0.80		
			2,500	0.47	0.50				
31	Wood charcoal	Less than 44 microns [1]	500	0.20	0.21	110– 370	0.94	0.3	780
			1,000	0.20	0.22	370– 840	−0.18		
			1,500	0.27	0.30	840–3,000	0.73		
			2,000	0.33	0.37	3,000–4,000	0.90		
			2,500	0.39	0.43				
32	Coconut charcoal	do.[1]	500	0.22	0.23	300– 550	0.46	0.2	780
			1,000	0.20	0.21	550–1,000	−0.24		
			1,500	0.26	0.29	1,000–2,700	0.71		
			2,000	0.32	0.35	2,700–4,000	1.02		
			2,500	0.37	0.42				
33	Graphite	do.[2]	500	0.19	0.20	200– 400	0.72	0.2	780
			1,000	0.19	0.21	400– 900	−0.15		
			1,500	0.25	0.28	900–2,500	0.70		
			2,000	0.30	0.34	2,500–3,000	1.1		
			2,500	0.35	0.39				

[1] Ball milled and screened thru a 325 mesh screen.
[2] Passes thru a 325 mesh screen as supplied.

In Table III, the ballistic data are set forth to illustrate the effect of carbon black addition to gas-producing compositions of the invention containing the indicated per-

Table III

CARBON BLACK EFFECT ON BALLISTICS OF SOME PLATEAU PROPELLANTS

Ex.	Lead compound (percent)	Carbon black (added)	Interpolated burning rate			Graphical n		Temp. coeff. of equilibrium pressure (percent/°C.)	Heat of exp. (cal./g.)
			Pressure (p.s.i.)	At 25° C. (in./sec.)	At 50° C. (in./sec.)	Pressure interval (p.s.i.)	n		
34	4.0% lead stearate	None	500	0.16	0.18	100– 300	1.0	0.7	801
			1,000	0.18	0.21	300– 860	0.0		
			1,500	0.25	0.28	860–2,500	0.78		
			2,000	0.31	0.35	2,500–4,000	0.90		
			2,500	0.37	0.43				
35	do	0.5	500	0.26	0.28	300–1,075	0.60	0.4	780
			1,000	0.39	0.42	1,075–2,900	0.17		
			1,500	0.43	0.48	2,900–4,000	0.55		
			2,000	0.46	0.50				
			2,500	0.48	0.52				

Table III—Continued

Ex.	Lead compound (percent)	Carbon black (added)	Interpolated burning rate			Graphical n		Temp. coeff. of equilibrium pressure (percent/°C.)	Heat of exp. (cal./g.)
			Pressure (p.s.i.)	At 25° C. (in./sec.)	At 50° C. (in./sec.)	Pressure interval (p.s.i.)	n		
36	4.0% lead molybdate	None	500	0.21	0.24	300–730	0.63	0.7	897
			1,000	0.31	0.34	730–2,050	0.47		
			1,500	0.38	0.43	2,050–4,000	0.62		
			2,000	0.45	0.49				
			2,500	0.50	0.55				
37	do	0.5	500	0.28	0.30	300–640	1.1	0.4	876
			1,000	0.34	0.48	640–2,000	0.45		
			1,500	0.54	0.58	2,000–3,000	0.15		
			2,000	0.60	0.64	3,000–4,000	0.63		
			2,500	0.64	0.68				
38	1.0% meta lead paste [1]	None	500	0.22	0.24	300–740	0.32		693
			1,000	0.25	0.27	740–1,300	0.00	0.28	
			1,500	0.28	0.30	1,300–4,000	0.70		
			2,000	0.34	0.37				
			2,500	0.40	0.44				
39	do	0.2	500	0.23	0.24	200–1,250	0.76		685
			1,000	0.39	0.43	1,250–2,900	0.08	0.26	
			1,500	0.47	0.49	2,900–4,000	0.58		
			2,000	0.48	0.51				
			2,500	0.49	0.52				
40	2.0% lead perchlorate	None	500	0.25	0.28	300–490	0.55		873
			1,000	0.30	0.33	490–1,125	0.24	0.47	
			1,500	0.37	0.43	1,125–2,500	0.67		
			2,000	0.45	0.51	2,500–4,000	1.06		
			2,500	0.53	0.59				
41	do	0.2	500	0.28	0.30	300–720	0.84		865
			1,000	0.40	0.42	720–900	0.32		
			1,500	0.41	0.45	900–1,375	−0.17	0.20	
			2,000	0.47	0.53	1,375–2,350	0.53		
			2,500	0.55	0.62	2,350–4,000	0.81		
42	4.0% lead 2-ethyl hexoate	None	500	0.16	0.19	100–200	1.2	0.3	828
			1,000	0.21	0.24	200–300	0.33		
			1,500	0.27	0.31	300–500	−0.38		
			2,000	0.34	0.39	500–720	0.19		
			2,500	0.42	0.50	720–1,800	0.58		
						1,800–4,000	1.1		
43	do	0.5	500	0.30	0.32	300–1,100	0.57	0.3	807
			1,000	0.45	0.48	1,100–3,100	0.26		
			1,500	0.52	0.54	3,100–4,000	0.50		
			2,000	0.56	0.59				
			2,500	0.60	0.63				
44	2.0% lead methoxy propionate	None	500	0.16	0.18	150–350	0.50		899
			1,000	0.22	0.25	350–680	0.18	0.70	
			1,500	0.28	0.31	680–1,750	0.65		
			2,000	0.37	0.45	1,750–4,000	1.2		
			2,500	0.49	0.59				
45	do	0.2	500	0.26	0.24	200–330	0.77		877
			1,000	0.28	0.29	330–800	0.42		
			1,500	0.31	0.34	800–1,325	0.03	0.21	
			2,000	0.37	0.43	1,325–2,025	0.63		
			2,500	0.45	0.52	2,025–4,000	0.89		
46	2.0% lead ethoxy propionate	None	50	0.23	0.26	300–530	0.91		837
			1,000	0.24	0.28	530–1,000	0.00	0.50	
			1,500	0.30	0.34	1,000–2,100	0.50		
			2,000	0.35	0.41	2,100–4,000	1.20		
			2,500	0.44	0.50				
47	do	0.4	500	0.22	0.25	310–1,145	0.75		823
			1,000	0.36	0.40	1,145–1,700	0.40		
			1,500	0.45	0.47	1,700–2,300	−0.21	0.09	
			2,000	0.46	0.45	2,300–4,000	0.65		
			2,500	0.45	0.51				
48	2.0% tribasic lead maleate	None	500	0.20	0.22	150–260	0.24		839
			1,000	0.25	0.27	260–770	0.06	0.45	
			1,500	0.32	0.37	770–1,950	0.67		
			2,000	0.40	0.47	1,950–4,000	0.93		
			2,500	0.49	0.57				
49	do	0.2	500	0.29	0.28	100–750	0.29		825
			1,000	0.32	0.34	750–1,350	0.00	0.36	
			1,500	0.35	0.42	1,350–4,000	0.76		
			2,000	0.44	0.50				
			2,500	0.52	0.60				
50	1% lead	None	500	0.22	0.24	300–710	0.37	0.3	696
			1,000	0.25	0.27	710–1,350	0.00		
			1,500	0.27	0.30	1,350–4,000	0.78		
			2,000	0.34	0.37				
			2,500	0.40	0.44				
51	do	0.2	500	0.22	0.24	500–1,250	0.84	0.3	682
			1,000	0.38	0.43	1,250–2,900	0.10		
			1,500	0.47	0.49	2,900–4,000	0.55		
			2,000	0.48	0.51				
			2,500	0.49	0.52				
52	4.0% lead sulfide	None	500	0.24	0.25	300–530	0.32	0.3	890
			1,000	0.28	0.30	530–1,200	0.20		
			1,500	0.35	0.38	1,200–4,000	0.82		
			2,000	0.44	0.49				
			2,500	0.53	0.59				
53	do	0.5	500	0.38	0.43	300–550	0.66	0.4	869
			1,000	0.54	0.59	550–1,775	0.44		
			1,500	0.65	0.71	1,775–4,000	0.19		
			2,000	0.72	0.77				
			2,500	0.74	0.80				
54	4% lead monoxide	None	500	0.17	0.19	185–550	0.02	0.4	884
			1,000	0.25	0.29	550–1,450	0.61		
			1,500	0.32	0.38	1,450–4,000	0.97		
			2,000	0.42	0.50				
			2,500	0.53	0.62				
55	do	0.5	500	0.23	0.26	100–190	0.60	0.5	863
			1,000	0.31	0.34	190–700	0.18		
			1,500	0.40	0.45	700–1,350	0.57		
			2,000	0.50	0.56	1,350–4,000	0.75		
			2,500	0.60	0.66				
56	1% tetraethyl lead	None	500	0.23	0.24	300–500	0.24	0.3	682

Table III—Continued

Ex.	Lead compound (percent)	Carbon black (added)	Interpolated burning rate: Pressure (p.s.i.)	Interpolated burning rate: At 25° C. (in./sec.)	Interpolated burning rate: At 50° C. (in./sec.)	Graphical *n*: Pressure interval (p.s.i.)	Graphical *n*: *n*	Temp. coeff. of equilibrium pressure (percent/° C.)	Heat of exp. (cal./)
			1,000	0.23	0.24	500–1,100	0.00		
			1,500	0.28	0.31	1,100–3,000	0.68		
			2,000	0.35	0.38				
			2,500	0.42	0.45				
57	do	0.2	500	0.23	0.25	920–2,175	0.29	0.5	674
			1,000	0.30	0.34	2,175–3,000	0.50		
			1,500	0.34	0.38				
			2,000	0.37	0.41				
			2,500	0.41	0.45				
58	1.5% lead acetate	None	100	0.064	0.073	100–260	0.15	0.7	699
			200	0.070	0.082	260–4,000	0.76		
			300	0.081	0.096				
			400	0.100	0.117				
			500	0.118	0.137				
59	do	0.2	100	0.066	0.074	100–270	0.19	0.5	690
			200	0.076	0.085	270–4,000	0.74		
			300	0.087	0.100				
			400	0.107	0.122				
			500	0.127	0.141				
60	1% lead ethoxy-acetate	None	500	0.16	0.19	300–380	0.24	0.7	820
			1,000	0.20	0.23	880–2,150	0.80		
			1,500	0.28	0.32	2,150–4,000	1.38		
			2,000	0.36	0.40				
			2,500	0.47	0.53				
61	do	0.3	500	0.22	0.25	300–1,250	0.70	0.2	807
			1,000	0.35	0.38	1,250–2,250	0.09		
			1,500	0.42	0.44	2,250–4,000	0.68		
			2,000	0.41	0.43				
			2,500	0.44	0.49				

[1] Lead flakes, 80% through 325 mesh,/mineral spirits containing 10% stearic acid—90/10.

The examples in Table IV illustrate that it is undesirable to employ more than the necessary amount of finely-divided carbon and that plateau ballistics are not obtained where the amount of carbon substantially exceeds the amount of lead or lead compound.

aliphatic compounds are generally operable in lowering the *n* value and the temperature coefficient of equilibrium pressure in smokeless powder compositions having a heat of explosion of not more than 900 calories per gram, some of the specific compounds, and particularly lead

Table IV

Ex.	NC 12.6% N	NG	TA	EC	Carbon black (added)	Lead stearate (nominal)	Burning rate 25° C. (in./sec.): 1,000 p.s.i.	Burning rate 25° C. (in./sec.): 1,500 p.s.i.	Graphical *n*: Pressure interval (p.s.i.)	Graphical *n*: *n*	Temp. coeff. of equilibrium pressure (percent/° C.)	Heat of exp. (cal./g.)
62	58.5	26	5		None	10	0.19	0.26	200–500	0	.3	750
63	58.5	26	5		1	10	.39	.44	1,000–3,000	0.3	.5	710
64	58.5	26			10	10	.39	.49	1,000–2,500	.6	.7	435
65	58.5	28	5.5	8	None	1	.22	.26	660–1,250	.2	.3	760
66	58.5	27	8.0	[1] 0.5	5	1	.30	.38	No plateau			740

[1] Nitrodiphenylamine substituted for ethyl centralite.
NOTE.—NC=nitrocellulose, NG=nitroglycerin, TA=triacetin, EC=ethyl centralite.

EXAMPLE 67

The following single base gas-producing compositions were prepared:

A. Nitrocellulose (12.6% N) ---------- 95.0
Ethyl centralite ---------- 1.0
Lead stearate ---------- 4.0
B. Same except for addition of 0.5% carbon black.

These compositions had the following comparative properties:

	A	B
Heat of explosion (cal./g.)	799	778
Pressure interval at lowest *n* (p.s.i.)	1,300–2,150	3,000–4,500
Lowest *n*	0.0	0.3
Burning rate at lowest *n* (in./sec.)	0.39	0.63–0.71
Temperature coefficient equilibrium pressure (percent/° C.)	0.2	0.4

From the foregoing examples and from the disclosure of the copending application, Serial No. 492,802, it is evident that while lead, its inorganic compounds and its stearate, are more effective than others. In like manner, while the addition of finely-divided carbon will raise the burning rate in the plateau region of all these compositions, some combinations of ballistic modifier and carbon are more desirable than others. From the combined viewpoints of effectiveness and economy, combinations of lead stearate and carbon are preferred.

From the examples it is further seen that relatively small amounts of finely-divided carbon will usually produce the desired burning rate increase in the plateau region. In fact, optimum results are generally encountered when the finely-divided carbon constitutes between 10 and 33% by weight of the lead and/or lead compound employed. Greater amounts of carbon may be employed up to 10% by weight of the gas-producing composition as long as the amount of carbon never substantially exceeds the amount of ballistics modifier. If the amount of carbon employed does exceed the amount of plateau-producing agent, plateau ballistics are detrimentally affected. Furthermore, increasing the carbon content of a particular powder composition brings about a corresponding increase in brittleness in the powder. In addi-

tion it will be appreciated that addition of unnecessary amounts of either the plateau-producing modifier or the carbon effects a cooling of the powder which lowers potential and ignitability. Consequently, it is undesirable to employ more of either modifier than is necessary to obtain the desired modification in ballistics.

While the ranges given for the conventional components of the single- or multiple-base powders are not critical as long as the heat of explosion of the powder with the added modifier does not exceed 900 calories per gram, it has been found that powders prepared according to these ranges are more apt to come within this critical calorific requirement.

The compositions of the invention may be prepared by solventless extrusion. In the conventional solventless process, water-wet nitrocellulose and the other ingredients are admixed in a Schrader bowl with water. The resulting slurry or paste is dried to 10% water and is colloided and dried between hot colloiding rolls which may be even-speed or differential-speed rolls as desired. The resulting colloided, dry sheets are then cut into disks or convolutely rolled into "carpet rolls." The disks or carpet rolls are then extruded to desired grain size. Flake powder may be formed by suitably shredding the sheet. The resulting grains are normally glazed, usually with graphite, to lower static generation and to improve flowing characteristics.

The compositions of the invention may also be made by the solvent process. In the usual solvent process, the water in hydrated nitrocellulose is first replaced, for example, by treatment with ethyl alcohol. A colloiding solvent such as ether or acetone is then added to the dehydrated nitrocellulose along with additional ingredients and a doughy mass is formed in a suitable mixer such as a Sigma blade mixer. This dough is then formed into green grains, usually by extrusion into cords and cutting the cords to the desired length. The green grains are then subjected to solvent removal steps. The greater portion of the solvent is normally removed by passing a warm inert gaseous medium such as air or flue gas over the grains. The remainder of the solvent which can be practically removed is then usually leached out by a water treatment. Water is then removed by an air dry step and the dry grains are normally given a glaze, usually of graphite, to lower static generation and to improve flowing characteristics.

In the usual casting process, tiny single- or double-base powder grains, prepared by either the solvent or solventless techniques, are introduced into a mold together with suitable plasticizers. When the castings are cured, preferably by warm air storage at temperature of from about 100° F. to about 160° F., the plasticizers cause the grains to coalesce into a unitary mass of plastic composition. The preferred casting process is that disclosed in the copending application of Gordon W. McCurdy, Serial No. 28,218, filed May 20, 1948.

As is well known to the art, colloiding solvent can be removed from powder grains of large diameter and web only with extreme difficulty. This difficulty increases as the web thickness is increased. It is therefore desirable to prepare grains of the multiple-base formulations of this invention by solventless extrusion or by a suitable casting process. It is preferred to extrude grains up to about 5 or 6 inches in diameter and to cast all larger grains. Casting of the larger grains is preferred because the cost and massive nature of extrusion presses large enough to produce grains of over 5 or 6 inches in diameter become prohibitive.

The single-base formulations given in the examples are preferably made by a conventional solvent process, extruded, and cut to the desired granulation. Such a process limits the possible size of the single-base grains to a diameter or web thickness which will allow sufficient removal of the colloiding solvent. Grains of solvent-colloided powder having large diameter and web are, of course, operable and as long as the heat of explosion does not exceed about 900 calories per gram, addition of the disclosed modifiers according to this invention will effect the desired modification in ballistics. It is, of course, well known that the change in ballistics during storage caused by gradual migration and evaporation of the colloiding solvent is the reason why large grains of solvent-colloided powder are not manufactured. As improved processes and means for solvent removal are developed, it will perhaps be possible to produce correspondingly larger grains of solvent-colloided powder which are ballistically stable.

It is not preferred to produce single-base grains by solventless extrusion or by casting because, in order to keep the powder in the single-base category, the plasticizer employed to bring about colloiding and/or consolidation must be of lower potential than the nitrocellulose. The necessary amount of plasticizer, therefore, so lowers the potential that such powders have only a limited application. Nevertheless, incorporation of the disclosed modifiers in single-base grains prepared by solventless extrusion or by casting still results in a low n value and a low temperature coefficient of equilibrium pressure.

If the gas-producing charges of this invention are made by solventless extrusion, the ballistic modifier or modifiers are preferably added at some time prior to dehydration of the water slurry and the additive system is mixed to a state of homogeneity. The slurrry is then dehydrate, the moist mass is rolled into colloided sheets, the sheets are male into rolls and the rolls are extruded in the conventional manner. However, it is often found advantageous to add the ballistic modifiers during the rolling operation, rather than to the water slurry. If the well known Schrader process is employed, the modifiers may be added to the hydrated nitrocellulose in the mixing bowl in any preferred order. A portion of the water is evaporated prior to rolling. The Schrader process is preferred when water-soluble plasticizers are employed.

If the charges of this invention are prepared by solvent extrusion, the ballistic modifier or modifiers are preferably added to the dehydrated nitrocellulose after it has been broken up in a mixer. The modifiers may be introduced with the plasticizer or plasticizers or may be added before or after introduction of the plasticizer as may be desired in the particular formulation.

If the grains are made by casting, the ballistic molifier is homogeneously incorporated during the preparation of the casting powder.

The heat of explosion of an explosive composition may be experimentally determined in the known manner by actually exploding a sample of the substance in a bomb calorimeter under conditions which insure complete combustion of the constituents of the composition, and measuring the heat liberated. However, in the case of smokeless powder compositions, which contain at most only small portions of inorganic material, it is usually desirable to determine the heat of explosion by calculation. The calculation of heats of explosion is especially desirable in order to accurately predetermine the calorific value of a proposed composition prior to its formulation. In this calculation, use is made of a simple relation; namely, the heat of explosion per gram of powder is equivalent to the sum of the products of the weight fraction of a given constituent by the contribution to the heat of explosion of the constituent. This contribution of the constituent is for convenience termed the "partial calorific potential" or the "partial heat of explosion," and is usually designated as "K_i." Thus, the heat of explosion of the composition is derived by the equation:

$$\text{Heat of explosion} = \Sigma X_i K_i$$

where X_i is the weight fraction of the powder component i.

For compositions consisting principally of carbon, hy-

drogen, oxygen, and nitrogen, K_i is quickly and accurately determined according to the following equations:

$$K_i = 67{,}392\ O_i - 40{,}702\ C_i - \Delta Ef_i$$
$$\Delta Ef_i = \text{H.C.} - 94{,}030\ C_i - 33{,}715\ H_i$$

where O_i is the number of gram-atoms of oxygen per gram of the powder component *i*, C_i is the number of gram-atoms of carbon per gram of the powder component *i*, H_i is the number of gram-atoms of hydrogen per gram of the powder component *i*, H.C. is the heat of combustion at 25° C. and constant volume, and ΔEf_i is the heat of formation per gram of the powder component *i* from its elements.

"Partial heats of explosion" for inorganic substances such as the ballistic modifiers of the invention are not quite as readily calculated but may, nevertheless, be determined according to methods disclosed by De Pauw in Z. f. ges. Schiess- und Sprengstoffwesen, 32, 11, 36, 60 (1937); or by Hirschfelder and Sherman in "Simple Calculation of Thermochemical Properties for Use in Ballistics," O.S.R.D. Report No. 1300, declassified and issued as PB27421S.

Actually, it is unnecessary to experimentally determine the K_i values for the various constituents of the smokeless powders in accordance with the invention since tables of the "partial heats of explosion" for these materials are available as published data. The following is a listing of the K_i values of the normally usel smokeless powder components and many of the operable ballistic modifiers in accordance with the invention.

Substance (i):	Partial heat of explosion (cal./g.)
Acetone	−1938
Carbon black	−3330
Diamylphthalate	−2190
Dibutylphthalate	−2055
Diethanol nitramine dinitrate	1294
Diethylene glycol dinitrate	1030
Diethylphthalate	−1746
Dinitrotoluene	−140
Diphenylamine	−2684
Diphenylurea	−2227
Diphenylurethane	−2739
Ethyl alcohol	−1749
Ethyl centralite	−2398
Ethyl urethane	−1639
Graphite	−3377
Lead	0
Lead acetate (trihydrate)	−282
Lead azide	385
Lead bromide	−137
Lead carbonate (basic)	−471
Lead chloride	−151
Lead perchlorate	1250
Lead chromate	977
Lead diacetylacetonate	−868
Lead ethoxyacetate	−639
Leal 2-ethyl hexoate	−1336
Lead fluoride	−127
Lead hydroxide	−189
Lead iodide	−91
Lead linoleate	−1982
Lead maleate (tribasic)	−320
Lead molybdate	403
Lead naphthenate	−2048
Lead oleate	−2010
Lead oxalate	58
Lead oxide (PbO)	67
Lead oxide (Pb_3O_4)	139
Lead oxide (PbO_2)	302
Lead methoxy propionate	−634
Lead ethoxy propionate	−1400
Lead stearate	−2000

Substance (i):	Partial heat of explosion (cal./g.)
Lead sulfate	−150
Lead sulfide	222
Lead tartrate	172
Lead tetraethyl	−1231
Nitrocellulose—	
13.25% N	1041
13.15% N	1027
13.00% N	1007
12.60% N	951
12.20% N	895
12.00% N	867
11.50% N	797
Nitroglycerin	1785
Nitroguanidine	720
Triacetin	−1284
Water	−5

In order to produce the "plateau" type ballistics of the invention, the modifiers must be uniformly incorporated with the other ingredients of the composition; that is, the modifier must be intimately admixed with the other ingredients within each particle of the composition whether the charge is a loose charge of individual grains or consists of a single grain of any desired size. The glazing or coating of a single grain or a plurality of grains in a loose charge will not produce the desired modification in the pressure-burning rate relationships. Thus, powder grains coated or glazed with a lead compound to render them free-flowing are not operable in the invention.

The advantages of the gas-producing compositions of this invention over presently available formulations are readily apparent. The compositions of this invention are characterized by distinguishing properties which have heretofore been found highly desirable but unobtainable; namely, a lower temperature coefficient of equilibrium pressure and a constant or more nearly constant burning rate over a wide pressure range within the zone of useful rocket pressures. Furthermore, by varying the carbon concentration in the gas-producing compositions of the invention within the prescribed limits, the burning rate of the plateau region, or region of low *n* value, may be greatly increased without shifting the plateau out of the zone of useful rocket pressures.

What I claim and desire to protect by Letters Patent is:

1. A gas-producing composition consisting essentially of a smokeless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of at least one material selected from the group consisting of lead, the inorganic compounds of lead and the aliphatic compounds of lead, and an amount of finely-divided carbon not substantially exceeding the amount of the said material, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

2. A gas-producing composition consisting essentially of a smokeless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead and an amount of finely-divided carbon not substantially exceeding the amount of lead, said gas-producing composition having a heat or explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

3. A gas-producing composition consisting essentially of a smokeless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead oxide and an amount of finely-divided carbon not substantially exceeding the amount of lead oxide, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of

less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

4. A gas-producing composition consisting essentially of a smolekless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead 2-ethylhexoate and an amount of finely-divided carbon not substantially exceeding the amount of lead 2-ethylhexoate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

5. A gas-producing composition consisting essentially of a smokeless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of a fatty acid salt of lead and an amount of finely-divided carbon not substantially exceeding the amount of fatty acid salt of lead, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

6. A gas-producing composition consisting essentially of a smokeless powder having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead stearate and an amount of finely-divided carbon not substantially exceeding the amount of lead stearate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

7. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of at least one material selected from the group consisting of lead, the inorganic compounds of lead and the aliphatic compounds of lead, and an amount of finely-divided carbon not substantially exceeding the amount of the said material, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

8. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead and an amount of finely-divided carbon not substantially exceeding the amount of lead, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate of relationship.

9. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead oxide and an amount of finely-divided carbon not substantially exceeding the amount of lead oxide, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

10. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith each particle thereof an amount not exceeding 10% of lead 2-ethylhexoate and an amount of finely-divided carbon not substantially exceeding the amount of lead 2-ethylhexoate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

11. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of a fatty acid salt of lead and an amount of finely-divided carbon not substantially exceeding the amount of fatty acid salt of lead, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

12. A gas-producing composition consisting essentially of a smokeless powder containing from 85 to 95% nitrocellulose and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead stearate and an amount of finely-divided carbon not substantially exceeding the amount of lead stearate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

13. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of at least one material selected from the group consisting of lead, the inorganic compounds of lead and the aliphatic compounds of lead, and an amount of finely-divided carbon not substantially exceeding the amount of the said material, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

14. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead and an amount of finely-divided carbon not substantially exceeding the amount of lead, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

15. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead oxide and an amount of finely-divided carbon not substantially exceeding the amount of lead oxide, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

16. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead 2-ethylhexoate and an amount of finely-divided carbon not substantially exceeding the amount of lead 2-ethylhexoate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope *n* of the line representing the pressure-burning rate relationship.

17. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly

incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of a fatty acid salt of lead and an amount of finely-divided carbon not substantially exceeding the amount of fatty acid salt of lead, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope n of the line representing the pressure-burning rate relationship.

18. A gas-producing composition consisting essentially of a smokeless powder containing nitrocellulose and at least one explosive nitric ester and having uniformly incorporated therein and intimately admixed therewith within each particle thereof an amount not exceeding 10% of lead stearate and an amount of finely-divided

carbon not substantially exceeding the amount of lead stearate, said gas-producing composition having a heat of explosion not exceeding 900 calories per gram and having a value of less than 0.7 for the slope n of the line representing the pressure-burning rate relationship.

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