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### (54) ELECTRICALLY CONTROLLED SOLID PROPELLANT

(76) Inventors: Charles Grix, Gold River, CA (US); Arthur Katzakian, Elk Grove, CA (US); Donald C. McGehee, Mather, CA (US)

> Correspondence Address: **MATTHEW J. TEMMERMAN 423 E. STREET** DAVIS, CA 95616 (US)

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### **Related U.S. Application Data**

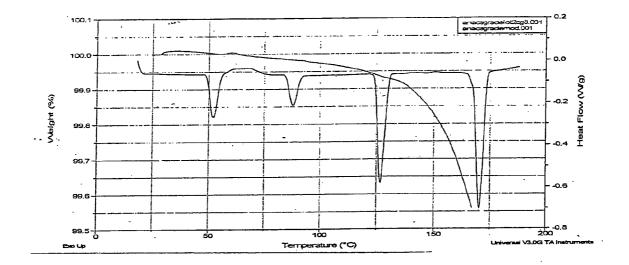
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- (52)

#### (57)ABSTRACT

An electrically controlled propellant comprising an ionomer oxidizer polymer binder, an oxidizer mix including at least one oxidizer salt and at least one eutectic material, and a mobile phase comprising at least one ionic liquid is disclosed. The PVAN polymer in the present invention may be of medium (>100,000) to high molecular weight (<1,000, 000). The present invention also may include the controlled cross-linking of the polymer using epoxy resins, the use of moisture barrier coating, the addition of an energetic combustion additives such as Chromium III and polyethylene glycol polymer.



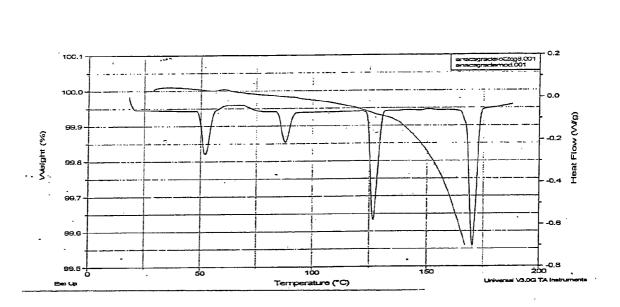
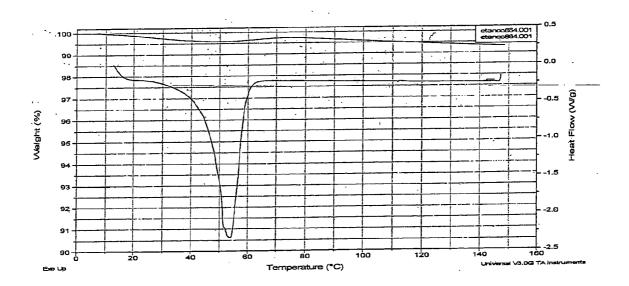


Fig. 1.

Fig. 2.



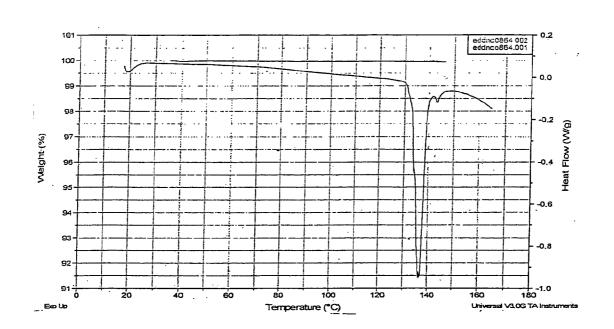


Fig. 3,



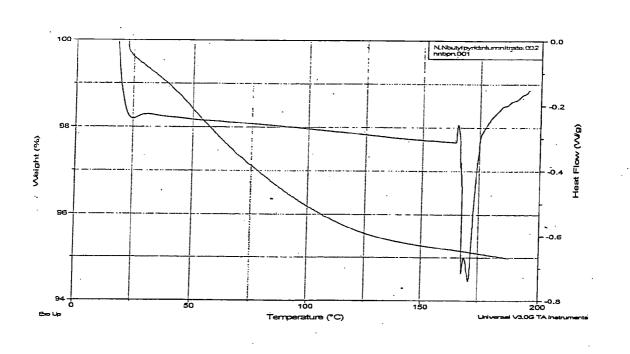
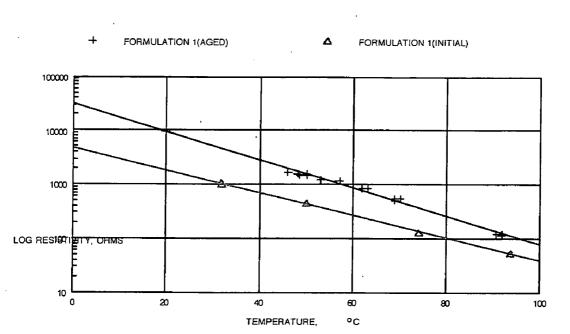
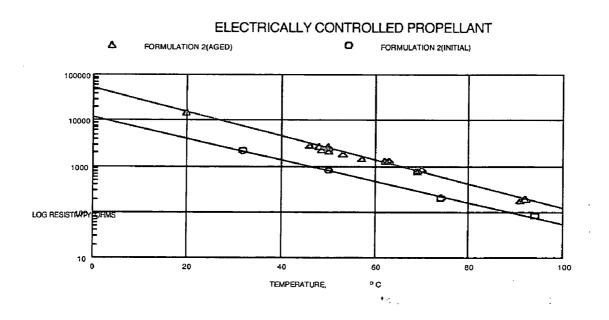


Fig. 5.

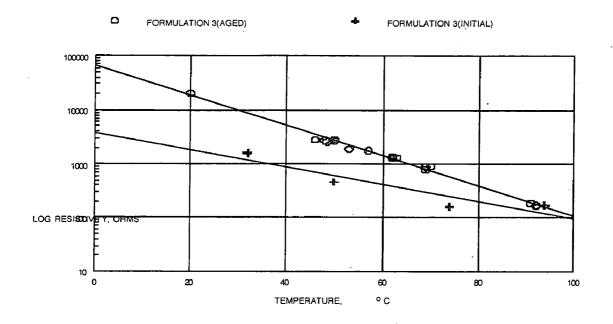


ELECTRICALLY CONTROLLED PROPELLANT

Fig. 6



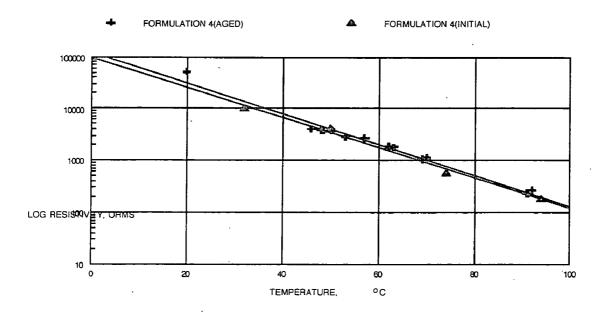
# Fig. 7



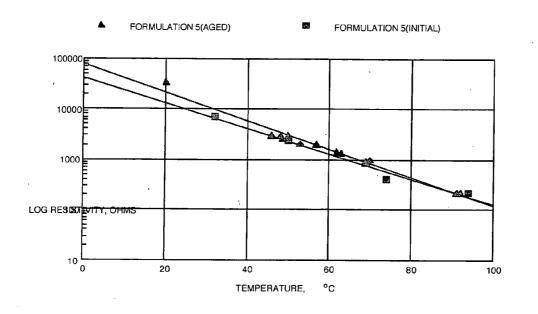
### ELECTRICALLY CONTROLLED PROPELLANT



## ELECTRICALLY CONTROLLED PROPELLANT



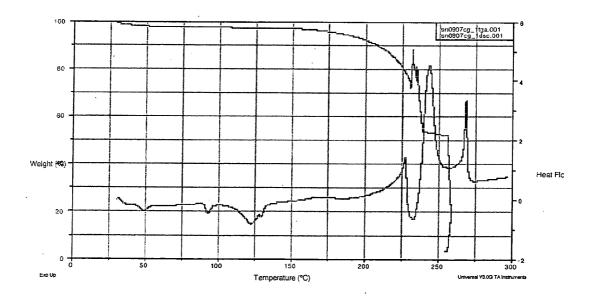
# Fig. 9



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## ELECTRICALLY CONTROLLED PROPELLANT

Fig. 10



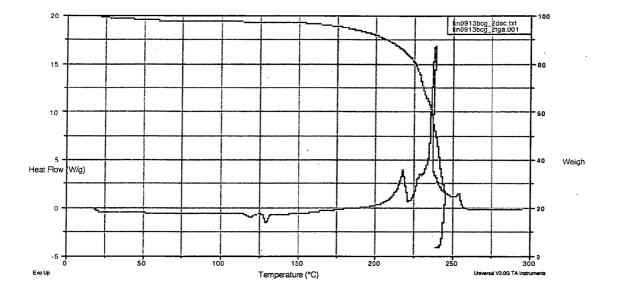
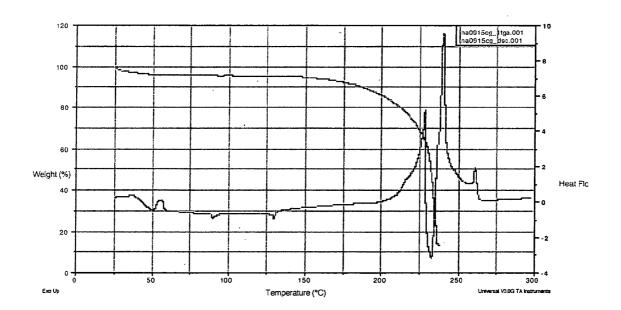


Fig. 11





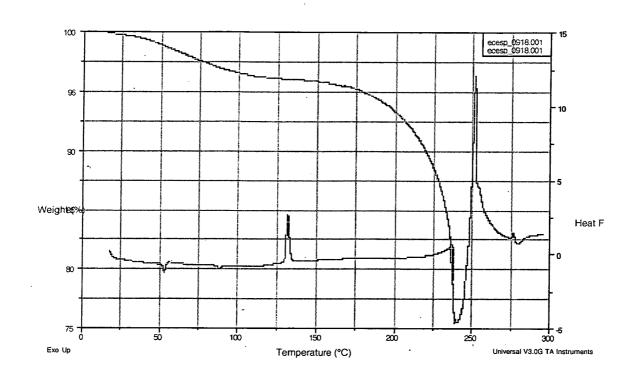


Fig. 13

#### ELECTRICALLY CONTROLLED SOLID PROPELLANT

#### **RELATED APPLICATIONS**

**[0001]** This invention claims priority from the provisional application with Ser. No. 60/375,903, which was filed on Apr. 24, 2002. The disclosure of that provisional application is incorporated herein by reference as if set out in full.

#### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

**[0002]** The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract # F04611-00-C-0010 awarded by the Air Force Research Laboratories.

#### BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

**[0004]** This invention relates to electrically-controlled propellants.

[0005] 2. General Background

**[0006]** For a number of applications, it is desirable to control the ignition, burn rate, and extinguishment of a propellant by the application of an electrical current. For instance, orbital attitude control rockets typically fire in short, controlled bursts to incrementally adjust the satellite's position. In such circumstances, there is a need to precisely control the duration and burn rate of the rocket.

**[0007]** In the past, Teflon and other substances have been used as electrically controlled propellants, but these prior art propellants suffer from two significant drawbacks. First, they often do not extinguish as quickly as desired after the electrical current has stopped. Second, these propellants provide none of their own energy, since all the energy for propellant gas generation comes from the electrical energy source.

**[0008]** Therefore, a new electrically controlled propellant has been developed, as described in U.S. patent application Ser. No. 10/136,786, the disclosure of which is incorporated herein as if set out in full. This new propellant comprises an ionomeric oxidizer binder, an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains the mix in a liquid form, and a mobile phase including at least one organic solvent.

**[0009]** This electrically controlled propellent requires the application of electrical voltage to initiate and sustain combustion, but the energy released is potentially much greater than the energy supplied. Using the combustion exhaust it may be possible to generate sufficient electrical energy by magneto hydrodynamics to sustain and control combustion once the propellant is ignited. Such a propellant system could also find useful application for "on demand" reusable gas generators and a controllable gas generator for automobile air bags.

**[0010]** However, the electrically controlled propellant disclosed in U.S. patent application Ser. No. 10/136,786 can melt or soften under certain circumstances during combustion, thereby decreasing its effectiveness. More particularly,

melting can undermine the ability of the propellant to be used in situations where the propellant must be ignited and extinguished multiple times. In addition, the fluid phase of the propellants in this application has sufficient volatility to slowly evaporate from the surface of the propellant, making it not suitable for use in the vacuum of space.

#### Objectives

**[0011]** Therefore, the inventors of the present patent have developed a new electrically-controlled propellant composition. This new composition is less prone to melting, and offers a number of other advantages, as explained below.

[0012] A first objective of the present invention is to provide an electrically controlled solid solution propellant that does not exhibit melt flow during combustion. Because of heat transfer into the propellant grain during combustion, the melting and/or softening places limitations on the motor design for multiple starts and stops. Because this is a solid solution propellant that is prepared by dissolving a suitable linear polymer into a melted eutectic oxidizer, reheating the propellant to its melting point causes it to turn liquid again. Although the use of higher molecular weight polymer raises the softening temperature and reduces the design limitation, it makes processing very difficult. Therefore, the molecular weight range of the PVAN is preferable restricted to the range between 500,000 and 1,000,000. Because, in general, the polymers being used have chemically reactable recurring groups along their chains such as primary amines, secondary alcohols and carboxylic acids, it is possible to produce cross-linking reactions between chains by reaction with epoxies, diesters and salts of diacids. The reaction rates for cross-linking can be significantly reduced by using the right curing system so that sufficient time is available after processing to cast the propellant. Once cast, the propellant is kept at 100° C., or not lower than 70° C., until it is cured. Co-oxidizers such as hydrazine nitrate, guanidine nitrate and hydroxylamine nitrate cannot be used when the crosslinking agent is an epoxy resin because they will preferentially react with it, thereby preventing the crosslinking of the PVAN.

**[0013]** A second objective is to improve the processing of the propellant. The main approach is to select a bifunctional molecule such that one of the functional groups quickly reacts with the polymer and the other functional group, which cannot react with the polymer, slowly reacts with other like groups. This provides the time necessary to cast the propellant. When the polymer is cross-linked, the propellant will no longer melt at the processing temperature. The cross-linked polymer keeps the propellant rubbery above the melting point of the oxidizer.

[0014] A third objective of this invention is to reduce the electrical resistivity of the propellant at and below room temperature while maintaining excellent extinguishment characteristics. The present invention addresses this property by using a new class of materials currently appearing on the chemical scene. These materials are ionic liquids (one example of such a material is n-butylpyridinium nitrate). They are characterized by maintaining their liquid phase over extremely wide temperature ranges, as low as  $-100^{\circ}$  C. to as high as  $+200^{\circ}$  C. (Chemical & Engineering News, "Designer Solvents", Mar. 30, 1998, pp. 32-37). They essentially behave as neutral ionic salts and, as such, have good conductivity. They also exhibit a wide range of miscibility with organic and inorganic materials. Another property of

these materials is that they do not boil in their ionic state and, as such, do not build a vapor pressure above the liquid (this property is desirable for vacuum storage). Instead, at the decomposition temperature of the propellant, the ionic property breaks down releasing the parent non-ionic molecules.

**[0015]** A fourth objective of this invention is to address the affinity these propellants have for moisture. Nearly all the ingredients making up the propellant have some degree of water solubility. The propellant, therefore, exhibits moisture pickup when left in contact with air for a given amount of time. Use of nitrocellulose functions as a barrier coat to retard moisture pickup, but does not interfere with electrical conduction of the propellant because the barrier layer is very thin.

**[0016]** A fifth objective of this invention is to provide improved chemical energy content and combustion rates in an electrically ignited propellant. Several energetic materials are used to not only increase the chemical energy of the propellants, but to increase their combustion rates without compromising the propellant extinguishment properties. Chromium III and other metal complexes increase combustion rate when ignited electrically over that of the noncatalyzed propellant.

**[0017]** A sixth objective of the present invention is to provide a formulation of a solid electrically conductive propellant composition, the burning of which produces non-toxic gases such as nitrogen, carbon dioxide and water vapor.

**[0018]** A seventh objective of the present invention is to provide a formulation whose ignition, combustion and combustion rate depend on the flow of a suitable amount of electrical current through the material.

**[0019]** An eighth objective of the present invention is to provide a solid composition that can be precisely ignited, burned, extinguished and reignited repeatedly with the application of voltage without significant change in performance characteristics from cycle to cycle.

**[0020]** A ninth objective of the present invention is to provide an electrically controlled solid propellant composition that possesses good and reproducible conductive properties over a wide temperature range without compromising ignition, combustion control, extinguishment and reignition.

**[0021]** A tenth objective of the present invention is to provide a formulation of a solid combustible composition that immediately ceases combustion when the voltage is removed or lowered below the threshold level for combustion.

**[0022]** An eleventh objective of the present invention is to provide a formulation of a solid combustible composition whose combustion rate is dependent upon the voltage level and/or electrical current level being applied above the threshold level required to initiate combustion.

**[0023]** A twelfth objective of the present invention is to provide a formulation of a solid combustible composition that can be ignited and extinguished for multiple cycles simply by the application and removal of electrical voltage.

**[0024]** Finally, a thirteenth objective of the present invention is to provide a formulation containing no volatile constituents. Further objects and advantages of the invention

will be brought out in the following portions of the specification, wherein the detailed description is for the purpose of fully disclosing the preferred embodiment of the invention without placing limitations thereon.

#### SUMMARY OF THE INVENTION

[0025] The present invention is an electrically conductive, gas-producing, solid solution propellant composition that can be ignited by applying electrical voltage and that can be extinguished by withdrawing electrical voltage. Propellant combustion rates are controllable by the amount of voltage and/or current applied above and beyond that needed for ignition. The present invention also provides a mechanism for preparation, ignition, combustion control, extinguishment and reignition of the disclosed electrically conductive solid solution propellant compositions for use in satellite control rockets and on-demand gas generators found in auto airbag inflators. The propellant composition of the invention is particularly well suited for use with orbital insertion and attitude control rocket motors for responsive and reliable satellite control. The invention can also be used for inflation of auto airbags, in a manner that is readily regulated, by controlling the voltage applied to the propellant in response to the size and weight of the person occupying the seat in the vehicle.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0026] FIG. 1** is a TGA and DSC Overlay for AN ACS Reagant Grade.

[0027] FIG. 2 is a TGA and DSC Overlay for ETAN lot 0864CG.

[0028] FIG. 3 is a TGA and DSC Overlay for EDDN lot 0864CG.

**[0029]** FIG. 4 is a TGA and DSC Overlay Curve for NBPN 0864CG.

**[0030] FIG. 5** shows the log resistivity versus temperature for the first sample.

**[0031] FIG. 6** shows the log resistivity versus temperature for the second sample.

**[0032] FIG. 7** shows the log resistivity versus temperature for the third sample.

[0033] FIG. 8 shows the log resistivity versus temperature for the fourth sample.

**[0034] FIG. 9** shows the log resistivity versus temperature for the fifth sample.

**[0035] FIG. 10** is a graph overlay TGA and DSC plot of batch 0907.

[0036] FIG. 11 is a graph overlay TGA and DSC of Propellant Formulation 0913.

**[0037] FIG. 12** is a graph overlay of TGA and DSC for propellant batch 0915.

**[0038] FIG. 13** is a graph overlay of TGA and DSC for propellant batch 0918.

#### DETAILED DESCRIPTION

**[0039]** In general terms, the present invention comprises an ionomer oxidizer polymer binder, an oxidizer mix includ-

ing at least one oxidizer salt and at least one eutectic material which maintains the oxidizer mix in liquid form at the process temperature, and a mobile phase comprising at least one ionic liquid. The present invention also includes certain changes to the general composition, including: (i) the use of a higher molecular weight (above 100,000) polymer, (ii) the controlled cross-linking of the polymer, (iii) the use of a moisture barrier coating, (iv) the addition of an energetic material such as Chromium III, and (v) the addition of low molecular weight polyethylene glycol polymer.

**[0040]** In the preferred embodiments, the ionomer oxidizer binder is polyvinylammonium nitrate (PVAN). The oxidizer salt preferably comprises ammonium nitrate (AN). The eutectic additive for the oxidizer salt may comprise a variety of salts or mixtures thereof, and preferably comprises an energetic material such as ethanolamine nitrate (ETAN), ethylene diamine dinitrate (EDDN), or other alkylamine or alkoxylamine nitrate, or various mixtures or admixtures thereof.

**[0041]** The mobile phase preferably comprises an organic liquid such as N,n-butylpyridinium nitrate (NBPN). The mobile phase may additionally comprise one or more alky-lamine oxidizer salts such as a relatively low molecular weight alkylamine, hydroxyethylamine or alkoxylamine nitrate, or various mixtures or admixtures thereof.

[0042] In one embodiment, the propellant composition of the invention comprises a polyvinylamine nitrate binder, an oxidizer mixture comprising ammonium nitrate and a eutectic amount of ethanolamine nitrate. Thus, for example, the propellant composition may comprise of between approximately 7.0% weight and approximately 12.0% weight of a polyvinylamine nitrate binder, between approximately 78.0% weight and approximately 83.0% weight of a eutectic mix of ammonium nitrate and ethanolamine nitrate, and between approximately 2.0% weight and approximately 8.0% weight of an organic liquid selected from the group consisting of N,n-alkylpyridinium nitrates such as N,nbutylpyridinium nitrate. The propellant composition may further comprise between approximately 0.5% weight and approximately 3.0% by weight of glycidylmethacrylate (GMAC) or other suitable epoxy resin.

**[0043]** The ignitable solid gas generating composition of the invention may comprise a polyalkylammonium binder (usually polyvinylamine in the nitric acid salt form and with a molecular weight of at least about 100,000), an oxidizer mixture comprising ammonium nitrate (AN) and a first additive which produces an eutectic melt which is liquid at a temperature well below the melting point of the ammonium nitrate, a mobile phase comprising ethanolamine nitrate (ETAN) and/or ethylenediamine dinitrate (EDDN) in combination with N,n-butylpyridinium nitrate.

**[0044]** The invention also provides an electrically conductive, ignitable solid airbag inflating composition that comprises polyvinylamine binder in the nitric acid salt form, having a molecular weight in excess of 100,000, an oxidizer consisting of ammonium nitrate alone or in combination with a co-oxidizer that produces a eutectic melt which is liquid at a temperature well below the melting point of the ammonium nitrate, a conductive liquid phase that is compatible and miscible with the oxidizers and binder in this composition and a suitable epoxy resin that is capable of crosslinking the polyvinylamine nitrate binder. **[0045]** In some embodiments the subject composition further comprises a combustion modifier additive, wherein the combustion modifier additive comprises a 5-aminotetrazole complex of chromium (III), iron (III) and copper (II) either alone or in combination with each other and, or, with an alkali earth chloride such as potassium or sodium chloride. The presence of these combustion modifiers causes the propellant to ignite and burn at lower AC voltages, but still extinguish when the voltage is either lowered below the voltage required for combustion or turned off.

**[0046]** In further embodiments of the invention, addition of small amounts of polyethylene glycol polymer (preferred molecular weight of 5,000 to 10,000) enhances combustion initiation and is used to lower the energy required to initiate and sustain propellant combustion as long as electrical voltage is being applied, but will not prevent extinguishment when the voltage is removed.

**[0047]** The invention also provides a method for electrically controlling the burn rate and extinguishment of propellant, comprising generally placing the above propellant composition into a conductive container, providing insulated conductors in the conductive container with exposed portions of the conductors being in contact with the propellant composition, and applying a voltage across the conductors to ignite the propellant. The method of the invention further comprises adjusting or controlling the voltage across the conductors to control the burn rate of the propellant composition, and may additionally comprise removing the voltage applied across the conductors to extinguish the propellant composition. The method may further comprise reapplying a voltage across the conductors to re-ignite the propellant.

[0048] In one preferred embodiment, a propellant composition comprising an ammonium nitrate/ethanolamine nitrate based eutectic oxidizer mixture in combination with polyvinyl amine nitrate, N.n-butylpyridinium nitrate and glycidyl methacrylate wherein the composition is fitted into a rectangular ceramic jacket fitted with two copper electrodes, one at each end of the long direction of the rectangular opening. This rectangular jacket is then placed on a rectangular phenolic section that is bonded to a support base. The electrodes extend into the rectangular opening at each end sufficiently to prevent the propellant from sliding through without first undergoing combustion. By applying voltage across the two electrodes, current is conducted along the propellant surface, igniting it and causing it to burn as long as the voltage is maintained. Immediately on termination of voltage, the propellant stops burning. Reapplication of voltage results in reignition. The rate of combustion is increased when the voltage is increased beyond that needed for ignition. Gravity causes the ceramic jacket that contains the propellant to move down as the propellant burns, thereby assuring continued contact with the electrodes.

**[0049]** Unlike previously known electrically ignitable propellant compositions, the propellant formulations of the present invention not only require electrical voltage to initiate combustion, but also requires continued application of voltage to maintain combustion. Another advantageous and unique aspect of the present invention is that when voltage is removed from the propellant, combustion ceases instantly, but can be reestablished upon restoration of the proper voltage. A third advantage of this composition is that

after cure it no longer melts at or above the processing temperature, thus enabling it to maintain its physical integrity under these conditions. A fourth advantage of this composition is that the burning rate is dependent on the applied voltage and/or current level.

**[0050]** Since the combustion-burning rate of the present invention is responsive to the voltage (energy input flux) of the electrical input and, because the heat is directly generated at the propellant surface electrically, the solid propellant is readily combustible under vacuum conditions. Unlike many other solid propellants requiring heat feedback from the burning surface to control the burning rate, no pressurization is needed to attain desired burn rates and, in reference to rocket motor applications, in attaining the desired thrust levels.

**[0051]** Due to the multiple ignition capabilities of the disclosed propellant, the present invention is ideally suited for satellite orbital insertion and attitude control rocket motor applications. For the aforementioned reasons, the proposed electrically controlled solid propellant system is more desirable and superior to the presently available plasma discharge propellant used in satellite guidance systems.

**[0052]** The present invention is essentially non-toxic and can be packaged easily since it is a solid, allowing safe storage for future use. Systems utilizing the present invention would see cost benefits from both reduced cost in materials and manufacturing.

**[0053]** Contained in the enumeration of the objectives above is the elimination of various disadvantages in the prior art. In addition, the state of the art has been advanced in several respects as will be evident below. In the process, unexpected and unique paths to the objective were discovered.

#### Material Preparation

[0054] The syntheses of approximately 200 grams each of ethanolamine nitrate, ethylenediamine dinitrate and butylpyridinium nitrate were carried out as follows: Ethanolamine nitrate was prepared by placing 122.16 grams (2.0 mol) of ethanolamine (99+%) and 163.35 grams (2.0 eq.) of ammonium nitrate (98%) into a 600 ml. glass beaker. The ammonium nitrate quickly dissolved into the ethanolamine with evolution of ammonia. The reaction was conducted in an exhaust hood to remove the byproduct ammonia formed in the reaction. The mixture was allowed to stir overnight. The next morning the solution was heated to 35° C., stirred for an additional 2 hours and then cooled to room temperature. To this reaction liquid was added an equal volume of ethanol and the resulting solution was placed in a refrigerator overnight. The next morning white rhombic crystals had formed. The crystals were collected by vacuum filtration. The collected and dried product crystals were purified by recrystallization from ethanol. The final product yield was 213.00 grams (85.9% yield). The melting point of the ETAN was determined by melting point analysis to be 53.56° C. using the TA 2920 DSC module. This indicates a pure product.

**[0055]** In a manner similar to the synthesis of ethanolamine nitrate, 90.60 grams (3 eq.) of 99% ethylenediamine were weighed into a 600 ml beaker. While stirring, 245.02 grams (3 eq.) of 98+% ammonium nitrate were added to the solution. The reaction proceeded with the evolution of ammonia. The mixture was allowed to stir overnight at room temperature. The next morning, white needle crystals had formed in the solution. The crystals were extracted three times with 300-400 ml of warm ethanol each, leaving behind pure white needles. The needles were dried in a 50° C. oven to a constant weight of 244.27 grams (87.50% yield). The melting point was measured using the TA 2920 DSC module and found to be 136.47° C., which indicated high purity.

[0056] A 2.0 molar solution of NBPC was prepared by dissolving 250 grams (1.42 mol) of the NBPC (Alfa Aesar Chemical) in 710 ml of D.I water. This solution was then passed through a 48"×3" resin bed of IRA 400 strong base anion exchange resin in the OH<sup>-</sup> form. This was done to remove Cl- from the quaternary salt in order to convert it to the quaternary base compound. The conductivity and the pH of the effluent were monitored to indicate when free base was breaking through to signal when collection of the effluent should begin. After all of the solution had been fed through the column, the conductivity and the pH of the effluent from the column measured 2.62 and 7, respectively. A deionized water wash was then put onto the column and after 18,000 ml of effluent were collected the conductivity rose to 20,000 ppm and the pH rose to 9, signifying that effluent should be collected. After 3,000 ml of this high conductivity effluent had been collected, the conductivity of material from the column measured 1,100 ppm. Collection was stopped after a total of 3,100 ml of effluent had been collected. The effluent was titrated to determine the chloride and the n-butylpyridinium content. The titration values indicated 0.888 eq. of free base and the Cl<sup>-</sup>, which was assumed to be from unchanged quaternary chloride salt, measured 0.451 equivalents.

[0057] A second ion exchange column measuring 1" I.D.× 44" long was charged with 566 ml. of Rohm and Haas C-433 weak acid resin (Na+) form. This resin was regenerated with 3 eq. of 1 N HCl to put the resin in the H+ form. The column was washed with D.I. water until the effluent measured less than 100 ppm. The effluent collected from the strong base resin bed that contained both free base and starting material was run onto the weak acid column to load the free base material and isolate it from the chloride salt. The collected effluent from the weak acid column measured 2,975 milliliters. Titration of the collected effluent showed that indeed the free base had loaded onto the weak acid resin, freeing it from the starting chloride. The free base level that had loaded on the column had increased to 0.903 eq., indicating some splitting had taken place between the weak acid resin and the residual quaternary chloride. To recover the material on the weak acid resin as the desired nitrate salt, the column was regenerated with 1,195 ml of 1.00 N nitric acid. The effluent collected from the weak acid column measured 1,580 ml. Titration indicated no Cl<sup>-</sup> and 0.385 eq. of excess acid. The product nitrate is a neutral salt and will not titrate with acid or base. The collected effluent was passed through the weak acid resin bed a second time to see if any base remained that could be removed with the excess in the effluent solution. The collected effluent and column washes measured 2,000 ml. Titration of this effluent showed again no Cl<sup>-</sup> and a 0.398 eq. of excess nitric acid, indicating no additional base remained on the column. This solution was concentrated in a 50° C. oven. The resulting solution was further concentrated on a vacuum roto-evaporator. The final net weight of product obtained was 245.83 grams. Titration

with standard base indicated that there was still excess nitric acid present in the solution. The excess nitric acid amounted to 0.565 equivalents in the product. To neutralize this remaining acid, a slurry containing 30.04 grams of sodium carbonate in 200 ml of IPA was added to the product and allowed to stir overnight. The next morning the solution was filtered and titrated. The titration showed 0.375 eq. of acid still present. To neutralize the remaining acid 45 grams of (28-30%) ammonium hydroxide were added to the product and the mixture was dried under vacuum, stripping away the IPA along with excess ammonia and water. The ammonium nitrate produced remained in the product. This was verified by titration of the product with strong base. The material was further dried in a vacuum oven at 70° C. and 30" of Hg vacuum. A TGA of the material indicated a 6.872% wt. loss at temperatures up to 140° C. The material was placed over 4A molecular sieves for 1 day and the TGA of the treated material was rerun. The weight loss was reduced to 2.75% indicating the weight loss is due to water still present in the product. This was confirmed by an IR spectrum, which showed an absorption band at 3500 cm<sup>-1</sup>. Additional molecular sieves were added and the material was retested.

[0058] A second method for preparing NBPN was investigated. The method takes advantage of the fact that the NBPC, sodium nitrate and NBPN are soluble in ethanol and that NaCl has limited solubility in ethanol. Into a 125 ml flask were placed 5.00 grams of NBPC, 25 ml. of anhydrous ethanol and 2.48 grams of sodium nitrate. The reaction was followed by titrating for Cl<sup>-</sup> as the exchange reaction produces the product nitrate salt. The NaCl was precipitated as the insoluble byproduct salt. The titration data for the reaction is given in Table 1. The results indicate 98.6% chloride removal.

TABLE 1

Experimental data for and sodium nit	the reaction of NBPC rate in ethanol:
Time of reaction min	Remaining Cl-, N
0	1.225
20	1.06
960	0.022

[0059] The ethanol was removed by evaporation and the residue was dissolved in IPA, stirred for 20 minutes and then filtered. The collected solids were washed with additional IPA and the total filtrate was titrated for Cl<sup>-</sup>. The titration indicated that 0.0035 eq. of Cl<sup>-</sup> were still present in the product. To determine if this was byproduct NaCl or unreacted NBPC, an additional 0.004 eq. (0.300 grams) of NaNO were added to the above filtrate solution, which was then stirred overnight. The next morning the solution was sampled and titrated for Cl<sup>-</sup>. The titration indicated 0.0034 equivalents of chloride were present. An additional 0.290 grams of NaNO3 were then added to the solution and it was heated to 40° C. for 2 hours followed by stirring overnight at room temperature. The solution was filtered and titrated and still showed 0.0034 eq. of Cl<sup>-</sup>. This indicated that the Cl<sup>-</sup> present might be from NaCl rather than unreacted NBPC. The solubility of NaCl in IPA at room temperature was measured and found to be 0.005 eq/liter.

[0060] The DSC and TGA scans for AN, ETAN, EDDN, and NBPN (FIGS. 1-4) are given below. The AN (ACS

Reagent Grade) is stated to be 98% purity. The DSC data also indicate that the ETAN and EDDN that were prepared as described herein are 99+% pure. As previously shown, the NBPN appeared to contain less than 3% water based on TGA weight loss as well as approximately 4% ammonium nitrate that formed when excess nitric acid was neutralized.

[0061] Medium Molecular weight PVAN is formed by the base hydrolysis of polyvinyl formamide (PVF) to form polyvinylamine, followed by neutralization with nitric acid. The recipe for preparing medium molecular weight PVF as reported in Air Products Publication No. 130-9205, *Vinamer*<sup>TM</sup> *EF Experimental Monomer for Amide and Amine Functional Polymer Systems* is as follows:

Reactants	Weight %	Weight, gr.
*Vinamer EF Monomer	15.0	150 (2.11 eq.)
Water	85.0	850
VA-044	0.1	1.0

**[0062]** \*Air Products no longer makes Vinamer monomer. The monomer was available and was ordered from Aldrich Chemical Co. as N-Vinyl Formamide 98% (lot 04418TS). The procedure given in the Air Products bulletin was followed to form the PVF and Polyvinyl amine and is as follows.

[0063] The mixture of N-Vinyl Formamide and water was placed in a 3-liter resin kettle, equipped with a glass stir rod and Teflon blade, thermometer, and nitrogen gas inlet tube. The pH of the mixture measured 4.5 and was adjusted to a pH of 9 by the addition of 0.20 grams of NH<sub>4</sub>OH. The mixture was then sparged with nitrogen gas for 5 minutes. Starting at 20° C., the mixture was stirred rapidly while the VA-044 was added. A nitrogen atmosphere was maintained during this procedure. After 1 hour the temperature was raised to 55° C. over a 60-minute interval. The heat was turned off, but the temperature continued to rise to 67° C. The reaction continued without heat and, after 3 hours, the temperature had dropped to 50° C. The heat was then turned on and the temperature was brought back to 60° C. After an additional hour at 60° C., the heat was turned off and the reaction mixture was allowed to stand overnight. The next morning the agitator and heat were turned on and 169.00 grams (2.11 eq.) of 50-wt % NaOH were placed into a 2 liter dropping funnel. The temperature of the mix was raised to 58° C. and the NaOH was added drop wise to the reaction mixture at ~1.0 ml./minute. An additional 1500 ml. of water were added to the kettle and stirring began. The temperature was raised to 84° C. The reaction solution was continuously stirred and heated for an additional 3 hours at 84° C. The stirring and heat were turned off and the solution was allowed to stand overnight.

**[0064]** After standing overnight the reaction solution turned into a gelatinous mass. It was transferred to a 2-gallon bucket and an additional 2 liters of water were added to it. This caused the mass to dissolve, yielding a viscous liquid. With rapid agitation 384 grams (6 eq.) of 70 wt. % nitric acid were added to the solution. After all the nitric acid had been added, the product came out of solution as a gelatinous mass. The liquid was removed by decantation and 500 ml of ethanol were added to the product. This caused the product

to harden somewhat. After standing for 30 minutes, the ethanol was removed by decantation and the resulting polymer was chopped up in a blender. The macerated product was dried in a 30° C. oven for 3 days, ground in the blender and sieved through a 200 mesh screen.

Preparation of Eutectic Oxidizer Compositions

**[0065]** Because the GN in the propellant formulation was found to interfere with the epoxy reaction with the polymer, it was removed. The current oxidizer formulation consists of ammonium nitrate (AN), ethanolamine nitrate (ETAN) and sodium nitrate (SN). the percent of each in the propellant formulation being; 70, 6, 8, respectively. Potassium nitrate (KN) and lithium nitrate (LiN) were evaluated in the propellant and found to be unsuitable. Propellants processed and tested with KN substituted for SN did not extinguish as well and propellants processed with LiN had poor mechanical properties and were very hygroscopic.

#### Chemically Crosslinked Propellants

[0066] It was also determined that GN interfered with the crosslinking reaction, presumably through reaction of the non-protonated NH group of the GN with the epoxy resin. Since GN was removed from the formulation, the ETAN was increased to lower the melting point of the AN. The oxidizer blend selected was heated to 110° C. to form a uniform melt. The polymer (PVAN) was added with stirring and dissolved in the oxidizer. The NBPN and 1,3-butadiene diepoxy resin (BDDE) were combined and added to the dissolved polymer mix with stirring. The mix temperature was 105° C. when the BDDE was added. Within 3 minutes of addition the mixture gelled. This formulation is shown below as #0904.

	Formulation #0904
Materia	Grams
AN ETAN PVAN NBPN BDDE	7.50 1.25 0.94 0.11 0.20

**[0067]** The above formulation was not oxygen balanced, especially with higher molecular weight epoxies such as RD-2 or vinylcyclohene diepoxide (4206), SN had to be added to the formulations. Two 10-gram batches employing each epoxy of these latter epoxy resins and SN were prepared, as shown below:

	Weight %	
Material	Batch 0937 A	Batch 0937 B
AN	71.00	70.00
SN	9.00	8.00
ETAN	5.00	6.00
NBPN	2.00	2.00
PVAN	10.00	12.00
RD-2	3.00	
4206	_	2.00

[0068] The two batches were processed as described above; the epoxy was added after all the PVAN had been dissolved in the melted oxidizer. A sample was cast of each and placed in a 50° C. oven overnight. The next morning a small piece of each was placed on a hot plate ( $\sim$ 125° C.). Sample A did not flow, sample B, however, did.

[0069] Two additional propellant batches were prepared in which the RD-2 was reduced to 2% and 1% and the PVAN increased to 11.00% and 12.00%, respectively. Each batch was processed as before and cured in a 50° C. oven for 3 days. When tested on the hot plate only the 2% did not melt and flow.

[0070] Five more epoxy resins were evaluated as crosslinking agents for the PVAN. They were: 1,4 cyclohexanedimethanol diglycidyl ether, diglycidyl-1,2-cyclohexane dicarboxylate, glycerol diglycidyl ether, glycerol propoxylate triglycidyl ether and glycidyl methacrylate. Each was first tested by adding it to a solution of PVAN dissolved in ETAN at 1:7 ratio of polymer to ETAN. To 1.2 grams portions of the PVAN/ETAN solution were added 0.05 grams of each epoxy resin. The mixtures were heated with stirring on a hot plate at ~125° C. until the material gelled. A control sample was done with the 1,4-butanediol diglycidyl ether (RD-2), which gelled after heating for 20 minutes at the same temperature. The glycidyl methacrylate and the glycerol diglycidyl ether reacted and gelled the mixture in about the same time as the RD-2. The other epoxy resins appeared to have some thickening effect but did not gel the polymer after 30-50 minutes of heating at 125° C. Quite possibly more of each of these latter epoxy resins is required to gel the propellant since their equivalent weights are higher than the epoxy resins that caused the propellant to gel. The glycidyl methacrylate differs from the other epoxy resins in that it is monofunctional in epoxy. It does, however, contain a carbon-carbon double bond that is quite active. It is believed that the final crosslinking with this material is via reactions of the double bonds with each other.

Evaluation of Liquid Conductive Additives for Conduction and Extinguishment

[0071] Propellant samples incorporating the ETAN, EDDN and NBPN were mixed and resistivity samples containing stainless steel electrodes were prepared, as well as samples to be evaluated in the combustion test apparatus described in U.S. Provisional Application Ser. No. 60/287, 799. The resistivity vs. temperature was measured for each sample at essentially zero voltage on a Wheatstone bridge using AC and DC voltage. The purpose was to see if there were any differences between AC and DC voltage in this test. The tests were also run to correlate electrical conductivity properties with ignition and combustion characteristics of the propellants. The ignition and combustion tests establish the voltage requirements for testing these propellants. The resistance, ac voltage and thrust were measured by the instrument setup also developed in U.S. Provisional Application Ser. No. 60/287,799, noted above.

Measurement of propellant resistance vs. Temperature

**[0072]** The test mold developed for measuring the resistance of the propellant samples includes  $1.5 \times 1.5$  cm. stainless steel electrodes which are embedded in an epoxy resin matrix to yield a 1.5-cm. gap between the electrodes. The propellant was cast between the electrodes. The resistance of

the mold before the propellant was cast into it was tested and measured showing that the epoxy base was not conductive. The following formulations (Table 2) were tested by preparing 20-gram batches of each and casting them into the molds. The tests were conducted to determine the effect, if any, of crosslinking on electrical resistivity.

TABLE 2

	Propellant Sample :	test form # and wt.						
Materials	1	4	5					
AN/GN, 84.5/14.5	16.00	16.00	16.00	16.00	16.00			
ETAN	8.00	8.00	8.00	6.00	6.00			
NBPN	2.00	_	2.00	4.00	4.00			
DMF	_	2.00		—				
PVAN	10.00	10.00	9.00	10.00	8.00			
1,3 BDDE	—	- $-$ 1.00						

[0073] The samples were prepared by weighing out all the ingredients except for the 1,3 BDDE and placing them in a 250 ml stainless steel beaker fitted into a heating mantle. The blend was heated to 130° C. and stirred until a clear liquid was obtained indicating complete dissolution of the polymer. Those samples that did not contain the 1,3 BDDE were cast directly into the mold described above. The samples that were to contain the epoxy resin were cooled to  $120^{\circ}$  C. The 1,3 BDDE was added and stirred for 2 minutes before casting the samples into the mold. Sample #3 could be cast, but the excess material gelled within seconds of the casting. Sample #5 was easily cast after the addition of the BDDE, unlike sample # 3, which gelled within minutes of the addition of the epoxy resin. A sample of #5 was placed on the hot plate and heated to see if the material required additional heat to gel the propellant, it didn't gel. The material did not gel until an additional amount equivalent to  $2 \times$  the amount used was added to the sample on the hot plate. The difference between sample #5 and sample #3 probably is related to the much higher level of NBPN use in #5 and the lower PVAN level. The presence of GN also could have an effect. The samples did not have to be gelled to conduct the resistivity measurements shown below

[0074] The tabulated resistance measurements made on propellant samples 1-5 are shown in Table 3 and plotted in FIGS. 5 through 9. The measurements were made as a function of temperature to establish a resistance/temperature profile for each propellant. The data shown in Table 3 were not expressed as specific resistances, since exact electrode measurements were not made. However, since the samples were made similarly, it was felt that they were close enough in area and separation to each other such that comparisons could be made. The values reported in Table 3 were the average readings obtained by using an AC bridge and a DC bridge, which gave values in close agreement with each other. The bridge units used were a CSC Design Mate 3,R/C Bridge and a Fordham LCR bridge, LC-340 with range selection from 10 ohms to 11 Megohms maximum. The samples were all conditioned in a Fisher Isotemp Oven, 200 series circulating oven with 30-inch sample leads connecting the sample plates to the bridge terminals for measurement. The oven temperature control was about  $\pm 3^{\circ}$  C. around the mean temperature obtained. The first set of readings were taken over a temperature range from 20° C. to 94° C. in steps of approximately 20° C. with at least 3 hours stabilizing time from one temperature to the next.

TABLE 3

	Resistance of Sample Specimens, ohms								
	Temperature		Sample #						
Date	° C.	1	2	3	4	5			
Dec. 29, 2000	20	5800	8700	11950	29500	12500			
Dec. 27, 2000	32	630	1330	947	6250	4150			
Dec. 27, 2000	50	260	485	273	1370	2500			
Dec. 28, 2000	74	75	125	96	355	243			
Dec. 28, 2000	94	31	49	110	115	135			
Jan. 2, 2001	62-52	670	895	1070	1560	1240			
n	50-49	903	1315	1525	2070	1625			
Jan. 03, 2001	48-51	942	1475	1525	2295	1710			
Jan. 03, 2001	58–53	715	1065	1125	1625	1215			

[0075] The samples were prepared by weighing out all the ingredients except for the 1,3 BDDE and placing them in a 250 ml stainless steel beaker fitted into a heating mantle. The blend was heated to 130° C. and stirred until a clear liquid was obtained indicating complete dissolution of the polymer. Those samples that did not contain the 1,3 BDDE were cast directly into the mold described above. The samples that were to contain the epoxy resin were cooled to  $120^{\circ}$  C. The 1,3 BDDE was added and stirred for 2 minutes before casting the samples into the mold. Sample #3 could be cast, but the excess material gelled within seconds of the casting. Sample #5 was easily cast after the addition of the BDDE, unlike sample # 3, which gelled within minutes of the addition of the epoxy resin. A sample of #5 was placed on the hot plate and heated to see if the material required additional heat to gel the propellant, it didn't gel. The material did not gel until an additional amount equivalent to  $2 \times$  the amount used was added to the sample on the hot plate. The difference between sample #5 and sample #3 probably is related to the much higher level of NBPN use in #5 and the lower PVAN level. The presence of GN also could have an effect. The samples did not have to be gelled to conduct the resistivity measurements shown below:

TABLE 4

	Candidate Formula	ations					
	Weight %						
Material	ASPEN 101	ASPEN 102	ASPEN 103				
Ammonium nitrate	70.00	70.00	70.00				
Ethanolamine nitrate	6.00	6.00	6.00				
Sodium nitrate	9.00	9.00	9.00				
PVAN	12.00	10.00	10.00				
Butylpyridinium nitrate	2.00	2.00	2.00				
BDDE	2.00	_	_				
RD-2	_	3.00	_				
GMA	—	—	3.00				

[0076] Four new samples, also prepared with ASPEN 101, were placed in the 70° C. oven: #2 and #3, using stainless steel electrodes, placed respectively 1.55 cm and 1.56 cm apart: and, #4 and #5 using Al electrodes, placed respectively 1.666 cm and 1.654 cm apart. Based on the results of the stabilization time required for sample #1, resistivities were determined as shown in Table 41. Next, the temperature of the oven was changed every 24 hours to determine the effect of temperature on resistivity. The order of temperature settings was as follows: from 70° C. to 36° C. to 52° C. Following this series, the samples were removed from the oven and placed in a cold box at 9° C. for resistivity measurements. All of the values are reported in Table 5:

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	Resistivity of Formulation #ASPEN 101 after ~24 hours individual temperature conditioning									
		Sample #								
Sample		1 2 3 4							5	
Temp. ° C.	AC	DC	AC	DC	AC	DC	AC	DC	AC	DC
70	1650	1140	330	350	340	340	1585	1585	1610	1610
36	8000	7550	3325	3670	3300	3560	7850	6020	6620	5660
52	3135	2100	1435	1370	1390	1320	4120	1700	2910	2100
9	142500	141000	50000	53000	60500	63000	76000	72000	72000	71000

[0077] A plot of the data given in Table 4 on semilog paper with the "X" axis as the Linear Temperature scale and the vertical "Y" axis as the log scale of Resistivity, produced reasonably predictive lines between 36° C. and 70° C. However, below 30° C. an unexpected increase in resistivity was observed. The implication was that a non-uniform change was taking place in the propellant below 30° C. It was suspected that something in the liquid phase may be crystallizing, resulting in a greater than normal increase in resistivity with decrease in temperature. It was also noticed that it became increasingly difficult to obtain well defined balance points on the DC bridge at all temperatures for the samples using aluminum electrodes. This effect was particularly pronounced at 70° C. and 52° C. In addition, it was noted that the aluminum electrode-containing samples had a much broader, less defined balance point than the samples with stainless steel electrodes. The effect was as though the sample resistance was a function of the AC voltage differential on the sample.

**[0078]** In an effort to confirm the moisture pick-up theory, the samples were placed in a 50° C. oven and resistivity measurements were periodically taken. The results showed a slow increase in resistivity over a 9-day period with the final values as shown in Table 6. The aluminum-containing sample resistivities appear to have returned to the Table 5 values for 52° C., but the stainless steel electrode sample values are 50% higher than before.

TABLE 6

Resistivity, Ω-cm	of Formulation # ASF	<b>PEN-101</b> at 50° C
Sample No.	AC Bridge	DC Bridge
1	2589	2323
2	2275	2188
3	2198	2043
4	8506	4174
5	5171	2989

**[0079]** As a result of these unpredictable values, a sample protocol was generated in an attempt to exclude uncontrolled variable effects. The new protocol was applied to samples prepared for formulation # ASPEN-102.

**[0080]** The values at 63° C. for ASPEN-102 (**FIG. 4**) are presented in Table 7. The sample #1 and #2 values were SS electrode samples and yielded resistivities as expected from the #2 and #3 samples of Table 510. Samples #3 and #4 each have one Al electrode and on SS electrode and provided DC bridge readings comparable to sample #1 and #2; the AC bridge readings are not consistent between sample #3 and #4 and are higher than that for the SS only electrode samples. Samples #5 and #6 use copper plates; the resistivity values are very consistent, but are higher than the SS only electrode samples.

TABLE 7

Re	Resistivity, $\Omega$ -cm, Formulation #ASPEN-102 after 24 hours Conditioning, 63° C.										
					San	nple #					
	1	2	2	3	3	4			5	1	6
AC	DC	AC	DC	AC	DC	AC	DC	AC	DC	AC	DC
690	694	592	592	894	562	1180	676	1086	1092	109	1075

Evaluation of Propellant Formulations with DSC/TGA

[0081] The overlay of DSC and TGA data for propellant batches 0907, 0913, 0915 and 091 are shown in FIGS. 10-13.

Test Propellants for Combustion

[0082] Samples of ASPEN 103 were prepared for ignition testing. Using a standard Variac coupled with a 4 to 1 step up transformer, a 6.42 gram sample of propellant, ECO00907, gave an initial resistance of 0.8 megohms in the test apparatus. A copper wire electrode was place through the wall of the test fixture on either side of the propellant test well, such that the propellant was kept in contact with the electrodes by gravity. The electrodes were recessed from the top of the fixture approximately 0.25". The test sample was ~1" wide by 1" long and 0.25" thick. Attempts to ignite the propellant at 200 and 250 volts AC were not fruitful. However, at 300 volts AC the propellant ignited and burned uniformly. The voltage quickly dropped to 276 and the current draw went to 0.81 amps. Approximately 1 gram of the propellant was consumed before one of the electrodes lost contact. The propellant had not melted and post burn examination revealed uniform combustion. Contact was lost because on one side the electrode was not all the way to the end, forcing unburned propellant to wedge between the electrode and the wall of the tester, resulting in a break in contact with the electrode. The propellant in that gap did not burn, preventing the propellant from moving up as combustion took place. This clearly shows the dependence of current flow through the propellant for combustion to occur.

**[0083]** In the next experiment the propellant was placed between the copper electrodes on the face of the test apparatus. The purpose was to view the ignition and combustion characteristics directly. These qualitative tests further demonstrated that combustion takes place preferentially along the shortest path, even if the difference in path lengths is less than 0.1 inches. Furthermore, these tests also seem to indicate that there is an effect of current flow beyond ohmic heating that causes ignition and/or continued combustion.

**[0084]** The electrodes on the test fixture were changed to flat copper strips that partially folded over at the top like the tips of skis to ensure good propellant contact. Propellants tested with this electrode configuration ignited and burned very uniformly and immediately responded to changes in voltage. The burns were controlled from barely burning to an intense burning that caused operator eyes to squint. These test samples also extinguished and ignited multiple times before running out of propellant.

Discussion

**[0085]** The resistivity measurements indicate that as the NBPN content is increased at the expense of ETAN, the resistivity of the propellant increases. However, the ETAN can crystallize below 50° C. The NBPN, being a liquid, prevents that from happening. There also seems to be an increase in resistivity as epoxy resin replaces PVAN. The resistivity data do reveal that at low levels of NBPN, the resistivity is lower than for the propellant sample using dimethyl formamide (DMF). Wherever there is propellant contact with an electrode and a pathway to the other electrode, the propellant will undergo combustion.

**[0086]** The crosslinking experiments indicated that certain epoxy resins could react directly with PVAN to effectively

cross link the polymer. This is not expected, since epoxy resins are only expected to react with free amines. No reaction is expected with and amine salt. The other surprising item is that the epoxy resin is able to react with the PVAN in the presence of other liquid amine nitrate salts without reacting at least appreciably with them. Guanidine nitrate being a nearly neutral salt appears to react with the epoxy resins. The reaction is believed to take place with the hydrogen atoms on the non-protonated nitrogens. The net result is that the propellant will no longer melt and flow at the processing temperature. Also, the pot life of the propellant at the processing temperature after the epoxy resin has been incorporated, is rather short. This can be improved by lowering the processing temperature. A drop of 10° C. in the processing temperature could increase the pot life by a factor of two or more.

**[0087]** Several important discoveries were made. The first was that PVAN will react with an epoxy resin to form a crosslinked matrix in the presence of molten AN, ETAN and NBPN, but not in the presence of GN and HN which interfere with the crosslinking reaction, thereby preventing crosslinking of the PVAN polymer after the propellant had been prepared. The third discovery was that RD-2, originally thought not workable, would crosslink the propellant and provides the necessary pot life at the processing temperature of 125° C. when no GN was present and that glycidylmethacrylate would also work, further improving the potlife. Finally, it was discovered that the non-volatile ionic liquid, NBPN, could replace DMF and DMAC, both of which are volatile, to provide conductivity to room temperature and below.

[0088] The first of these discoveries is very important because it makes possible the chemical crosslinking of the propellant without first altering the polymer to provide free amine groups. This simplified the formation of polymer for this application. The second discovery is a subset of the first find in that it reveals what kind of materials would interfere with the crosslinking process using epoxy resin. Although the prohibition to use of these and materials like them is somewhat restrictive, there are sufficient materials and combinations that can be used to still make this a viable process. The third discovery is very important because it revealed that RD-2, heretofore thought to be unusable, not only works, but also provides ample pot life at the higher processing temperature, as well as glycidylmethacrylate, which gives even greater potlife. Useful formulations based on this epoxy resin have many commercial uses.

**[0089]** Resistivity measurements made on the latest propellant formulation using aluminum and stainless steel electrodes has shown a significant difference between the two. No explanation is offered for this behavior.

**[0090]** One skilled in the art will appreciate that the present invention can be practiced by other than the preferred embodiments, which are presented for purposes of illustration and not of limitation.

We claim:

1. A propellant composition, comprising:

an ionomeric binder of molecular weight greater than 100,000 but less than 1,000,000;

- an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form; and
- a mobile phase including at least one non-volatile organic solvent.

**2**. The propellant composition according to claim 1, wherein the molecular weight of said ionomeric binder is between 500,000 to 900,000.

**3**. The propellant composition according to claim 2, wherein said ionomeric binder comprises a polyalkylammonium binder.

4. The propellant composition according to claim 3, where said polyalkylammonium binder comprises polyvinylamine nitrate.

5. A propellant composition, comprising:

an ionomeric binder;

- an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form;
- a mobile phase including at least one organic solvent; and
- a crosslinking agent for crosslinking said ionomeric binder.

6. The propellant composition according to claim 5, wherein said cross linking agent comprises an epoxy resin.

7. The propellant composition according to claim 6, wherein said epoxy resin is selected from the group consisting of glycidylmethacrylate, 1,3-butadiene diepoxy, glycerol diglycidyl ether, vinylcyclohexene diepoxy, and 1,4-butanediol diglycidyl ether.

8. A propellant composition, comprising:

an ionomeric binder;

- an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form; and
- a non-volatile ionic liquid that maintains its liquid phase over a wide temperature range.

**9**. The propellant composition according to claim 8, wherein said non-volatile ionic liquid comprises N,n-bu-tylpyridinium nitrate.

**10**. The propellant composition according to claim 9, wherein said non-volatile ionic liquid comprises dimethyl formamide.

**11**. The propellant composition according to claim 10, additionally comprising an alkylamine oxidizer salt as part of said mobile phase.

12. A propellant composition, comprising:

- an ionomeric binder;
- an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form;
- a mobile phase including at least one organic solvent; and

a moisture barrier coating.

**13**. The propellant composition according to claim 12, wherein said moisture barrier coating comprises nitrocellulose.

14. A propellant composition, comprising:

an ionomeric binder;

an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form;

a mobile phase including at least one organic solvent; and

a combustion modifier additive.

**15**. The propellant composition according to claim 14, wherein said combustion modifier additive comprises a 5-aminotetrazole complex of chromium (III).

**16**. The propellant composition according to claim 15, wherein said combustion modifier additive comprises a 5-aminotetrazole complex of iron (III).

**17**. The propellant composition according to claim 16, wherein said combustion modifier additive comprises a 5-aminotetrazole complex of copper (II).

**18**. The propellant composition according to claim 15, 16, or **17**, additionally comprising an alkali earth chloride.

**19**. A propellant composition, comprising:

- an ionomeric binder;
- an oxidizer mix including at least one oxidizer salt and at least one eutectic material which maintains said oxidizer mix in liquid form;
- a mobile phase including at least one organic solvent; and

polyethylene glycol polymer.

**20**. The propellant composition according to claim 19, wherein said polyethylene glycol polymer has a low molecular weight.

**21**. The propellant composition according to claim 1, additionally comprising a a crosslinking agent for crosslinking said ionomeric binder.

22. The propellant composition according to claim 21, wherein said mobile phase including at least one non-volatile organic solvent is a non-volatile ionic liquid that maintains its liquid phase over a wide temperature range.

**23**. The propellant composition according to claim 22, additionally comprising a moisture barrier coating.

**24**. The propellant composition according to claim 23, additionally comprising a a combustion modifier additive.

**25**. The propellant composition according to claim 24, additionally comprising a polyethylene glycol polymer.

**26**. A method for electrically igniting and controlling the burn rate of a propellant, comprising:

- providing a propellant composition according to claim 1, 21, 22, 23, 24, or 25;
- placing said propellant composition into a conductive container;
- providing conductors in said conductive container such that at least a portion of each said conductors is in contact with said propellant composition; and

applying a voltage across said conductors.

\* \* \* \* \*