SAFER LIQUID MONOPROPELLANT FOR LOW VELOCITY/HIGH ENERGY AVALANCHE CHARGES: INITIAL TESTS RESULTS, APPLICATION AND USE CASE

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ABSTRACT: Avalanche control explosives have been used since the 1950s. Though these explosives are dangerous to make, expensive to ship and need a large area for storage, they remain in use. Avalanche charges in use today are virtually all Class 1.1D Explosives (mass explosion possible), since more insensitive Class 1.4C (minor explosion hazard) materials have been largely unsuitable for avalanche control applications. “Green Environment Monopropellant” (GEM) is new to the avalanche control industry. GEM’s formulation is different than conventional explosives and is based on hydroxylammonium nitrate (HAN) as the primary oxidizer with fuel materials consisting of azoles and/or polysaccharides, among others. The modeled energy density of GEM exceeds that of available commercial high explosives. GEM is Class 1.4C and is highly insensitive to ignition by spark, flame or shock. Unlike conventional high explosives, this liquid monopropellant is safe to manufacture, and does not use any highly toxic or explosive ingredients. We have now demonstrated that it is possible to detonate GEM at low velocity using 40 grain detonation cord (also a Class 1.4D explosive) for initiation. Testing was done with 0.73kg charges of GEM and compared to a commercial emulsion explosive, both tested in wet snow (~40% snow density) for relative performance. Initial measurements of liquid and gelled GEM shock wave velocities are approximately 448 and 507 m/sec., respectively, which are comparable to commercial emulsion explosives. The GEM produced 200-250% larger crater excavations for both surface and buried charges than the emulsion explosive. Detonation of GEM also produced double (2x) the overpressure as the emulsion explosive at a distance of 6m. These higher energy, low velocity shock waves from GEM charges should be well suited to use in maritime and wet snow avalanche conditions. Since GEM is a Class 1.4C Explosive, it requires less than 1% of the land space/footprint for magazine set back as the same amount of Class 1.1 Explosive. US ATF regulations require 23.9 hectares for 454kg of Class 1.1D material, but only 0.05 hectares acre to store 454kg of Class 1.4C material. Reducing these setback distances from explosives storage magazines, can increase usable ski resort land asserts while reducing the overall hazard to the general community.

KEYWORDS: Avalanche control explosives, Class 1.4 explosives, liquid monopropellant, explosives storage

1. INTRODUCTION

Avalanche control explosives have been routinely used worldwide since the 1950s. Though these explosives are dangerous to make, expensive to ship, and require large areas for magazine storage, they remain in widespread use. The avalanche charges in use today are virtually all Class 1.1D Explosives (*mass explosion possible),* since more insensitive Class 1.4C (*minor explosion hazard*) materials have been largely unsuitable for avalanche control applications. Liquid monopropellants are new to the commercial energetics industry. They were initially developed as a safe alternative to the extremely toxic hydrazine propellant used in-space satellite propulsion (Sutton and Biblarz, 2017). With our new monopropellant development now completed, we report on testing results for these formulations as high-performance avalanche charges with reduced shipping and storage hazards.

Over the last 20-years, two major efforts have focused on advanced monopropellant compositions produced from energetic ionic compounds. The European (Bofors et. al., 2009) monopropellant (LMP103s) is based upon ammonium dinitramide (ADN) and was the first to successfully fly in space. The other monopropellant, was development was by the Air Force Research Laboratory, Edwards AFB and focused on a non-ADN propellant composition for higher performance and safety (Spores et. al., 2013). They focused on hydroxylammonium nitrate (HAN) as the oxidizer with propriety stabilizers and fuel components to develop their AF-M315E liquid monopropellant (Figure 1). A satellite using AF-M315E is scheduled to be space tested as part of NASA’s Green Propulsion Infusion Mission (GPIM) later this year.

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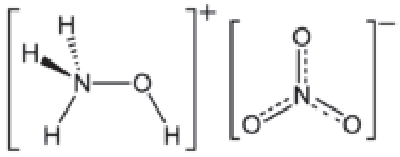

Figure 1. The molecular structure of hydroxylammonium nitrate, an ionic liquid oxidizer.

2. NEW GREEN ELECTRIC MONOPROPELLANT FORMULATION

Our own four-year development efforts focused on modifying HAN-based electrically-controlled solid propellant (ESP), Sawka and McPherson (2013) for use as a general purpose, low hazard liquid monopropellant. By eliminating the stringent and unneeded "in-space" materials requirements, such as vacuum stability, and >20-year storage life we focused on commercial use for oil/gas well stimulation and avalanche charges.

The new monopropellant is also based on hydroxylammonium nitrate as the primary oxidizer but uses low cost fuel materials of azoles and/or polysaccharides, among others (Table 1). This Green Electric Monopropellant (GEM) does not use any highly toxic or explosive ingredients. The modeled energy density of GEM exceeds that of available commercial high explosives (McPherson, 2016, McPherson and Manship, 2016) and has a high density (>1.5 gm/cc). GEM passed all testing requiring to achieve a US Department of Transportation shipping classification of Class 1.4C Explosive; and is highly insensitive to ignition by spark, flame or shock. GEM is oxygen balance and combustion products are also green with low toxicity. The primary GEM combustion products are: H_2O- 44%, CO_2- 29% and N_2- 24%.

Table 1. The generalized formulation of Green Electric Monopropellant.

Ingredient	Loading (%)
HAN	65-79
Co-oxidizer	2-7
2,2'-Bipyridine	0.1-1.0
Water	1-10
Stabilizer (Nitrogen heterocycles)	1-20
Fuel additive (soluble sugars)	15-30

US Patent: 9,534,880 and 9,182,207

GEM is safer to handle and environmentally friendly to manufacture. No high shear mixing is required and there are no explosive dusts, toxic vapors or hazardous waste created during manufacturing of GEM. The only waste product produced during manufacturing is distilled water, from the oxidizer concentration process. After oxidizer concentration, manufacturing is a simple one pot mixing process requiring only about 12m^2 of floor space for a small manufacturing facility. These smaller safer manufacturing laboratories may be well suited to more local/regional production of this propellant rather than slow expensive international shipping from a few global manufacturing.

3. INITIAL FIELD TESTING OF AVALANCHE CHARGES

Both ESP and GEM may be ignited, controlled *and extinguished* using electrical power and imbedded electrodes which results in typical burning rates of 2-20 cm/sec. at 6895 kPa, (Sawka and McPherson, 2014). We have now demonstrated that it is also possible to detonate GEM, at low velocity, using 40 grain detonation cord (also a Class 1.4D explosive) for initiation. A charge is simply prepared with liquid GEM contained in a mylar bag then wrapped with detonation cord and inserted into a cardboard container (Figure 2 and 3A). A standard #8 detonator is used to initiate the detonation cord. The ignition of the detonation cord aerosolizes the liquid GEM, which is then ignited by the shock and turbulence, causing a transition from deflagration to detonation.

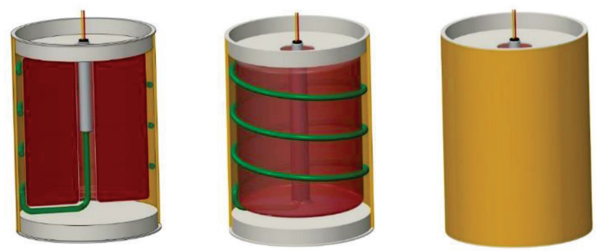

Figure 2. Left to Right. Assembly method for GEM charges. The liquid GEM contained in a mylar bag then wrapped with detonation cord with a #8 detonator positioned in the center. The whole propellant charge is then inserted into a cardboard or other suitable container.

In 2018 we conducted the first field tests of GEM based monopropellant at Mt. Rose Ski Tahoe, near Reno, Nevada. Testing was done with 0.73 kg charges of GEM and compared to a commercial emulsion explosive, both tested in wet snow (~40% snow density) for relative performance. We determined shock wave velocities using a high-speed Phantom camera. Measurements of liquid and gelled GEM shock wave velocities are approximately 448 and 507 m/sec., respectively; which are comparable to commercial emulsion explosives. The GEM produced 200-250% larger crater excavations for both surface and buried charges than the same weight emulsion explosive (figure 3 and Table 2). Detonation of GEM also produced double (2x) the overpressure as the emulsion explosive at a distance of 6m (Table 3 and figure 4).

Figure 3. Top, GEM charge contained in a mylar bag and wrapped with detonation cord and #8 denotator. Bottom, heavy wet snow blast crater formed by GEM detonation exhibits no discoloration.

Table 2. Measured blast crater dimensions for tested explosives.

Snow Pit Dimensions		
Blast at surface	Width (m)	Depth (m)
Emulsion	0.81	0.53
Liquid GEM	1.07	0.53
Gelled GEM	1.07	0.53
Blast 0.45 m below surface	Width (m)	Depth (m)
Emulsion	1.88	1.02
Liquid GEM	2.49	1.35
Gelled GEM	2.62	0.94

Table 3. Measured overpressures.

	Measured Overpressure at Radius (kPa)	
Blast at surface	3m	6m
Emulsion	25.5	6.5
Liquid GEM	31.7	13.1
Gelled GEM	31.7	13.1

This increase in performance is as predicted by the Cheetah 8.0 thermochemical code from Lawrence Livermore National Laboratory. This data also indicates that the detonation/combustion of the GEM aerosol “cloud” was highly efficient, maintaining a low velocity while providing a higher energy density charge than emulsion explosives demonstrating that for the same weight charge, GEM provides more blasting power. This is most important for hand thrown and canon launched rounds where weight and space are at a premium. These higher energy, low velocity shock waves from GEM charges should be well suited to use in maritime and wet snow avalanche conditions.

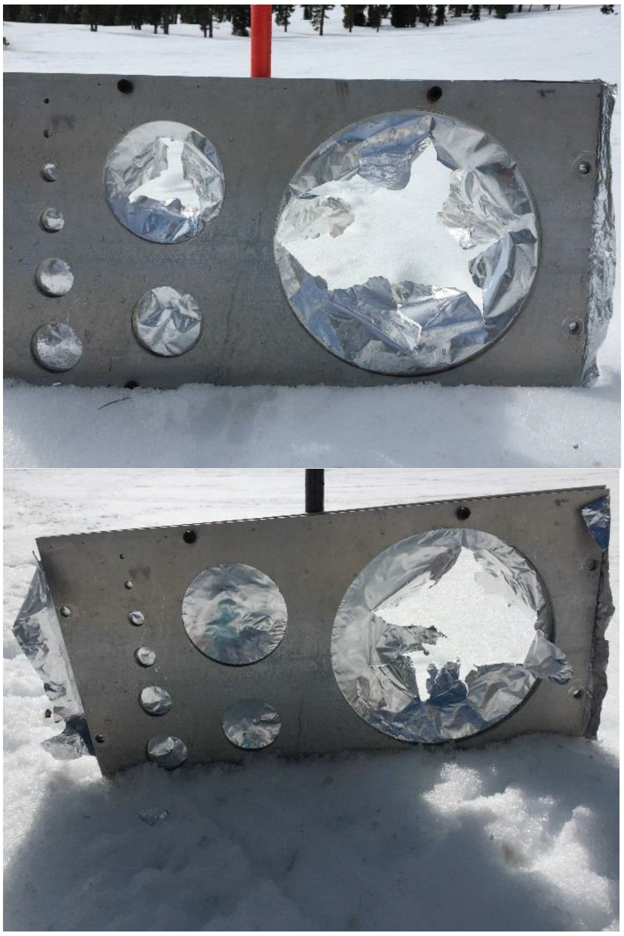

Figure 4. “Bikini”-type gauges used to measure overpressure for explosions. Each burst foil hole represents a doubling of overpressure. Top: GEM, and Bottom: emulsion explosive.

4. GEM STORAGE AND USE CASE

For ski areas and surrounding communities, ATF regulations in the United States permit Class 1.4C explosives storage magazines on less than 1% of the land area need as the same amount of Class 1.1 Explosives, in use today. These ATF regulations require 23.9 hectares for 454 kg of Class 1.1D material, but only 0.05 hectares to store 454 kg of Class 1.4C Explosive. For 2268 kg of Class 1.1 Explosive storage an area of 60 hectares is needed verses only 0.5 for the same amount of Class 1.4C Explosive storage. While set back distances for Class 1.1 Explosives storage magazines can be reduced in half with barriers such as cement wall or trees, the reduced distance is still significantly greater than the requirements for 1.4C explosives (Table 4).

Reducing these setback distances from explosives storage magazines, can increase usable ski resort land asserts while reducing the overall hazard to the general community.

Table 4. Quantity distance requirements for High and Low Explosives from American Table of Distances for Storage of Explosives (12/1910), as revised and approved by the Institute of Markers of Explosives.

	Class 1.1 High Explosive un-barricaded*	Class 1.4C Low Explosive min distance
< 454 kg	244m	23 m
<2,268 kg	387 m	35 m

5. FUTURE TESTING

The results presented here were obtained during our first field testing in Spring 2018. We planned to conduct further testing of charges during winter 2019. Our focus will be on scaling GEM charges to larger charges and testing in dryer snow type. We also plan to test GEM in gun launch projectiles and long linear charges.

REFERENCES

E. Bofors, P. Sjoberg, H. Skifs, P. Thormahlen and K. Anflo, 2009: Insensitive Munitions and Energetics Materials Technology Symposium, 2009: A Stable Liquid Mono-propellant based on ADN.

M.D. McPherson, 2015: Green Electric Monopropellant, Green Monopropellant Alternatives to Hydrazine JANNAF / NIRPS Joint Technical Interchange Meeting Proceedings.

M.D. McPherson and T. Manship, 2016: Liquid Electrically Initiated and Controlled Gas Generator Composition. US Patent 9,328,034 B2.

Sawka, W.N., and M.D. McPherson, 2014: Electric Solid Propellants: A Safe, Micro to Macro Propulsion Technology,” AIAA 2013-4168

R.A. Spores, R. Masse, S Kimbrel and C. McLean, 2013: GPIM AF-M315E Propulsion System. 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Cleveland, Ohio.