The Use of Boron Potassium Nitrate ($BKNO_3$) in Recovery Deployment Systems for High Altitude Sounding Rockets

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The mission objective of the Ramblin' Rocket Club's experimental rocketry project, otherwise known as Georgia Tech Experimental Rocketry (GTXR), is to reach the Kármán line using a two-stage high altitude sounding rocket. To ensure the safe recovery of the second stage, the energetic deployment system onboard must be able to operate in low pressure environments. To meet this requirement, the chemical compound BKNO3, otherwise known as BPN, which is commonly used in the aerospace industry, was chosen due to its oxidizer , Boron, which allows it to sustain ignition in low-oxygen environments. Other advantages of BPN are its resistance to large changes in temperature, chemical stability , and its high-pressure spikes which rival other commonly used chemical compounds for energetic systems. In order to characterize these high-pressure spikes, a testing chamber was designed and manufactured to measure the pressure readings for varying amounts of BPN. The lid of the chamber held an identical deployment system to that of the second stage, with the addition of a pressure transducer with a range of 3 to 10,000 psi. Initial testing found BPN's pressure readings to follow linearity. The significance of this data is later discussed and analyzed.

I. Nomenclature

BP	=	Black Powder
BPN	=	Boron Potassium Nitrate ($BKNO_3$)
DAQ	=	Data Acquisition System
GTXR	=	Georgia Tech Experiemental Rocketry Project

II. Introduction

To successfully recover a two stage space shot rocket, the recovery deployment system must always function nominally, and be reliable. The most common method used is a system of redundant charge wells whose energetic is BP. During the development of GTXR's recovery systems, the decision was made to switch to the energetic BPN from BP, because BPN's properties were more favored for the reliability it provides in low-pressure environments[1].

BPN, with its aforementioned properties needed to have its pressure curves tested, to determine its viability and efficacy in recovery deployment systems. The BPN used for the testing in this paper was acquired from Fire-Fox Enterprises. The formulation procured, is composed of 24% Boron, 75% Potassium Nitrate, and 1% Ethyl Cellulose, which diverges from those offered by other suppliers, such as Pyrotechnic Specialties in Byron, GA. One of the most common formulations of BPN from Pyrotechnic Specialties is MIL-P-46694 Type IA, whose composition is 24% Boron, 70% Potassium Nitrate, and 6% Lupersole.

For the purpose of testing, the assumption was made that the BPN procured from Fire-Fox Enterprises had similar aging characteristics of the formulation MIL-P-46694 Type IA[2]. This assumption allowed for the following to be considered true.

- Magnesium contamination levels in amorphous Boron fell within acceptable tolerances outlined in formulation OS 11608
- Moisture content of the BPN granules were negligible.
- Whilst in storage, No magnesium had hardened on the exterior of the granules.

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• Whilst in storage, No Potassium Nitrate had leaked from the granules.

Thus, with storage conditions presumed to be consistently maintained at 20°C with relative humidity below 80%, the trials described below can examine the performance of Fire-Fox Enterprises' BPN formulation in deployment systems.

III. Testing Procedure

Given the potential hazards posed by the handling of BPN during testing, the following procedures were made with extreme caution and safety in mind. The process began with the assembly and inspection of the steel testing chamber which had a volume of 0.056 m^3. Anything that could alter the volume of the chamber was removed. The chamber was then set onto level asphalt surface away from flammable items and gas pressure vessels. Next, a silicon high temp o-ring was attached to the 12.1 cm diameter aluminum lid which contained the pressure release valve, pressure transducer and the charge wells. The pressure release valve was checked to be in the closed position before Teflon tape was wrapped around all threads. A pressure transducer was then inspected by DAQ personnel for damages and if the transducer was approved for use, DAQ personnel would then wrap the threads in Teflon tape. Once both the transducer and pressure release valve had undergone inspection to ensure the threads had been properly wrapped, they would then be installed into the lid.

With the chamber now ready, and the lid assembled, the BPN could now be loaded into their charge wells under a minimum personnel step. This was accomplished with at least two trained personnel wearing the proper safety equipment: eye glasses, respirators, headphone ear protection, gloves, and a blast face shield. One member of the personnel would remove a single e-match from its safety box and slide the protective red cap away from the pyrogen. The empty charge well was used as a guide to shape the e-match so the pyrogen head was at the center of the charge well. Next, one personnel member would hold the plate steady while the other completed a semicircle with the e-match wire at the bottom of the charge well. Two coils were then made from the e-match wire to match the inner diameter of the charge well. The wire was then extended up the wall of the charge well and taped down with masking tape. A remaining portion of the wire was taped to the outside wall of the charge well. The rest of the wire was measured to ensure it reached the length needed to connect to the terminals before being cut. A scale was then prepared with units in grams with a single plastic cup set on top. The scale was tared to read zero before BPN was measured out. Before taking the BPN out of its static bag, all personnel were checked to be free of static electricity by discharging themselves on any on a piece of metal. Once discharged, the personnel carefully opened the tin containing the bag of BPN. Visual inspection was conducted on the BPN to check for evidence of moisture or discoloration.Once verified to be containment free, a plastic spoon was used to scoop BPN into the plastic cup to the desired weight. Given the density of the BPN, less than a spoonful is usually needed. Therefore, it was recommended that only 1/8th of a spoon of BPN be placed into the plastic cup at once. After reaching the desired weight of BPN, the plastic cup's contents was poured into the charge well and was then followed by cellulose insulation packed over the BPN until it reached the top of the charge well. To secure the contents, duct tape was then ripped into small strips and wrapped over the charge well until fully covered. The personnel then ensured no powder could escape the charge well by gently shaking the contents to observe for cracks in the tape. Once seal was verified, the wires from the e-match would be carefully connected into the wire terminal.

Following BPN packing, The lid was then cautiously installed into the testing chamber. Proper alignment was ensured to minimize movement while inside the chamber. Once secured, a minimum of four 4-40 screws were inserted around the outer diameter of the testing chamber to secure the lid to the steel casing. Then the valve was checked to be in the off position and the wires were adequately spaced apart at least ten feet from the testing chamber. Leading up to ignition, all personnel on site were alerted to imminent testing and were given appropriate ear protection at least 5 minutes before a count down started. At the end of the countdown the two wire ends were connected to a 9 volt battery. After audible or visual confirmation of ignition minimum personnel would approach the testing chamber with work gloves and a respirator. Using the pressure release valve, the pressure was slowly released with the outlet pointed away from any persons and flammable material. Afterwards the lid was extracted from the chamber and cleaned with dry paper towels until the charge well were free of debris. After each test, the chamber would be cleaned of soot, and any hardened substances would be sanded away.

IV. Results

Eight tests were conducted with varying amounts of BPN. The results are as follows.

The first test contained 5 grams of BPN which ignited however an improper seal in both the forward and aft ends of the chamber allowed for gas to escape, this led to noise polluted data where a pressure spike was not very noticeable as shown in Figure One. The second test attempted to collect data with 5 grams of BPN, but structural weakness in the lid led to permanent damage of the threads for the pressure transducer and thus testing had to be halted until a new lid could be manufactured. The third and final test again ran five grams and the data collected indicated a good seal which is represented in Figure One. This was the first successful absolute pressure reading during the testing process. Despite the low quantity of BPN, the combustion byproducts could still cause issues. Most notably after successive ignitions, the plastic wire terminals mounted to the lid began to melt, making the screw heads inaccessible, as shown in Figure Two. These had to be replaced before further testing could continue.

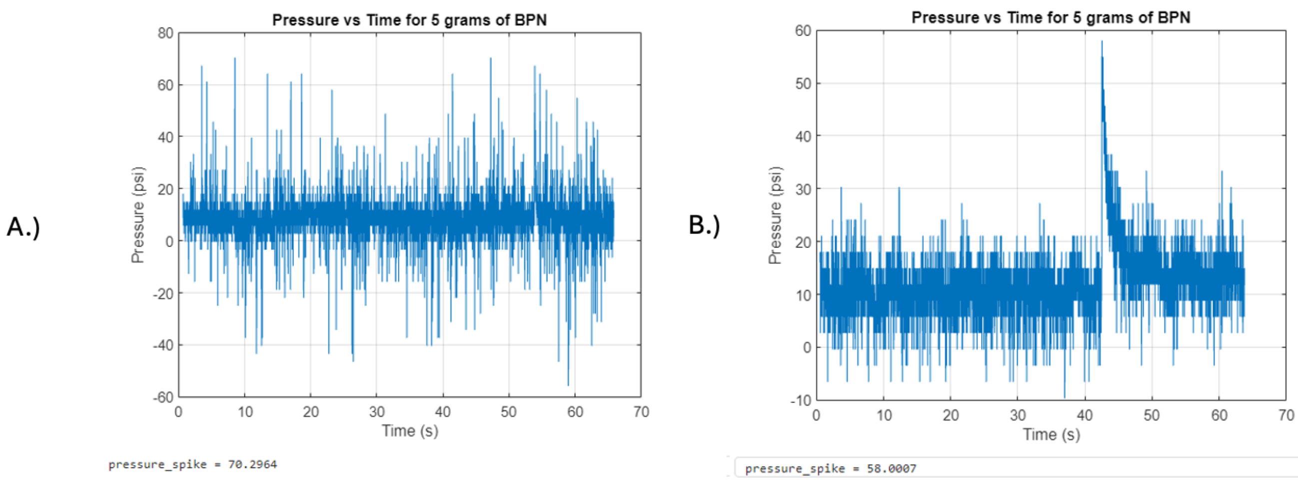

**Fig. 1 A.) Initial 5 gram test data, improper seal caused by faulty lid.
B.) 5 grams test data with new lid**

Fig. 2 Melted wire terminals after 5 gram test

The second round of testing consisted of 3 additional tests, of six, seven and eight grams of BPN. Other than the melting issues as previously mentioned in the five gram test, All of these tests occurred nominally, no permanent damage and good data flow from DAQ, however it must be noted as the quantity of the BPN increased, the soot began to leave more residue on the lid itself and was difficult to clean off after every successive test. The data is shown in figure three

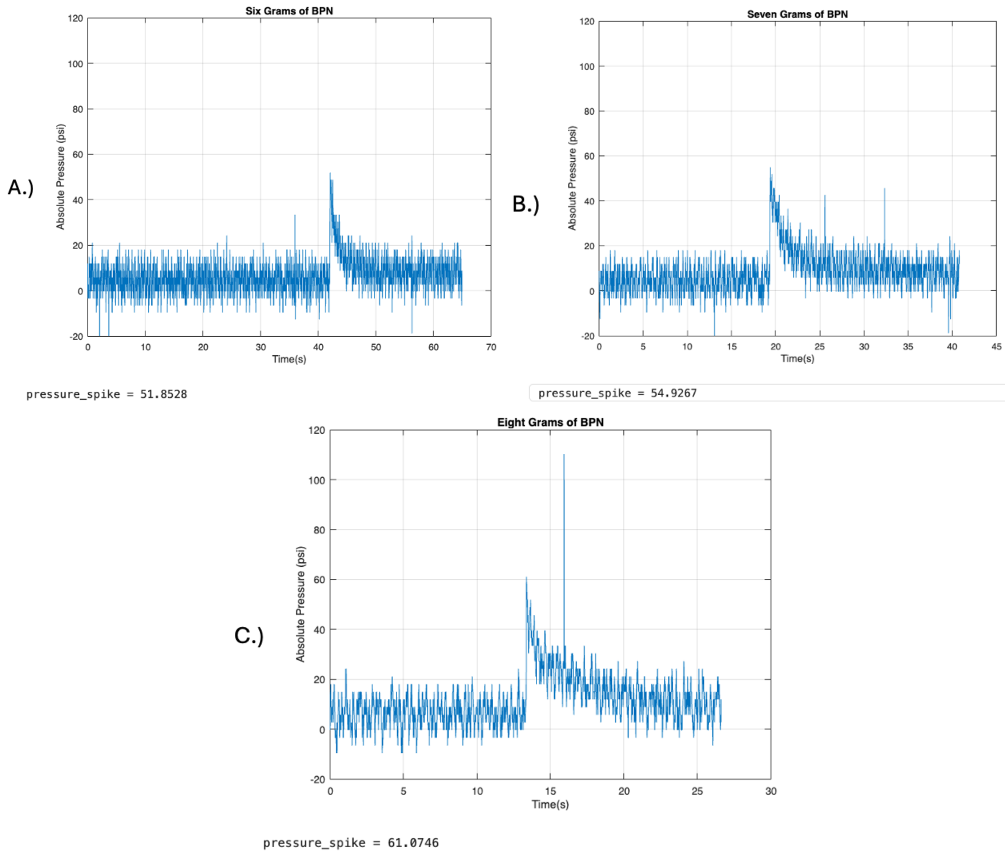

Fig. 3
A.) 6 grams of BPN Test Data
B.) 7 grams of BPN Test Data
C.) 8 grams of BPN Test Data

The final round of testing consisted of a 10 gram and 15 gram test of BPN. The 10 gram test was loaded in and ignited, its data is shown in figure four. After the 10 gram test, the wire terminals, which were attached via epoxy to the lid, snapped off and the plastic body of the wire terminal began to melt from the heat. The soot from the BPN had also caked onto the lid and side walls of the chamber, becoming hazardous to handle without proper PPE. Another observation was the formation of a brown-orange haze wherever the PVC chargewell had direct contact with the exhaust gasses after ignition. After this initial test, the lid was thoroughly cleaned and re-assembled in preparation for the 15 gram BPN test. Once the 15 gram test was loaded, it was ignited and the following was observed. Every surface had been completely caked in soot, the wire terminals, wires and PVC were completely scorched and would require replacement before further testing could commence. There was less ash produced by the cellulose insulation. As shown in figure five, the lid could not be reused with out extensive cleaning and repair.

By plotting each pressure spike over grams, we can see a linear trend for pressure, resulting in a predictable psi for certain quantities of BPN.

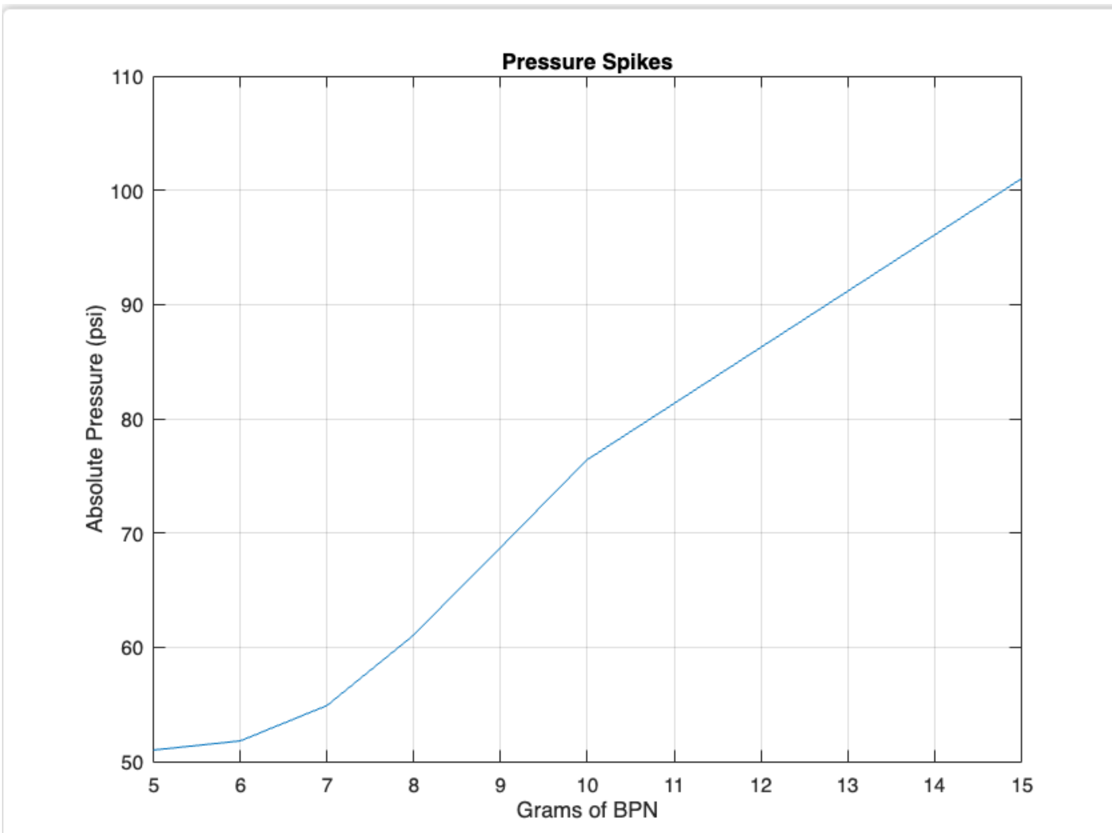

Fig. 4 Pressure spikes at each weight of BPN

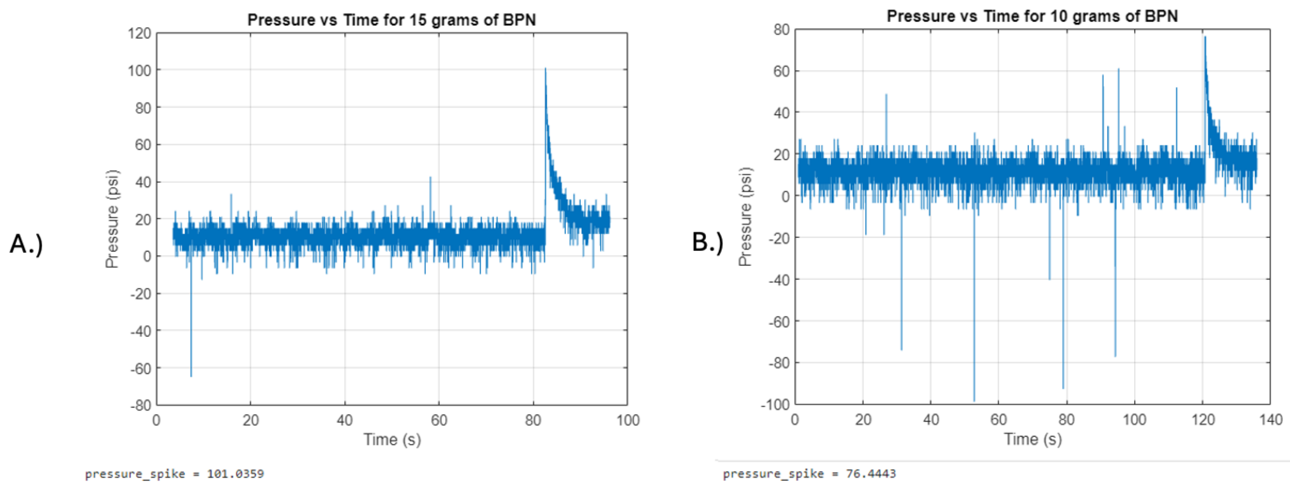

Fig. 5
A.) 10 grams of BPN Test Data
B.) 15 grams of BPN Test Data

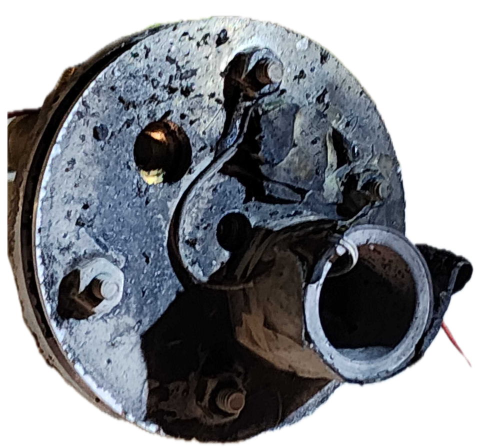

Fig. 6 Aftermath of 15 gram ignition

V. Analysis

During testing with BPN several concerns arose about its prospects for use in a recovery deployment system. These concerns can be significant enough to warrant the use of alternative energetics. However, these concerns can be mitigated with proper care and engineering, ensuring that the advantages of BPN outweigh its disadvantages.

The first concern came from the soot that is produced after the combustion of BPN. This soot is mainly carbonaceous, therefore it can be hazardous to handle. This hazard requires the handler to wear proper respiratory protection, non-porous gloves, and goggles. In flight systems, this soot can coat materials and make it difficult to handle them properly after recovery. Fabric, such as that used in parachutes, can have small amounts of static electricity which causes the soot to stick to such material and hinder pre-flight operations through the need of PPE. Steps can be taken to mitigate this such as wiping, soaking, or rinsing components that are contaminated with the soot. The quantities of BPN needed for soot to become an issue can be determined to be in masses higher than seven or eight grams.

A second issue with the use of BPN in these systems is the temperature of the air once BPN is combusted. This concern was founded from observations made after testing and during lid cleaning. At and around six to eight grams, the temperature of the air was seen to be only enough to slightly melt and deform the plastic of the wire terminals. The main issues arise from BPN quantities above nine grams. During the testing of this quantity an orange-brown residue was observed on the PVC. At temperatures of 220 Celsius the PVC of the chargewell will begin to decompose and release Hydrochloric (HCl) gas [3], which causes the residue observed. This can prove to be hazardous in settings where these chargewells are not single use. Advanced respirators are needed to be able to filter HCl and can cause severe irritation in the lungs if inhaled. At the same temperatures that PVC begins to decompose and release HCl, most commercial nylon shock cord reach their melting point which can cause fires to spread from the shock cord to the parachute, compromising the recovery system.

These issues are not minor, severe injuries or destruction to property can occur if BPN is mismanaged. Important steps must be taken to reduce the quantity of BPN needed to shear the shear rivets in the deployment system, as well as the parachute needs to be properly protected from flames and high temperatures. As previously stated the current operating design for the deployment system use less than 7 grams of BPN and keep the parachutes protected by a nomex blanket and kevlar sheaths for the shock cords.

VI. Conclusion

BPN is a strong choice for an energetic required to reliably deploy the recovery system of a two stage sounding rocket. However BPN must be chosen carefully in order to safely fly other systems in the rocket. Too much BPN can lead to hazards to the crew and safe recovery of the rocket. To improve future testing, a temperature sensor is to be added in order to correctly characterize the temperatures experienced in the chamber for varying amounts of BPN. Overall the use of BPN in recovery deployment systems can be safely used and be a more reliable alternative to BP.

References

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