



Summary of Proposed
Propellant Casting Schemes

Rev.2006/01/06

INTRODUCTION

This document summarizes a collection of six propellant casting schemes that were proposed by various participants in the *ss-main@sugarshot.org* e-mail discussion forum during the period Dec.12-16, 2005. Subsequently, a seventh scheme was proposed and is included in this document.

The schemes are presented in chronological order based on when they were proposed. For convenience, the methods are named after the person who made the proposal. In the case where more than one person contributed significantly to a scheme, both names are shown.

Comments collected (to date) on the seven schemes are also included

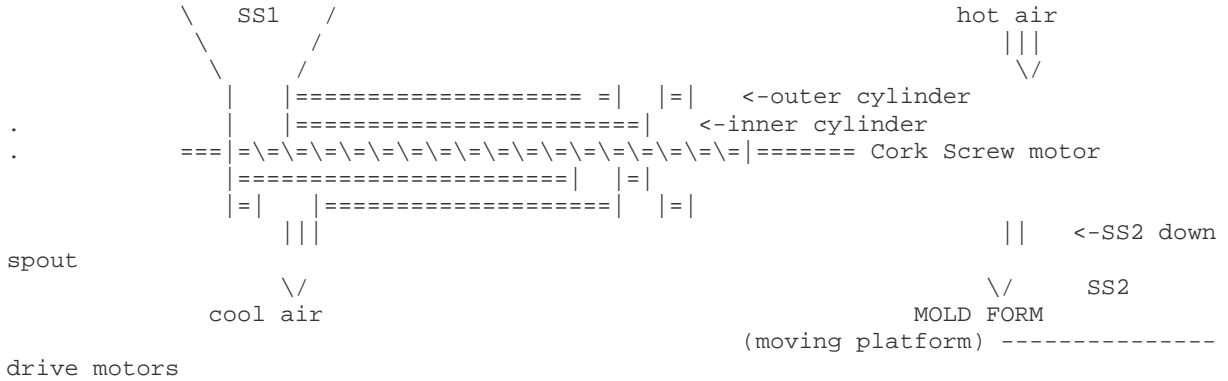
1. TUCKER/RIDER METHOD Continuous propellant feed; air or oil convection heating system
2. COLBURN/PEARSON METHOD Single jacketed steam kettle
3. VRBEC METHOD Multiple electrically-heated melting vessels
4. LEV/COLBURN METHOD Passive melting/settling of dry-mixture in casting mould
5. KRECH METHOD Aqueous liquor solutions of KN and sorbitol
6. YAWN METHOD Continuous powder feed; dribble-melting onto rotating casting mould
7. KRECH/NAKKA METHOD Liquid phase sorbitol and aqueous KN solution utilizing batch-processing approach.

The underlying purpose of producing this document is preparation for a detailed study and comparison of the various schemes by the *Propellant Development Team* with the goal of making a rational selection of one or more methods to be considered for further study including lab testing, thermal analysis and possible prototyping.

1. TUCKER/RIDER METHOD

"Cork Screw" Concept to continuously produce propellant for SS2S.

Relating to the ASCII figure, the dry powder SS1, is put in a funnel bin, to be conveyed by a "cork screw" through a hot air heated cylinder. The SS1 melts to become SS2 and is directed into a MOLD FORM by gravity.



-This is an easily transported device, trailer or pick-up truck.

- SAFETY being paramount, the "hot air temperature" is easily monitored, and the electrics (motors) are isolated from the fuel, in the event of there failure.

-The hot air source is isolated.

- Motors aren't necessary, since hand cranks could be used instead, but that sounds fatiguing and inconsistent in QC.

-The Cork Screw needs low tolerance, and should NOT contact the inner cylinder.

-Cork Screw motor speed is easily set to assure SS2 is properly melted.

- The inner cylinder and the SS2 down spout should be of fairly heavy gauge to conduct heat, that would prevent SS2 from solidifying in the spout.

-The outer cylinder can be insulated for higher thermal efficiency.

-The MOLD FORM platform will need to rotate, move in and out to distribute the SS2 within the toriodal form and perhaps change level, relative to the spout, to prevent too much air cooling between the spout and the cured propellant. That is well within the capabilities of the SS2S group.

The "Cork Screw Concept" is a low tolerance device, and should be cheap to build. The "Cork Screw" itself I've seen to clean ashes from old fashion wood stoves, it could also be called an auger or large spiral wood drill.

1) Oil as medium to transfer heat is obviously superior in many respects, however it may be expensive since hot oil will certainly cause serious burns if it contacts skin. For example hot water near 80C is bad enough, oil at ~150C is ouch, so any system using oil must certainly be designed

with great care and with very strict quality, but it looks like the "Cadillac", on the block, especially where the heat exchange occurs.

2) Thinking about "air" as the medium, quoting Mr. Nakka, ~"1 cubic metre/minute" (ref below \pm) will be the minimum required. By comparison cheap bathroom fans do ~50 cubic feet/minute
~2 cubic metres/minute, so that seems at hand. So if we used air we can circulate that through a convection oven using insulated aluminum dryer tubing. In that case the cool air output from the exchanger is returned to the convection oven for reheating. That convection oven can be gas or electric, depending on other things, and are cheap to buy used.

The inner cylinder (in which the propellant is conveyed by corkscrew), can be quite improved by aluminum fins attached by pipe clamps to the outside of it to circulate the air efficiently and improve heat exchange, those are cheap details. That's a "Volkswagen" approach, air cooled.

In the corkscrew method the propellant output should be "bucketed" away to the bulk mold. There's no way to reduce the 34 kg "charge" but it needn't be dangerously near the propellant preparation area.

That actually simplifies things. Everyone knows how easy it is to pour a pot of melt into a mold. The buckets can be insulated with fiber glass & duct tape and a lid if cooling is a problem, going to the casting station. (Special thanks to Mr. Rider for his links)

For SS2S ==>>>
Ken S. Tucker
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Copper tubing is used for oil circulation because of heat-resistance, non-sparking, easy availability, ease of fabrication. I recommend all non - thread/non expansion joints be brazed rather than soldered, to make joints stand up to heat from flowing oil. I recommend copper be well-grounded on the heater side of the block wall to eliminate buildup of static electricity and prevent any power arcing or other events from creating an unsafe condition near the propellant.

This process is very similar to what we need to do, which is produce a molten liquid propellant from a powder in a relatively constant process to fill the molds for our bates grains. This is the continuous-melt process described by Ken Tucker in his email to Richard N. requesting densities of powdered and molten KNSB.

Rather than electrical heating, I recommend use of a feed screw immersed in a temperature-regulated oil bath. The oil is circulated through a copper tube system through and behind a site-built cement block wall and heated behind the wall (to separate the KNSB safely from the oil-heating process) in a larger heat-exchange section of tubing or vessel using propane burners with variable petcock control of the flames. This way one can precisely control the temperature of the circulated oil by mounting two or more candy thermometers in the oil trough at a couple points along the feed-screw oil bath, and adjusting the flames accordingly. The oil is circulated back through the wall and back into the trough using a high temperature fluid pump, readily available.

The use of propane for heating the oil avoids the necessity of large electric generators, and gives us an easy-to-transport infinitely variable heat source for precise control of oil temperature.

Here, is what I envision as a workable prototype for a system to do this using a feed screw system similar to the plastic heating process described above (see attached .jpg for a visual conception of the apparatus).

Start in a tent we will call the mixing/milling tent. This is the prep area where our Sorbitol and KN03 will be combined and ball-milled to thoroughly pulverize and mix it just prior to processing the propellant. Prior to this the components have been stored in separate locations sealed in pre-measured amounts in plastic containers (doubled trash can liners in 5 gallon pails, liners twist tied shut and desiccant pouches inside and outside the liners).

The ball mills will use antimony-hardened lead balls for milling media. They do not spark or produce static. They are available at www.unitednuclear.com and are the only safe way to mill black powder. The level of safety with sorbitol and KN03 is similar or a little safer than black powder production. Ball mills will be loaded with pre-measured components to produce the proper ratio for finished propellant. Once milled sufficiently, completed portions of powder will be staged for feeding the production line.

Details of safety procedures for staging and milling components and short-term storage and staging of completed powder will be formalized by the propellant production team and approved by Richard and Bill.

Shortly before sufficient powder is produced for a production run (one or more complete bates grains, depending on the total production schedule prior to launch), the oil bath for the feed screw assembly will be brought up to production temperature. Once oil bath is at nominal starting temperature, the production run will begin.

The production run begins with pouring propellant powder into the hopper bin, which is agitated throughout the production run by electric vibrator to keep powder flowing down into the feed screw entry port. A key duty of crew attending the hopper is to assure there is always a good supply of propellant powder in the hopper to keep propellant production and flow constant. Electricity for vibe and for feed screw is provided on site by a gasoline generator.

After the feed screw assembly has been at temperature for sufficient time to melt propellant contained in the feed screw, a grain-making technician starts the feed screw motor, and the screw begins pulling new propellant powder down the heated feed screw barrel. As powder advances along the feed screw to the exit nozzle it melts to final consistency and is even more thoroughly mixed.

Smooth liquid propellant flow begins at the exit nozzle almost immediately, and one grain-making technician proceeds filling grain molds while others level, scrape, and otherwise complete the mold finishing and handling procedures. Once all planned molds are filled, the flow through the hopper is stopped and the hopper is removed. Excess mixed propellant powder (in hopper and staging containers) is either destroyed or moved to storage at a secure, safe location away from personnel and property. Excess mixed propellant in the feed screw may be used to fill smaller engine grain molds if any are ready. The feed screw is run until liquid propellant stops flowing out the nozzle. The feed screw motor is stopped, the oil heater and circulation pump are shut down and clean-up commences, consisting of removing the exit nozzle assembly and cleaning it with water and scraping any remaining molten or cooling propellant from the open end of the feed screw assembly.

Description of production line machinery and equipment used above and depicted in attached .jpg:

Hopper bin is like a funnel feeding into an electrically driven Feed screw (augur) encased in metal barrel (cylinder) submerged in an oil bath (trough). Assembly is of sufficient length to produce fully mixed and melted SORB/KN03 at exit end when oil bath is at a pre-determined operating temperature. Exit nozzle has heat-tolerant flexible extension long enough to allow directing/adjusting flow of completed propellant and manage filling of grain molds.

Oil bath trough has 1/2" copper pipe circuit exiting at beginning of feed screw path, running through 8" block wall to high-temp circulation pump and heating station. After heating station, copper circuit runs back through block wall and enters oil trough at end of feed screw path (with this arrangement oil will be slightly hotter near end of feed screw and cooler toward beginning, as freshly heated oil will flow into trough at the exit end and flow in reverse direction of propellant along feed screw).

Heat to oil is provided by propane burner(s) under heating vessel expansion area of copper circuit. Every professional chef knows if you want to control the temperature of anything you are cooking and keep it constant, gas flame is accurately and infinitely adjustable from a whisper to a roar. This will give us tight control over oil temperature (measured at mid-trough and end of trough with mounted candy thermometers) and will provide a plentiful and easily transported means of instant heat. Flame and heating station will be separated from exposure to propellant components and finished propellant by small cement block U-shaped wall (built on site, very easy) and by the length of the copper pipe circuit. Copper pipe and trough will be wrapped with fiberglass bats of insulation to prevent unnecessary loss of heat, fluctuation of oil temperature, and waste of fuel.

The feed screw can be researched, planned and sourced through resources found at the web-site <http://www.feedscrews.com/> . Feed screws are used in production situations like this all the time, and the temperatures and configuration involved are fairly simple engineering problems, Which Ken Tucker is already getting a handle on. I am communicating with a technical resource person at that web-site about the particulars of engineering this application and will report further with the results. If he agrees this sounds like a feasible application, perhaps we have a starting point for a simple, effective design to automate the production of propellant to a fair degree and produce it quickly and with great repeatability of quality and consistency.

There would be no concern about deforming of the screw or the tube/barrel because they can be designed for applications involving great heat. Also sparking would not be a concern because of the materials and tolerances involved. This should give us a safe and continuous means of rapidly producing the required amounts of propellant.

Some primary questions we would need to answer to bring this design to fruition are:

What length of feed screw would we need, and what dimensions will work best with the materials we are working with? These answers will likely come from our friends at the feed screw web site and Ken Tucker's expertise.

What will be the optimum design for the oil bath in which the feed screw is immersed? Will it be a trough or an enclosed sleeve? It seems to me a trough

would be an easier design to transport, fill with oil, monitor in use, and drain when it is time to take it down, but I could be way off base.

What temperature will our oil need to be at for proper heat transfer to the feed screw tube and processing of our propellant? What oil is best to use?

This is just more food for thought. I encourage anyone to add to, modify, or correct anything contained here, or use it as a springboard for something else completely that will work even better.

1. A filter screen in the hopper fine enough to catch debris or foreign material that makes its way into the powder and stop it before it falls down into the works. This will make much less likely Bill's very valid mention of a scenario involving a metal filing causing a spark, and also will improve the purity of our propellant, an important consideration.

This screen would need to be inspected and cleaned of debris before each production run to prevent fouling of the powder feed path.

2. Related to number 1, I recommend that powder that has been milled be run through a screen to filter out foreign material when it is poured from the ball mill into the staging containers as an additional step of mechanical purification.

3. To eliminate another concern of Bill's; the danger of the feed screw barrel becoming a pressure vessel, increasing the violence of an accidental ignition, perhaps instead of an enclosed barrel the augur can rest in a U-shaped metal trough, open at the top. The sides are tall enough to allow the entire augur to be submerged in the oil, and this U-trough is covered at the top with a very fine screen to prevent foreign matter from falling into the propellant as it makes its way down the feed screw. This leaves the molten propellant open to the air and prevents any pressure build-up at all, and if it ignites, the flames go straight up, as in a melting pot.

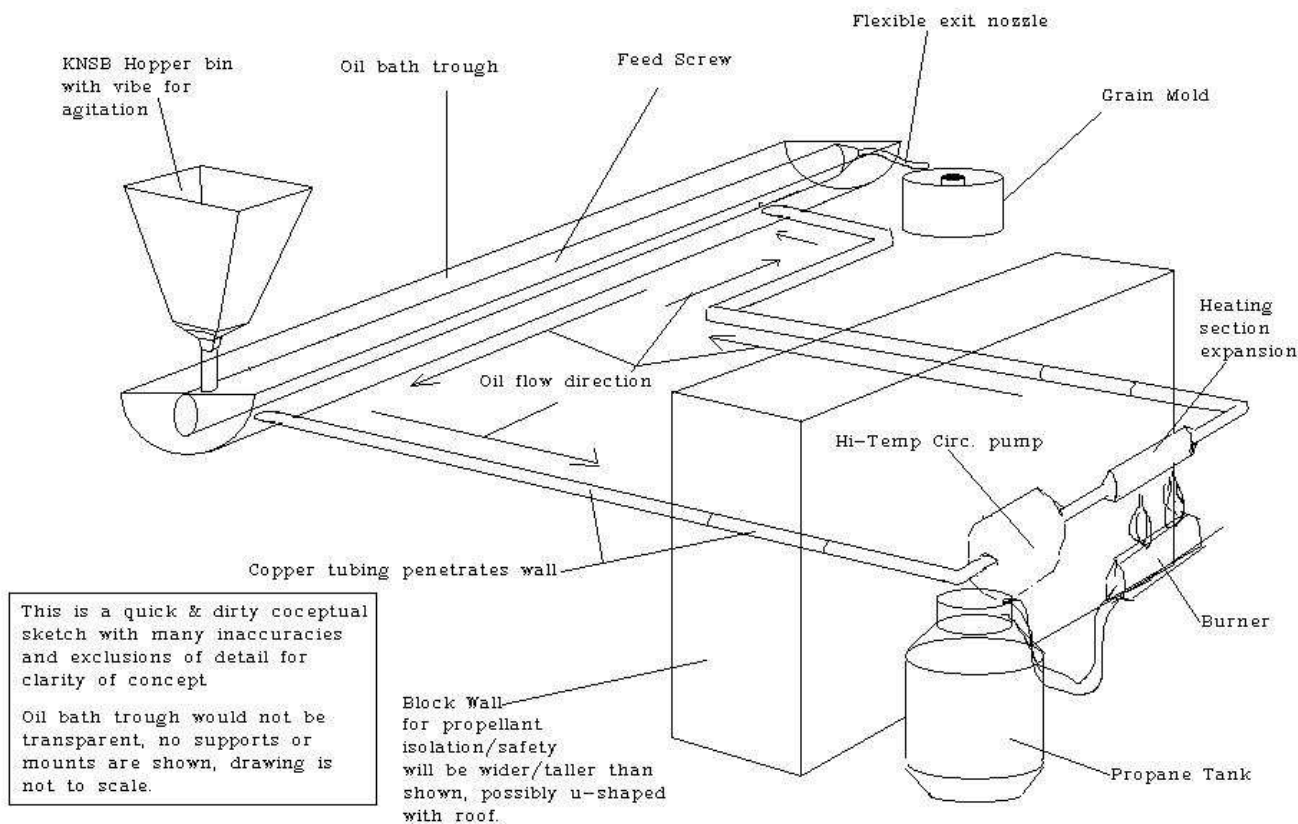
This change will reduce the efficiency of the operation of the feed screw, and will allow some heat to escape from the molten propellant. We can probably live with these losses to gain the added safety they represent.

It may be well to fully enclose the first foot or so and the last foot in a barrel/cylinder so the powder is guided on the first bit of its trip and the molten propellant is forced out into the flexible dispensing tube.

One final advantage of the open-top augur would be better ease of cleaning after production runs.

If there is a level of interest in further investigating this method, I recommend Ken Tucker visit the Feed Screw website <http://www.feedscrews.com/> and converse with Ron (link in upper left corner of home page) about this project. It sounds like Ken is already crunching numbers and doing design work and research preliminary to going a similar direction, and he is definitely our thermodynamics maven.

Brent Rider



2. COLBURN/PEARSON METHOD

I own a stainless steel double-jacketed kettle used for steam heating. I got it to use for asphalt propellant years ago and have never used it. It has a 2 inch outlet. For casting t n t, the arsenals used a flexible tube, stored at a height greater than the liquid level. They then just dropped the tube to a lower height to pour, no valve at all.

This kettle looks to be about 10 gallons.

It has a wall of about 1/16 inch apparently, is perhaps 30 inches in diameter by about the same in height. The jacket seems to be about 1/2 to 5/8 inch and completely covers the "pot" from the upper rim to the 2 inch outlet at the bottom.

BC

Just wondering if anyone has put any thought in to Steam Jacket Melting pots.

I used to work in a number of kitchens working my way through college. In the big kitchens we made soup and other products in Huge Steam Jacketed double broilers. The temps were easy to control and caused no hot spots in the mix.

I think that a stream system and jacketed pots could be designed to be somewhat portable.

Scott Pearson

3. VRBEC METHOD

I agree with Randy. Melting Sorbitol first and then adding Potassium nitrate would probably be best. If we could order Potassium nitrate already factory milled to the right particle size we don't even need a mill, which would save us time and money. Personally I like things that are simple and robust. I would go with a simple scheme. Melting and pouring would be done at three melting stations so that each would produce 4 grains in a period of 1-2 days, which is quite manageable. Stations would be separated at least 100 meters apart. Each station would be manned by only one to maximum two operators and would be equipped with following items: electrical generator, melting pot, heating device(oil bath or just an electric hot plate), electric stirring device and a mould. First all Sorbitol would be melted and then the operator would add Potassium nitrate in several batches while continuously stirring. When propellant is thoroughly mixed it would then be poured into the mould. Melting pot could be mounted on a pivot so the heavy pot wouldn't have to be lifted. All that an operator would have to do during process is to closely control the temperature. From a safety point of view there isn't much to say. Operator would be equipped with a heavy duty protective clothing with face protection. Clothing would be similar to what firefighters are using- covered with a layer of reflective material to protect from radiative heat. Alternatively there could be a small garden pool (about 5-10 meters from the melting station) filled with water so that an operator could jump into if accidental ignition occurred. Good thing about a melting pot is that if the propellant would ignite all of the energy would be directed upwards and there is no fragmentation. The only thing that we would have to worry about is radiative heat and droplets of molten potassium carbonate(product of combustion). As Richard has proved with his experiments KNS propellant is not very prone to autoignition so I think that if the whole process is done with common sense the chances of serious accident are remote. It just came to me that if we will be doing this in the middle of Black Rock Desert there will be a very small relative humidity (correct me if I'm wrong)so we won't have problems with handling sticky propellant blocks.

Andrej Vrbec

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4. LEV/COLBURN METHOD

Lot of interesting ideas. I have one too - There is a problem mix and cast batch of 50 kilos of propellant. Do we need them mix and pour at all?

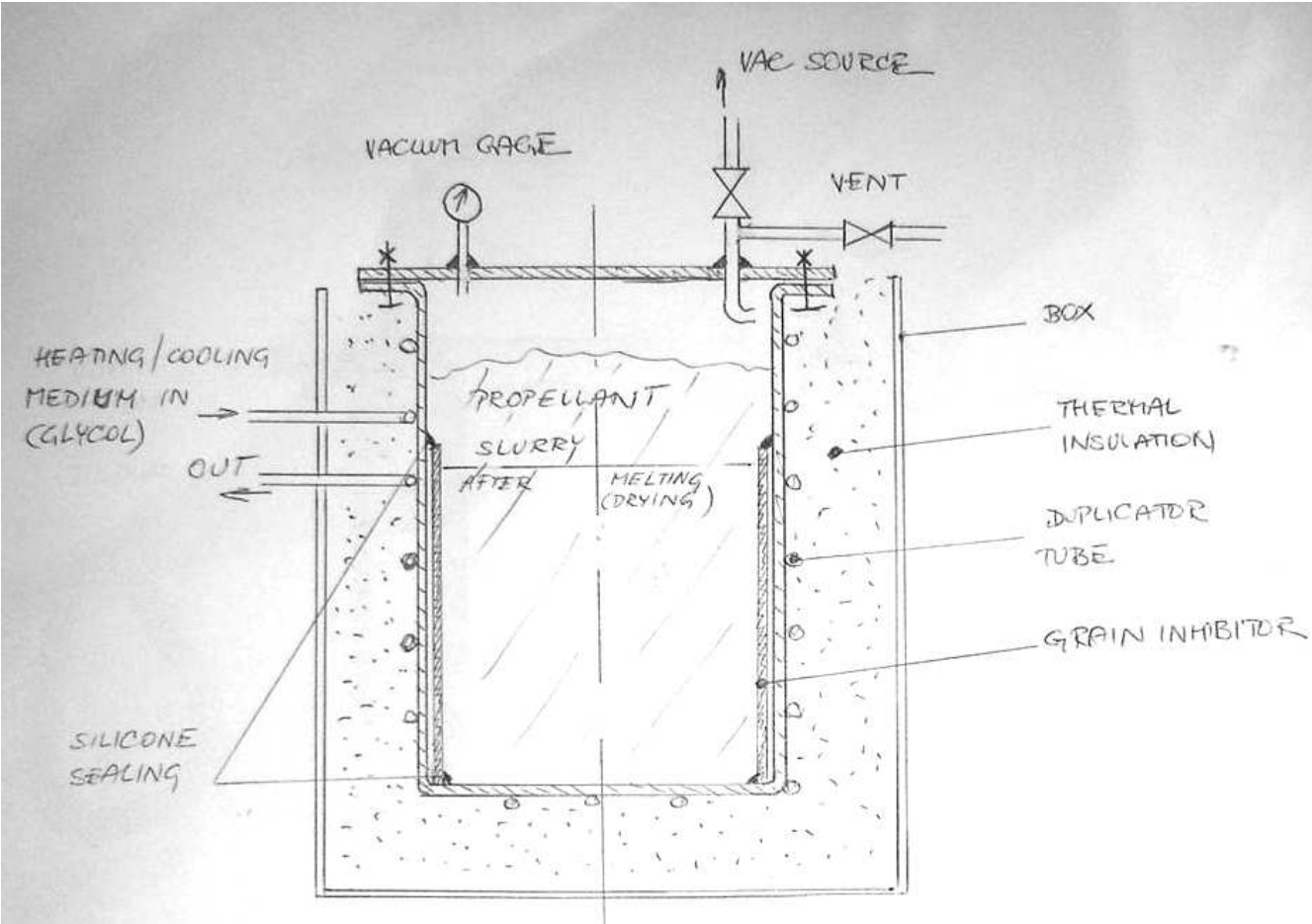
If slurry of the sorbitol, just a little bit water and KNO_3 would be placed into the melting bowl [lets say melting & evaporating can] of the same dimensions as the grain inhibitor or, slightly higher for potential evaporating bubbles, heating and casting could be performed directly in the grain inhibitor. The grain inhibitor - material must be done from material sustainable to survive high temperatures anyway. If the apparatus would be vacuum tight, melting, evaporating of water from the mixture & cooling could be done without any manipulation with the propellant. Because of vacuum process there would be no bubbles, amount of water should just enough to make the mixture not flammable; therefore would be easy and safe to mix the batch prior the heating just by hand.

Jacketed heater would be very likely lot more safe than direct heating, regular glycol-based antifreezes would be suitable as heating/ cooling medium.

I see just big disadvantage right now - process would be very time consuming, because almost all the energy necessary to heat-up mixture to the boiling point and evaporate all water from the slurry must be transferred through the bottom of the grain [grain wall has high thermal resistivity anyway].

I haven't seen any big sedimentation during melting/pouring at all - even if there would be any, I think it could be eliminated by heating on the temperature where the sorbitol is still heavy liquid....It sounds nicely - but is it feasible?

r+



For a recent project, I used a sorb propellant for a gas generator. By using a slightly longer casting tube, I was able to place the entire amount of the grain in a powdered condition into the casting tube, around the mandrel. Now I did pre-press it a bit to consolidate it. That is a step we could not do with the size of the SStS grains. But the next step was drastically simple. The entire casting tube, mandrel and propellant were heated together. The propellant after curing was marble-like achieving a high density (which I did not measure). Now in a vacuum, the pressing step might be omitted. This is a very safe process because nothing is done with heating until the assembly is in an oven at which time it can be heated and cooled remotely (and evacuated). The casting tube can be nested with an extension, to get the pre-melt volume, which is then removed after cooling.

1. The propellant must end up in the casting tube. It is done with this method in the safest possible manner, cold and unmelted.
2. The propellant must be heated. In this method it is heated remotely, no personnel required to be near during the entire heating and cooling cycle.
3. A precise amount of propellant is to be added to the casting tube. In this method it is done by dry weight, no losses due to material sticking to pouring funnels, etc.
4. This method has little heritage. Has to be proven by much more testing.
5. Little equipment is required, pretty much the minimum for making the propellant- a heating unit and a vacuum unit and the grinders and blenders.
6. The propellant is not melted in bulk, so it is a slow process or one requiring many heaters. One heater may do multiple grains, however.

BC
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5. KRECH METHOD

There are many advantages of working with liquids and solutions.

1.) No milling of the KN is required if a solution of a hot KN/H₂O is used for the oxidizer stream. This eliminates at least one process step and saves considerable time and expense. If heated to ~110 C, ~2000 kg of KN will dissolve in 1 kg of water. For a 34 kg propellant casting, this is ~ 22 kg of KN and 11 kg (liters) of water. The total volume is less than 30 liters. A 2 cubic ft (58 liter) double ended cylinder is all that is required for the dissolution, heating, and distribution of the KN liquor.

2.) A second, identical container can be used for the hot sorbitol or SB/H₂O solution at ~110 C.

3.) The two liquid streams can be directed through a static mixer heated to ~125 C to an identical third cylinder heated to ~125 C. If the receiving cylinder is evacuated and the supply cylinders are evacuated, and the supply cylinders are pressurized with N₂, the two flows can be regulated to produce a uniform 65/35 KNSB solution which would flow into cylinder 3. No auger, liquid pump, etc. would be required. If a multi ribbon slit injector is used to admit the mixed solution into cylinder 3, a significant amount of water could be removed by the vacuum pumping.

4.) Once cylinder 3 is filled, you should have properly mixed molten KNSB liquor at 125 C. If the cylinder is heated under vacuum to ~150 C, more water will be driven off, and the mixture should be water clear.

5.) At this point the hot clear mixture can be vacuum transferred to a heated grain casting chamber with the liner and a central core plug. If the top plate has a multi-plate ribbon slot injector, the final dewatering of the propellant grain will be accomplished.

6.) This will produce a dry, void free, high density propellant grain requiring minimal finishing all without active milling, pumping, mixing, or the handling mixed oxidizer/fuel powders so there is absolutely no static electricity issues at all.

7.) While a bit more expensive than the backyard stove method of dewatering and hand casting, it will be extremely cheap compared with the procurement, assembly, operations and cleaning of the convention kettle system for the quantities of propellant required. It can also be remotely operated if desired, so that the only close in operations would be the loading of the KN and SB into cylinders 1 and 2, and the removal of the cooling propellant grain from apparatus.

The entire process requires only an electrical generator to power hot fluid pumps for the cylinder and plumbing heating, and a water pump for water ejector vacuum pump.

A modified gas fired hot water tank heater with flow thru booster could be used to heat the recirculated oil for cylinder heating. Alternatively a steam or pressurized hot water generator could be used for an environmental friendly system without oil. A recirculating water ejector pump can be used to supply the vacuum.

The steam or pressurized hot water system may be more attractive as a water tank truck could be rented and parked at the launch site to supply the water and for fire suppression if required.

If you use the heated liquids method with gravity and/or pressure and/or vacuum and a static mixer (see attachment) you can mix your propellant quite accurately without an auger at all. Extending the concept further, if you evacuate the grain casing mold, you can suck the slurry into the casing and vacuum remove the water at the same time.

The water remaining in the propellant slurry will be determined by the slurry temperature by Raoult's law. (It's the same process as making real hard candy.) If you use a vacuum slit filling process method going into the vacuum grain casing device, you will force the slurry into ribbon candy like sheet with great surface area and further remove the water to the vapor pressure and de-aerate the propellant at the same time. (There won't be any air since the propellant is so hot and the solubility of gases in a solution near the boiling point is vanishingly small.) This method would give near theoretical density to the propellant grain.

You don't need a very good pump either. A large water aspirator pump that pulls to 20 torr would be sufficient and have no moving parts.

Robert Harry Krech
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6. YAWN METHOD

If the mixing is done at Black Rock, hot air might be cheap. Depending on the season and the time of day, the environment could supply a good bit of heat. A few movable mirrors might help a flat panel heater get its charge up to the melting point of sorbitol.

Slightly more seriously, what about using the casting tube itself as the melting vessel, and using hot air to melt dry propellant as it is dribbled into it a little at a time?

I envision the casting tube sitting on a turntable, rotating slowly. A regulated heat source supplies hot air through a long insulated pipe. A hopper with a screw drive meters in small amounts of powdered mix, dropping it evenly onto the rotating surface. Hot air melts the new addition and fuses it to the surface, forming a thin layer of new propellant on each revolution. The lower end of the developing grain could be allowed to cool, only the upper surface needs to stay hot. A loose cover keeps heat in, unwanted objects out, and supplies a platform for the temperature sensors and a cheap PC camera. This device operates with the attendant at a safe distance, lounging in the "safety" pool behind the wall and in the shade, watching the "show" on a laptop. That's my job.

Perhaps two hoppers could be used, one for KNO_3 and one for sorbitol, each with a regulated dispenser tuned to the proper ratio, and a mixing device installed downstream to create the dry mix just before it is dribbled in. Inclusion of air in the propellant might be a problem. This method does not seem compatible with vacuum-processing. But if one spun the casing at HIGH speed....

Jimmy Yawn
jyawn@sfcc.net

7. KRECH/NAKKA METHOD

After studying the preceding six proposed casting schemes, I attempted to come up with a proposal that avoids potentially hazardous features of certain schemes, combined with the innovative and positive features of other schemes. The scheme proposed here is based primarily on the Krech method, which takes advantage of the liquid phase of the propellant constituents to produce a consistent end product in a relatively safe and expedient manner.

In this method, powdered sorbitol is heated within a holding tank to liquid form (tentatively @130°C). Within a second tank, potassium nitrate is dissolved in hot water to produce a highly concentrated solution, tentatively 80/20 ratio @ 160°C. The two tanks together hold enough liquid to produce one 34 kg propellant segment.

When the required temperature within the two holding tanks has been attained by use of a suitable heating method, the "casting" process begins. Individual valves on each tank release a metered amount of the two liquids into a single transfer pot, tentatively enough to produce a 2 kg batch of propellant. A beam balance, upon which the transfer pot sits, is used to accurately meter out each constituent. The combined liquids, which presumably would be of a fairly low viscosity (similar to liquid honey?) would be stirred briefly to fully integrate the two liquids.

The transfer pot would then be fitted with a non-secured lid and vacuum applied. Due to the high vapour pressure of the hot solution, the residual water would be drawn off presumably quite rapidly. The beam scale would be used to determine when all moisture has been removed.

The transfer pot would then be mated to the casting mould assembly for production of the propellant segment. The mould assembly would be fitted with a non-secured lid, sealed to retain vacuum within. The valve on the bottom of the transfer pot would then be opened and the propellant slurry would be drawn into the casting mould by atmospheric pressure. When all propellant within the transfer pot has been drained, it is once again filled with the two liquids and the process repeated. For a 34 kg propellant segment, the process would be repeated 17 times. On this basis, the time to produce one segment has been estimated to be roughly 10 hours. On a 24 hour operating cycle, the required 12 segments could be produced in 5 days. The overall time can be reduced by using a transfer pot with a greater capacity (3 or 4 kg?) or by using two such apparatuses.

One advantage over the Krech method is a reduced energy requirement, which can be approximately equated to a directly reduced production time. Calculations of the estimated energy requirements for one 34 kg segment by the Krech method is 10.3 kilowatt-hrs. The method proposed here has a calculated energy requirement of 6.4 kilowatt-hrs. These figures compare to an energy requirement of 1.6 kilowatt-hrs. for the "standard" casting method of melting powdered sorbitol and KNO₃. Details of these calculations may be found at <http://sugarshot.org/downloads/thermocals1.pdf>

Other positive features:

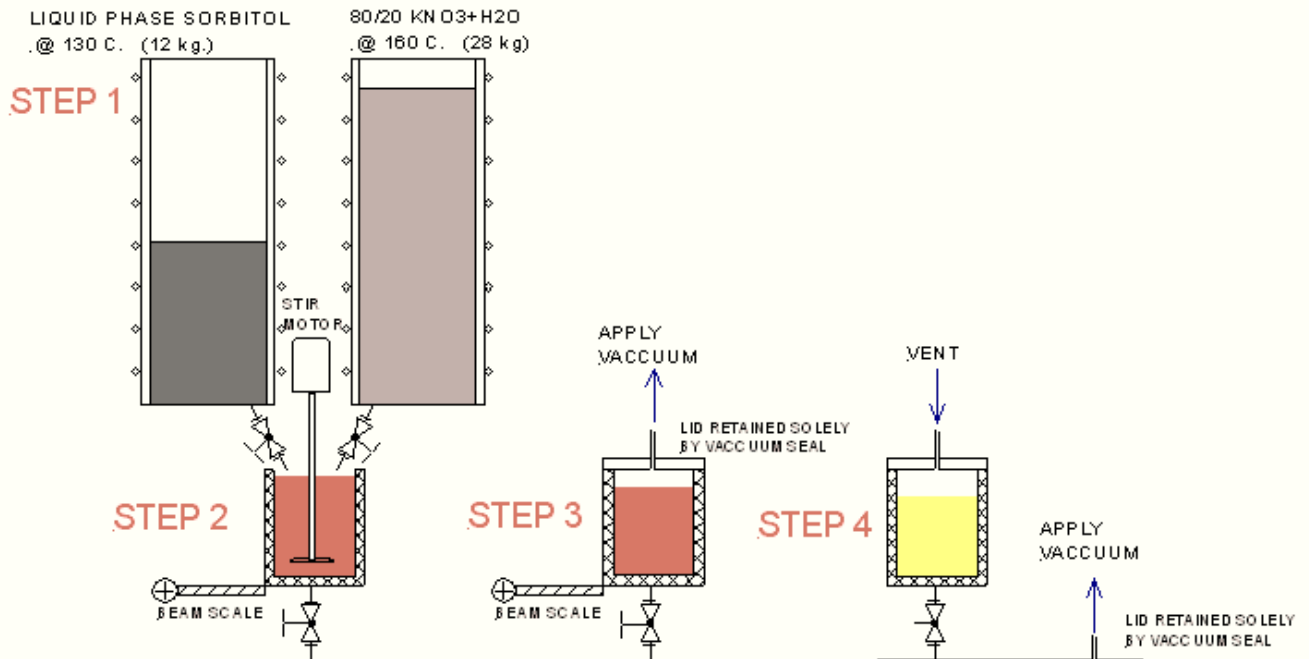
- no pre-mixed (hazardous) powder required
- no milling of KN required; fertilizer grade should be suitable
- as with the Krech method, a homogeneous propellant is produced which should lead to more consistent and predictable motor performance
- lack of confinement of propellant eliminates risk of explosive condition
- minimal exposure of hot propellant reduces risk of accidental ignition

- relatively small batch size of propellant reduces hazard of, and consequence of, accidental ignition
- large mass of propellant present in casting mould is protected quite effectively against accidental ignition
- actual process is relatively simple and requires minimal operator exposure to hazardous operations
- propellant is not subjected to friction (as with auger method)

Negative features

- process is untried and research and testing required to determine if feasible
- greater complexity than most other methods. Design & build will require much effort and greater cost
- greater energy requirement than standard casting method (i.e. slower)
- protection against accidental operator scalding is needed
- characterization of resulting homogeneous propellant would be required

This scheme is illustrated in the figure below.



STEP 1

SORBITOL AND $\text{KNO}_3/\text{H}_2\text{O}$ SOLUTIONS ARE HEATED TO REQUIRED TEMPERATURE.

STEP 2

SORBITOL AND $\text{KNO}_3/\text{H}_2\text{O}$ SOLUTION ARE LOADED INTO TRANSFER POT. SOLUTION IS STIRRED CONTINUOUSLY.

STEP 3

VACUUM IS APPLIED TO SOLUTION TO DRAW OFF ALL H_2O . WATER CONTENT IS DETERMINED BY MASS REDUCTION.

STEP 4

TRANSFER POT MATED TO CASTING MOULD. VACUUM APPLIED WHICH DRAWS IN PROPELLANT.

NOTES:

1. Heating tanks hold enough Sorbitol & $\text{KNO}_3/\text{H}_2\text{O}$ for one 34 kg. segment.
2. Transfer pot holds approximately 2 kg of propellant.
3. Rough time estimates:
 Step 1: Heat up tanks of solution - 1 hr.
 Step 2: Load transfer pot - 0.1 hr., Stir 0.1 hr.
 Step 3: Vacuum drying - 0.2 hr.
 Step 4: Transfer to mould - 0.1 hr.
 Time per 34 kg segment - $1 + (0.1+0.1+0.2+0.1) \times 17 = 9.5$ hr
 Time per 12 segments = 114 hrs (4.75 days)

ASSESSMENT OF THE VARIOUS SCHEMES

The pages that follow contain the comments that were received (to date) on the various schemes.

Note that the different colour text distinguishes & identifies comments from the various contributors.

1. TUCKER/RIDER METHOD

COMMENTS:

This method of manufacturing “sugar” propellant is particularly interesting because it hypothetically can be used for production of any size propellant grain, from small conventional sized motors, to our 34 kg. segments or even larger should the need ever arise. This is truly a mass-production method that could see application outside of the SStS project.

I like this system, but I’m not yet convinced that it will be as simple or inexpensive to construct as it has been suggested.

Excellent long-term possibilities. A designer’s dream. Lots of things to make and do.

PROS:

- All schemes need to consider the consequence of accidental fire at the loading and processing stage. Loading of KNSB powder into the hopper can be restricted to small quantities (< 1 kg). Only a relatively small amount of propellant (1 kg or less) would be present in the auger at any one time. In case of a fire at the loading point, the hazard would be lessened by the small quantity of powder consumed. Conventional fire-resistant gear worn by the operator should provide complete protection. The same is true for an auger fire.
- Feed rate is readily adjusted by a variable speed motor
- The device can be run non-stop until all segments have been cast
- With good design, overall casting operation can be done with little operator effort and in a timely manner.
- Even greater safety might be achieved if dry ingredients are not premixed; instead KN and sorbitol can be fed into separate hoppers and mixed as part of the auger process.

Consistency of end product should be good.

Much development time, lots of variables. Complex, violates KISS principle. Desert launch will not permit building any structures on BLM land (the protective wall.)
Danger level is quite high. Personnel likely have to constantly oversee what is happening. Probably expensive in the long run when everything is done properly. Dry mix required up front. Lots of moving parts, usually a no-no in processing propellant. Hot air source required. More energy required than most other methods. Very intensive development period required.

CONS:

- If the auger is enclosed (capable of retaining pressure), the result of an auger fire could be catastrophic, even with the relatively small amount of propellant present. Design of the auger would need to address and eliminate this concern.
- Such a scheme has never been tried before.
- A lot of development work, including prototype building and testing would be needed.

- It is unknown how efficiently the heated auger would melt the powder and transport it along.
- Jamming and friction in the auger is a possibility and would need to be accounted for in design.
- Oil heating system would be complex and possibly susceptible to failure.
- Critical parts would need to be readily field replaceable.
- Air heating has not been tried before.
- Remote operation is not possible, as an operator is required to feed the hopper and empty the bucket on a regular basis.

It was mentioned that for safety the propellant output be “bucketed” to the mold. That seems like it could be tough in practice. The full amount needed for a grain is a lot to move and if you do it in smaller batches we may have quality control issues.

I’m concerned about the amount of hot oil and the potential for someone getting burned.

There also is a lot of propellant (three segments worth) in close proximity at certain times in the process.

HAZARD LEVEL:

Relatively low.

Because of the amount of hot oil and the amount of propellant in close proximity, I think the hazard level is higher than that with other methods

2. COLBURN/PEARSON METHOD

COMMENTS:

Could this be used as a double boiler using oil instead of steam? That would pose less of a burn hazard from hot oil than an open trough of hot oil or a double boiler set up made from two separate containers.

Is it possible to get more of these or use it at one of the “melting stations” proposed in the Vrbec method?

Steam kettle is available

PROS:

- Such vessels are readily available at low cost.
- Process could possibly be (largely) remotely operated.
- Overall concept is relatively simple.
- Steam is a safe medium as a heat source, as maximum temperature is easily controlled.
- With good design, grain production time may well be rapid
- Transfer of slurry to casting mould would be simple & relatively safe.
- “Loading” hazard level can be reduced by first melting sorbitol, then stirring in KN.

Steam kettle should be able to quickly melt the propellant

Little kinetic energy put into mass of propellant. No moving parts. Fairly efficient in energy usage. Safety level moderate as most of the operation can be remotely conducted.

CONS:

- All schemes need to consider the consequence of accidental fire at the loading and processing stage. All 34 kg of propellant must be loaded into the vessel, and subsequently the slurry is contained in a single batch during the heating operation. The result of an accidental fire during loading or heating could be exceptionally hazardous. Due to elevated temperature of slurry, the entire batch could be consumed nearly instantly, creating great potential hazard with scattered liquid propellant and liquid K_2CO_3 combustion product. Conventional fire-resistant gear worn by the operator would not likely offer adequate protection.
- Pressurized steam constitutes a certain hazard.
- Product would likely need to be stirred in order to melt the batch in an acceptable timeframe. As such, a stirring paddle would need to be developed.
- A source of steam, including a means of circulating such, would need to be developed.

One steam kettle is not enough to produce the required number of grains in a reasonable time frame

Steam or hot oil source required. Dry pre-mix required. Cleaning of output tube required between batches likely. Some development required.

HAZARD LEVEL:

High.

Same as method three, potentially very low hazard level

3. VRBEC METHOD

COMMENTS:

This scheme represents a “scaling-up” of the most popular method used to manufacture “sugar” propellant.

Straight forward.

PROS:

- Process is very simple and well-proven
- Cost of apparatus would be relatively low.
- Development time would be minimal.

This method seems to have the potential to be one the safest methods if proper procedures are put into place and followed. Could also be one of the quickest to produce the number of segments needed? Three or Four stations could be used. Also could be broken down into teams responsible for one of the “stations” that way everything that would be needed for one station could be the responsibility of that team thereby dividing the work load. Each “Station” team would be responsible for acquiring and transporting everything to the site. The list of what each “Station” team would need would be determined by the overall propellant team.

Direct attack on the problem. Using a technique that requires little development. Safety is moderate.

CONS:

- All schemes need to consider the consequence of accidental fire at the loading and processing stage. Since the total propellant batch (34 kg) is split among 3 or more stations, the mass of propellant that would be consumed would be reduced, but nevertheless would be significant (5-10 kg, for example). Conventional fire-resistant gear worn by the operator would not likely offer adequate protection.

Could require significantly more man power than the Tucker/Rider method

In the form stated, requires much equipment. (All methods may require much equipment). Operator has to stand by and process propellant. Moderately complex

HAZARD LEVEL:

Moderate.

I think this method could have the lowest hazard levels

4. LEV/COLBURN METHOD

COMMENTS:

I have actually used this method as stated in my e mail, successfully.

The following is a list of conditions/cautions/tests I feel should be met in order for method #4 to work well enough to use, incorporated with a description of how I envision it working. Also a few thoughts that might make it easier or make it work better. If method #4 can be made to produce reliably good-performing grains repeatedly, it is the way to go (in my opinion).

Caveat/Condition #1: In our “recipe” it is of prime importance that the ingredients be finely milled and extremely well mixed to an evenly distributed compound, since agitation during the melting/settling process will be minimal. The only way I can see to accomplish this is to mill the components together in a ball mill for a sufficiently long time to produce an admixture where the components are both micron-fine and homogeneously distributed. Lead/Antimony balls are highly recommended for this procedure since they mill most efficiently and will not spark.

Smaller batches of propellant powder can be produced and staged, then added to the prepared casting mold which starts out on a scale. With the mold assembly mass (including inhibitor sleeve) as the tare weight, powder is added until correct mass of powder is reached. At this point I recommend the mold be covered and moved to a platform with concrete settling vibrators attached, and the mold vibrated while evacuated of air to settle the powder and compact it somewhat. After this procedure (at least as a test for the first grains produced), the lid should be removed (after re-pressurizing) and inside mold surface should be inspected for any powder made “airborne” by the vibration that has adhered to said surfaces. Any such dust should be wiped off, and the mold should then be massed on the scale again and powder added to make up any deficit created by vibrate dust removal. Finally, the mold top is attached again and the mold re-vibrated while evacuating again to a fairly total vacuum.

Another possible procedure would be to overfill the molds by a certain small percentage and do a trimming/cutting procedure on the top of the finished grain to reach the final grain dimension and weight. This may be extraneous, but I believe in testing the procedure, it will become apparent what will be necessary to produce a sufficiently “pretty” final product in terms of precise mass and shape of the top grain surface. This depends a bit on the viscosity of molten KNSB slurry and its propensity to adhere to the inhibitor sleeve above the main body of the propellant as it melts and settles.

Caveat/Condition #2: The mold must be long (tall) enough to hold enough un-compacted powder to produce the final grain mass once it is vided, heated, and settled. To accommodate this I recommend that inhibitor sleeves are produced that exceed the length of the column of unsettled propellant powder by at least a couple inches. The excess sleeve will be trimmed off the top of the completed grain, possibly including the “excess” grain material if it is necessary to use the “mold over-charging” and trimming procedure I mention in the previous paragraph.

Caveat/Condition #3: It must be proven that using a quiescent heating procedure (preferably in vacuum) will produce grains that are homogeneous in consistency and have the proper density (same as a stirred/agitated/poured KNSB grain). Also it should be confirmed through testing that quiescently heat-fused grains do not suffer an appreciable decrease in impulse or damage to good

burn characteristics due to incomplete mixing of components or poor density/casting inclusions (this is the best argument for casting in a vacuum as air is removed from the raw powder). The way to test this is by good scientific method using a “control group” of stirred and poured grains test-weighed, measured, and fired in a test stand, comparing impulse and thrust curve against same-sized grains produced using method #4. These tests must use grains big enough to assure the scale of the final product is taken into account.

One thing that could be tried to improve the success of heat fusing would be to (again) attach concrete vibrators to the oven or outer sleeve in a way that transmits the vibrations to the mold and slurry as it is heated. I think this might cause an almost catalytic effect similar to tapping a jar with a super-saturated solution to cause crystal formation. If there is absolutely no agitation, the powder particles may tend to remain powder. If vibrated, they “bump into” one another, and are forced to break their form and enter liquid state. Vibration would also shake loose any pesky pockets of air, and if vibrated while the chamber is evacuated to vacuum, would prevent air pockets from forming.

The only negative I can think of to using vibrators during heating is the possibility of damaging electrical heating elements. They can be brittle and may not hold up well to vibration. If electrical heating is employed, it may be advisable only to vibrate before heating is begun during evacuation, and after heating is done, or if the elements can be mechanically separated from the vibrations. Otherwise an alternate heating method should be considered.

Caveat/Condition #4: The proper temperature and length of time to “bake” the mold to liquefy the KNSB completely through must be determined so we know when all the propellant has been melted/fused. The mold(s) should be designed with a cover that incorporated valves and pressure fittings/tubes necessary to evacuate the mold and create the vacuum only within the mold itself. The mold can then be heated in a more normal oven (if an oven setup is used) using heated air as well as radiant heat (It also opens up the possibility once again of a steam or oil sleeve for enhanced heat transfer and control of temperature). The mold core to produce the center cavity should be metal tube open to the heating medium from the bottom for heat transfer to the KNSB from inside and out (see sketch of possible mold designs).

Having a sealed mold that can be evacuated to vacuum provides better and more efficient heat transfer to the mold rather than just through radiant heat if the entire oven were sealed and depressurized. It is also cheaper and easier to make a sealed mold than a whole heating oven or chamber. Radiant heat is the only method of heat transfer in a vacuum other than direct contact of the mold with hot surfaces, and it would be difficult to heat the mold evenly and completely without air or oil as a medium of heat transfer in contact with the mold itself. A sealed depressurized mold is the way to go.

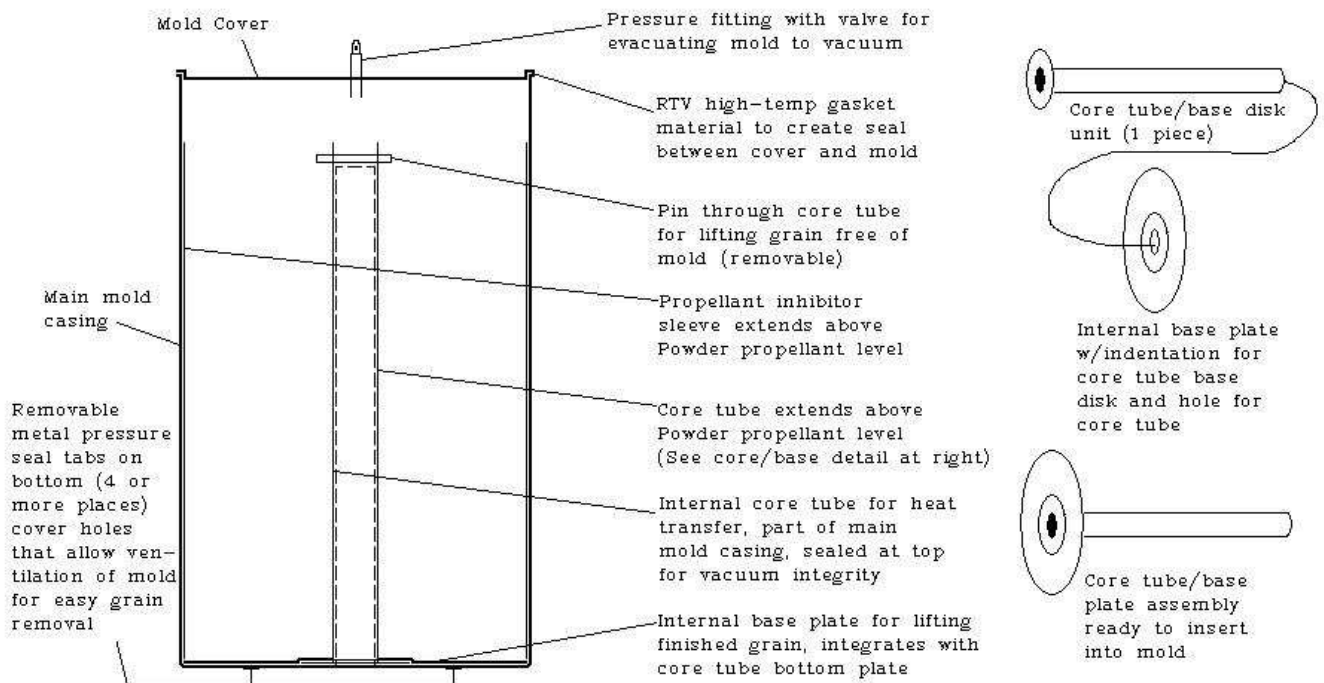
I understand the concerns of using oil and the possibility for burns, but whatever method we use we will be dealing with moving very large hot things unless we leave the molds in the oven/heating chamber until completely cool. This could make for unattractively long cycles to produce a single bates grain. If there are 3 molds for each oven/heater that makes one grain in the oven, one grain cooling, and one mold being prepared. The oven or heating device has the potential to be expensive unless some existing device (like Bill’s idea of a Turkey-deep-fryer) can be used.

The turkey deep-fryer may be perfect. Our molds will be about 10" in diameter and will be between 1.5 to 1.8 feet long if my calculations are close. That just about fits in one of those turkey fryers. They are cheap and readily available, and again, fired with propane, perfect for transport to the launch site, and economical of electrical generation capacity. We can rig it up to remote-start them and remotely activate evacuation pumps, vibrators, etc. That way we could be making several grains at a time, at a safe distance. We can put handling lugs on the molds so they can be lifted while hot to a cooling area by a team of two using welding gloves and bent-metal handling hooks of some description.

If we use the deep fryers, oil is the proper heat-transfer medium (any cheap vegetable oil should be fine, I think), and the mold should be made submersible to above the level of the propellant and seal oil-tight as well as air-tight (proper gasket material to be considered here). The metal pressure fittings should extend above the mold cover so they can't touch the oil. Vibrators should be affixed to the outside of the kettle, and oil level should be low enough so vibrating does not cause oil-spills down the sides that can be ignited by the flames. Hmmm. A few bugs to work out, but that's what we're here for. Whether an oven or turkey-fryer is used, the mold idea is pretty solid I think.

Anyway, the cautions, tests, etc. are all complete and valid in my mind. It's all just food for thought as usual, all to be corrected and improved by the team. And here I thought I wouldn't be wordy. 3 pages text already. That's enough for now. I hope all the reading isn't overwhelming. I still think if method #4 would not work out for some reason, some form of continuous-feeding and melting production would be the way to go. I do hope #4 works, it seems to be simplest and cheapest as far as using existing available equipment and simple procedures.

Here is a sketch of some mold-design thoughts on the next page (also included in the e-mail as a separate jpeg file).



The core tube with base plate should be very sturdy since it is used to pull/lift the grain from the mold using a steel pin through the top of the core tube.

Just a note on the removable pressure tabs on the bottom of the mold. They are sealed in place before each grain production cycle with RTV high-temp sealant/gasket material, inexpensive and available at your friendly neighborhood Wal-Mart in the automotive section.

As I hope you can see, the mold casing has a core tube which the removable core tube slides down over. This allows heat circulation/transfer. The assembly of the removable core tube with base disk and the base plate that covers the whole bottom of the mold will combine with the inhibitor sleeve and holes in the bottom after the seals are removed to make the grain easy to extract from the mold. The base plate provides a base to allow the core tube to be pushed down and out of the finished grain as well

A couple changes to the mold design that simplify construction and improve the performance of the design:

1. The core tube should extend from the bottom cover through the top cover and the top cover will pressure seal around the core tube as well as around the rim. This negates the need for the inner core tube that was part of the main mold casing, which now becomes a simple cylinder open at top and bottom. The core tube with flange is inserted through a core-sized hole in the mold bottom and sealed to the bottom with a bead of RPV gasket material around the perimeter of the flange. This creates an open tube entirely through from bottom to top, where heating media (air, water, or oil) can circulate for maximum efficiency in heat transfer to the propellant. It should cut by 1/3 to 1/2 the time needed to liquefy the propellant, should assure better heating and melting of the propellant overall.
 2. The bottom of the mold is a cover that just fits snugly over the bottom end of the mold. The circumference of the top cover is modified to fit over the top of the mold the same way. The top and bottom cover now can be simply sealed with a light bead of RPV gasket just at the extreme edge of the top and bottom cover. This will also make the mold MUCH easier to disassemble when the grain is ready to be un-molded.
 3. The valve on the cover used to evacuate air from the mold will be moved off-center so it is located between the rim and the core tube.
 4. I neglected to mention using mold release compound and putting a paper disk on the bottom of the mold (doughnut shaped) to aid in grain removal. These steps are pretty standard practice when casting grains, but I should mention them anyway.
I realize I am sealing many kg of propellant in a pressure chamber where an accidental ignition could have bad results. I suppose we could skip the top cover and melting in vacuum, but with thermostatically controlled heat levels, how much risk is there really of an ignition? Would it be a sufficient safety measure to run the apparatus remotely?
-

Herewith some comments and suggestions on the proposition from Lev and Colburn.

I believe that the easiest method consists in:

1. premixing dry KNO₃ and sorbitol powder (preferably in small quantities for safety reasons)
2. pouring it in the melting bowl or reservoir and as Bill proposes "of the same dimensions as the grain inhibitor
3. to continue with Bill's words: ".....heating and casting could be performed directly in the grain inhibitor".

Contrary to the Lev/Colburn proposal I do not see the need for a heating coil. The system I use for the manufacturing of large (9 cm in diameter, 30 cm long and a mass of about 8 kg) zinc sulfur-aluminium grains is quite similar and functions extremely good. I use a container with a diameter of 20 cm in diameter and 80 cm high (picture 1). It is partly filled with oil and insulated to reduce heat losses. It is heated with an electric plate heater (somewhat smaller in diameter). Inside the container an aluminum reservoir which is closed at the bottom (but can be removed) is placed. The reservoir is then filled with the propellant powder. The temperature of the oil can easily be controlled and is kept between 135°C and 155°C (when the mixture reaches its lowest viscosity). After some time (about one to one hour after starting up the process) the propellant starts melting and the powder level decreases (if needed one can add new portions of powder). After about another 2 hours everything is molten.

To remove air bubbles one can apply vacuum (not foreseen in the actual system) or stir the liquid. It is also possible to lift the reservoir from the oil bath and vibrate it on a vibration table. The density of the grain is usually 95% of its theoretical value (4 gr/cm³).

Because the zinc-sulfur-aluminium shrinks when cooling, the grain can easily be removed from the reservoir and coated. In none of the cases I found any difference in composition between both ends of the grain. The grains used as end burning grains did not show any significant difference in burning rate at the start and the end. Also the centre of gravity was always found exactly in the middle. With the same process also tubular grains with the same dimensions as the end grains have been manufactured. In this case a slightly conical cylindrical rod is already put in place when adding the powder. Because the propellant shrinks when cooling a V-type hole is created at the top. This needs to be cut away but can be used in other grains.

The point however is can this system also be used for KNO₃-sorbitol. To find out I did a small scale experiment yesterday and took some pictures. For the experiment I used a 5.3 cm reservoir and about 400 gr of KNO₃-sorbitol powder. I applied roughly the same temperatures as for Zn-S-Al. My findings are the following:

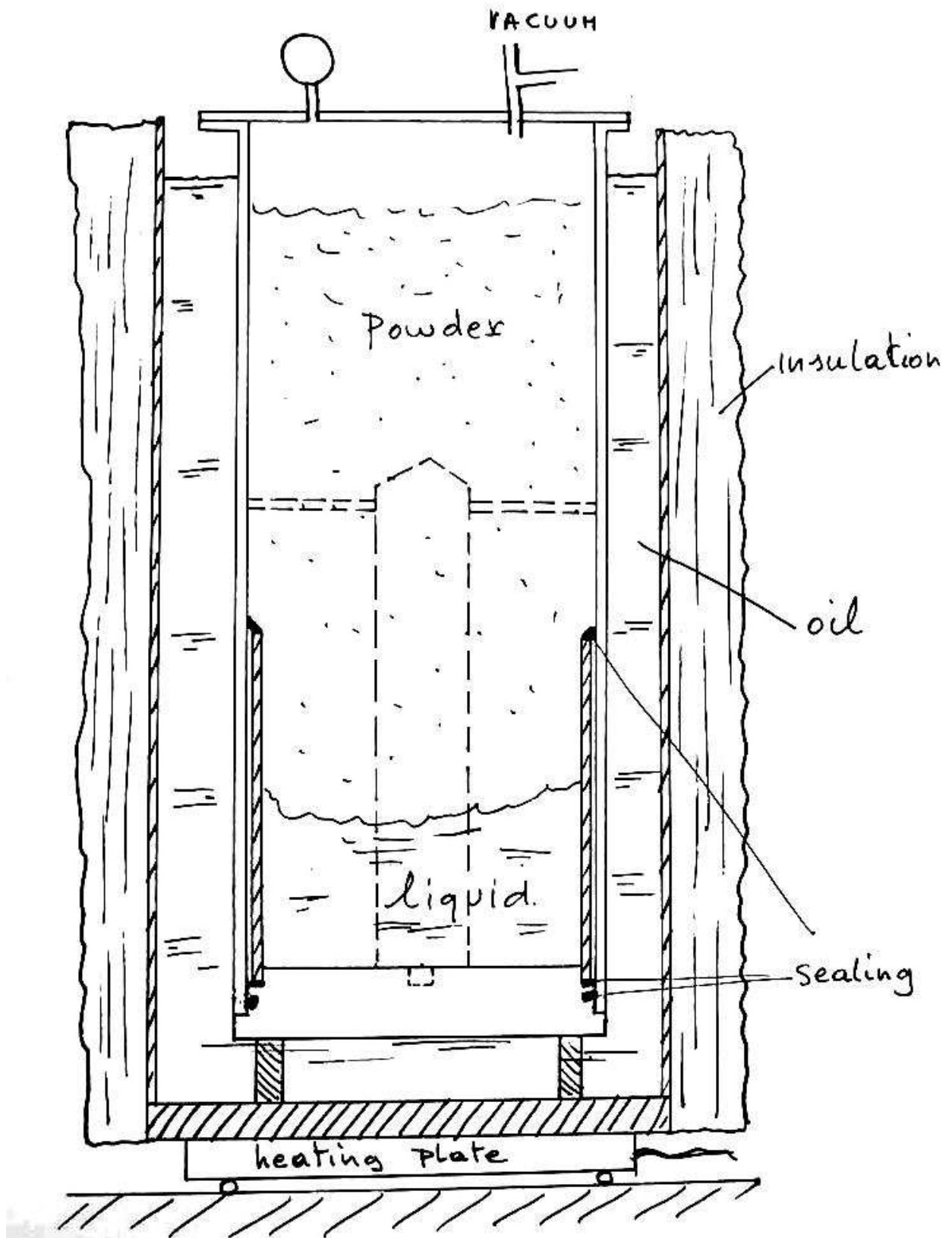
1. The KNO₃-sorbitol (65/35) mixture became sufficiently liquid to fill up the void.
2. some stirring or vibrating may be needed to remove most of the air bubbles
3. after cooling the grain sticks to the aluminium reservoir and cannot be removed.
4. at the top of the grain one can see that at several locations the grain separated from the wall (picture KNO₃ grain).
5. the density was 1.71 gr/cm³.

Overall I strongly believe that this approach can work. Although i believe that the separation from the wall only happens at the top, care must be taken .

I suggest the following changes to the Lev/Colburn proposition (also see drawing):

- replace the insulation in the drawing by oil and place the insulation at the outside of the container.
- Heat the container from the bottom (for safety reasons the heating plate should be smaller than the container)
- Because the powder has a much lower density than the liquid the reservoir must be at least 2 times the length of the grain
- propellant powder can be added during the melting process and vacuum applied after liquefaction, but this is not advisable (for safety reasons)
- It must be made possible to open the reservoir from the bottom in order to release the grain (in the Lev/Colburn proposal this will probably give trouble). This plate can also be used to fix the distance of the grain and to position or even fix the cylindrical rod to create the central hole.
- to prevent the propellant to stick to the bottom plate a sheet of aluminium of other material can be used which can be easily removed afterwards.
- the idea to seal the grain inhibitor from the reservoir is very interesting. Actually I use silicon sealing to prevent any oil from penetrating into the reservoir.

The relatively low propellant density will certainly increase with larger diameters and when applying vacuum.





PROS:

Should produce a good quality propellant

Fully remote during heating and cooling cycle. Safety level high. Simple, adheres to KISS principle. No moving parts. Little development time.

CONS:

Although simplicity is generally a good thing, it should be recognized that the KISS (Keep It Simple Stupid) principle is not really applicable for our application, being incompatible with safety (i.e. stupidity violates safety). A safe system often involves greater complexity than what is needed for pure functionality.

The thing that I don't like about this method is that we'd need a lot of equipment to produce the 12 segments. I think that we'd want at least three or four of these systems minimum. The problem is that I don't think that we'd be able to remove the segment from the heating vessel until it was nearly cured, or we risk deforming the grain.

I don't like the idea of melting the propellant in a vacuum container. Hot propellant, in a pressure vessel seems like a bad idea. I don't think that there is much of a chance that it could ignite, but if it did I'd rather it be in an open container than in a pressure vessel.

Some form of heating and vacuum capability is required. Might be slow unless multiple grains are done simultaneously.

HAZARD LEVEL:

The presence of a single large mass of combustible powdered propellant would represent a serious hazard. As well, the process of loading of the powder into the mould could be risky. A single spark could conceivably set off the charge with serious consequence to personnel involved. Powder burns much more rapidly than slurry or solid form. As such, I would consider the hazard level to be high unless some procedure is developed to eliminate these concerns.

I have concerns about the pressure vessel, but less burn potential from hot oil (or in this case glycol)

5. KRECH METHOD

COMMENTS:

The method as described is quite complex. Simplification could well be possible.

I think that the idea of dissolving in water warrants further investigation, but I think that the method described here is overly complicated. Maybe a combination of method three and method five could work

Ingenious.

I have tried evaporation method with different candy compositions, including KNSB. The method itself is very simple: just mix components and some water, heat to complete solution and further to complete evaporation of water. But there are big problems with KNSB.

First, on boiling, KNO₃-sorbitol-water solution forms very large bubbles, about 3-5 cm in diameter. When burst, they throw hot propellant drops all around. Interestingly, this problem can be completely eliminated by addition of 1% yellow iron oxide to the initial mix. Boiling become very smooth.

Second, there is only one method to control completeness of evaporation: it is weighting. Jimmy' method, that works well for KNSU, doesn't work for KNSB.

And even bigger problem for large batches - viscosity. Near the end of evaporation propellant is thixotropic and it is very difficult to stir. Resulting propellant resembles soft clay and cannot be poured. So manual transfer of hot propellant would be need, which is very hazardous for large batches.

So I think this method is not suitable for propellant batch more than 100-200 g.

PROS:

A novel approach that could represent advancement in sugar propellant technology.

Rather than being of "composite" form, the resulting propellant would be "homogeneous" and as such, careful control of oxidizer particle size would not be required, as is the case with conventional methods. More consistent and predictable motor performance could likely result. Since it would not be necessary to mill the KN and it would be dissolved, any fertilizer grade could be suitable.

This method could potentially produce the best quality grain

A successful system would be quite useful and safe. Propellant ingredients in aqueous slurry would be very safe and readily handled.

CONS:

Very energy intensive, consequently a long processing time would be required.
Method is untried and would require a lot of up-front experimentation to determine if it is feasible.

Method is quite complex

Great amount of energy required. Very complex, much development time required. Requires instrumentation for success likely. Safety moderate to good. Lots of equipment. Probably expensive.

HAZARD LEVEL:

Low.

Potentially very safe

6. YAWN METHOD

COMMENTS:

Mirrors? As crazy as that initially sounded to me, the more I thought about it the more I liked it. Unfortunately I think it's a bad idea to have some part of the system dependant on nature.

The method of having the casting tube on a turn table has appeal, but I think that it needs extensive testing to see if the method would work and if so, would the quality of the grain be acceptable?

Wouldn't the hot air that is being blown onto the powdered propellant just blow it away? If we did get it to work , would it be a fast enough system?

As always, Jimmy has an interesting idea.

PROS:

Uses cheap and readily available energy.

CONS:

Untested. Slow.

Complex. Much development time required. Cannot create structures on BLM land. Vagaries of both overcast and wind will play a major role in the productivity or workability. Safety moderate, some operator attention is probably required. Lots of moving parts.

HAZARD LEVEL:

Processing of powdered propellant could represent a significant hazard. Minimizing quantity (batch size) of the powder could alleviate the problem.

7. KRECH/NAKKA METHOD

COMMENTS

1) The docs and diagram don't indicate whether the bulk KNO₃/H₂O solution container would be covered. With this solution to be held at 160 C over the course of 9+ hours, will we need to deal with the possible effects of H₂O evaporation by covering and/or replenishing it?

2) In fact I'm wondering if both bulk solutions could be replenished during the interval when the small batches are being processed. Most likely, the key issue is whether the solution temps would restabilize quickly enough to make this a completely continuous process, or whether some "thumb-twiddling time" between batch pours would then be required. If we stick to 2kg-sized batches, this means replenishing 1/17th of the bulk solution by weight during each 1/2 hr batch processing phase; this is a small enough fraction that one suspects 1/2 hr might be sufficient time to allow the temps to stabilize. This ongoing replenishment, then, could potentially save almost a half day.

3) What's your main rationale for a 2kg batch size rather than, say, 4kg? Is this the point where you think the smaller batch becomes as big a safety issue as the two bulk containers because it's now been mixed? Or does it, for example, simply take twice as much time (or longer) to vacuum-dewater it if the batch size is doubled, so there'd be no net time savings? Etc.

As you can guess, I'd lean towards a bigger batch if possible, since it has the potential for considerable savings in pour time -- though obviously there might be a tradeoff between this and (2) above.

"potassium nitrate is dissolved in hot water to produce a highly concentrated solution, tentatively 80/20 ratio @ 160°C"

Saturated KNO₃ solution has b.p. 115 C and concentration 338.5 g KNO₃ in 100 g water.

I have tried evaporation method with different candy compositions, including KNSB. The method itself is very simple: just mix components and some water, heat to complete solution and further to complete evaporation of water. But there are big problems with KNSB.

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