Jacobs' Rocketry

Propellant

Types of Propellants

There is quite a number of propellants used in experimental rocketry and often people will get attached to one type or another and become quite knowledgeable about that propellant. The three most common types of propellants are compressed powder, usually black powder, sugar propellant (most commonly sucrose, dextrose and most recently, sorbitol) and composite propellant using ammonium nitrate or ammonium perchlorate as the oxidizer and a powdered metal (usually aluminum or magnesium) as the fuel). There are three well known people who are "experts" in each of these propellants: David Sleeter (Teleflite Corporation) has a book on black powder motors "Amateur Rocket Motor Construction." John Wickman has a book "How to Make Amateur Rockets" and his propellant of choice is composite propellant. Richard Nakka is the sugar rocket specialist and has the most comprehensive experimental rocketry website bar none.

Note: You will see the term "**grain**" used throughout this website. In black powders and smokeless powders, the grain size refers to the size of each particle of powder which is quite small, on the order of 1/16". In rocketry, the propellant is compressed or cast into large forms just smaller than the motor diameter. A motor may use one to as high as seven or more grains in a motor or the propellant may be cast directly into the motor (case bonded grains) in which case the entire mass of propellant is referred to as the grain.

Compressed propellant

Compressed propellant is prepared dry but may be wet at some stage of the preparation. It is loaded into the motor casing by compressing with constant mechanical or hydraulic pressure or by impact such as by blows of a mallet or hammer. The burn rate depends on how fine the components are ground, how intimately it is mixed, and the density which is determined by how much it is compressed. Compressed propellants are normally loaded into wound paper tubing which has a lower burst strength than PVC or metal. An amateur will normally use blows to compress the propellant and this means the amount of compression can vary and so getting a consistent rocket motor becomes difficult and can result in burst motors or motors with lower thrust. This is why I switched to cast sugar propellant. It is also easy to split the casing because the hammer blows can create tremendous hydraulic pressure on the casing. The normal way to avoid this is to use an external clamp around the entire outside of the case. A series of hose clamps can be used but this takes a fair amount of time to put them all on and take them all off. I used a wood clamp that you can see in my free manual. David Sleeter uses a fabricated steel clamp but a lot of people don't have the tools to do that.

Zinc-Sulfur

In the early days of experimental rocketry powdered zinc and sulfur were a common propellant. This was also referred as "micrograin." The optimum mixture was 2.04 parts zinc to one part sulfur by weight. Its burn rate depends on how small the particle size is for each and how much it is compressed. The more dense it is compacted, the slower the burn rate. It's burn rate is between 14 and 290 inches per second. At 160 lbs/ft^3 and 1000 psi, the following has been measured*:

Burn rate - 90 in./sec
Flame Temp - 2600 F
Effective Exhaust Velocity - 1490 ft/sec
Specific Heat Ratio - 1.25
Molecular Weight - 97.45 lbs / mole
Specific Impulse - 45 sec

* from "How to Make Amateur Rockets", John H. Wickman, 2nd Ed, pg 3-3

Because it is so difficult to compress the powder to a known value consistently, rocket motors made with this formula typically either don't have much power and may not get off the launch pad, or they blow up from over pressurization. It is not used by any serious rocketeers today.

Black Powder

Black powder is made from Potassium Nitrate (KNO_3), Charcoal and Sulfur. The common ratio is 75:15:10. Like zinc-sulfur, the burn rate depends on the particle size and how much it is compressed. Black powder can be used used as a propellant with more consistency than zinc-sulfur and is the propellant used in small commercial model rocket engines. My 1979 manual explains how to make and use black powder for rocket engines. David Sleeter took the development to the next level and published his book, *Amateur Rocket Motor Construction*. The burn rate of black powder can be slowed by the addition of other components. I used calcium carbonate. David uses baking soda. David also varies the type of charcoal used to get different burn rates and to control chuffing. He adds Red gum as a binder (I used Gum Acacia) and either water, alcohol, or acetone is added before loading so the powder will compress more. I did the same but also loaded it dry with good results.

Black powder, regardless of how fine it is ground, in the initial dry mix state is not very powerful. It must be mixed with a little water until it is a darker color and then dried again. While it is wet, it can be pushed through a window screen to form grains. This grain powder is extremely fast burning. Or it can be again ground up to a powder and then it is still very fast burning. It is likely that the wetting dissolves the KNO_3 and then coats it around the charcoal and sulfur particles so that it is in much more intimate contact with them. Richard Nakka notes that sulfur is only used in conventional black powder so it will ignite more easily from a spark such as is used in flintlock guns. He makes black powder from 80% potassium nitrate and 20% charcoal by weight for one of his igniters and presumably, this would also apply for black powder motors but I have not tried this yet.

Sugar-KNO_3

Sugar and potassium nitrate are the ingredients for the common "caramel candy" propellant. Normally it is heated to a thick slurry but it also can be just mixed together dry and then compressed in a motor tube in the same way as black powder. As with all compressed propellants, the particle size of the constituents and the degree of compaction is what determines the burn rate and efficiency of the propellant and so it is difficult to get a consistent product. Mixed in this way, it also is not as powerful as when it is mixed more intimately through melting or dissolving in water and then heating. The ratio is the same as for the melted variety: 65% potassium nitrate, 35% sugar. See the Carmel Candy Propellant page for more information on the melted method of preparing this propellant.

Composite Propellant

There is some variation in the definition of *composite propellant*. It generally is considered to be a propellant where the oxidizer and the fuel (reducing agent) are intimately mixed together with a binder. Some define the composite propellant as being a rubber-like consistency and then the binder is that which gives that property. However, asphalt was an early binder and the finished product was not very elastic. Many also consider epoxy propellants to be classed as a composite and although it is tough rather than brittle, it definitely is not elastic. The other problem with the definition is that the binder is also a fuel. It can serve as the only fuel in the propellant, the main fuel with smaller amounts of other fuel, or another substance may be the main fuel with the binder being a lesser contributor. During the developmental years, some propellants such as those using synthetic rubbers were cast at elevated temperatures where they were liquid and then became solid when they cooled. Others, essentially all propellants for amateur rockets and many for commercial rockets, now are liquid at room temperature and a curing agent is added which reacts chemically with the binder to cause it to harden over a period of time, usually minutes to a few hours. Other substances that can be added are plasticizers and burn rate modifiers. A plasticizer can be added to some to decrease the viscosity (make it thinner) so that the propellant pours easier and makes the casting process easier. Iron oxide can be added in small amounts to increase the burn rate and there are other chemicals that could be added to slow it down (not common). There are several types of iron oxide, different chemical formulas, with varying amounts of iron and oxygen. For example, ferric oxide (Fe_2O_3) is red, ferrous oxide (FeO) is black, and ferrous ferric oxide (Fe_3O_4) is green.

This type of propellant solves one of the biggest problems of other propellant types and that is brittleness. Any propellant that is brittle can crack and that invariable causes over pressurization of the motor due to increased burn area and catastrophic failure. Cracks can occur not only from rough handling but also from the high pressure, thermal stress, and g-forces experienced in flight. The bigger the grain size, the more potential for cracks.

Virtually all motors for amateur use and most composite propellants for commercial or military rockets use Ammonium Perchlorate as the oxidizer. The oxidizer comprises 50% to 80% of the total by weight. The fuel is usually a powdered metal, either Aluminum or Magnesium. The particle size of the oxidizer and the powdered metal will make a difference in the burn rate, the smaller the size, the faster the burn rate. These propellants are harder to ignite than black powder or sugar based propellants and require a longer burning, more intense igniter.

John Wickman is his great book *How to Make Amateur Rockets* gives these two formulas for composite propellant:

Ammonium perchlorate	68%	Ammonium nitrate	60%
Aluminum	18%	Magnesium	20%
R45M Binder	14%	R20LM Binder	20%

Propellant Preparation Methods

Grinding

Grinding is done to reduce the chemicals to a very small particle size. This is required for any compressed powder motors and for dry melting (melting the mixture without water.) You can grind the chemicals separately or you can grind them together IN CERTAIN SITUATIONS. If grinding together, there must be no metal involved in the operation so there can be no sparks and the heat generated must be very low. Otherwise, you could ignite the powder. All propellants that are mixed together dry are very flammable. A ball mill with non-metallic "balls" is the only acceptable method and even then, precautions must be taken in case of ignition. The dust inside can be explosive.

Mortar and Pestle

A small amount can be done with a mortar and pestle but a person usually is looking for an alternative pretty quickly. It can still be a good way when experimenting with different formulas because it can be washed out quickly and easily in preparation for the next chemical. This is also a good method for preparing mixtures for igniters which don't use much for each one.

Blender

You will probably read on many web sites that a blender is not a good method of grinding chemicals. One reason is that it is harder to clean and you have to make sure that there is no residue from a previous different chemical before grinding the next. Also, a blender doesn't work that well with solids. Nevertheless, it is a possibility and can be used. Sometimes you have to keep pushing the chemical into the blades because it tends to stack up and stick to the sides of the container. Be aware that you can quickly dull the blades so don't use the kitchen blender. Get one from a thrift store and dedicate it to your own project.

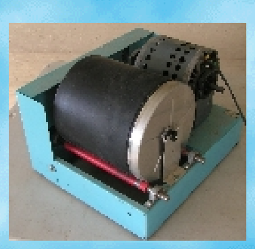
When I first started experimenting with black powder motors thirty years ago, I used potassium nitrate and sulfur from the drugstore. I ground up charcoal briquettes for the charcoal. There are binders in charcoal that make it a poor source and that is probably why I found that a formula of 68% KNO3, 20% charcoal, and 12% sulfur worked best for my chemicals rather than the normal 75%, 15% 10%. I needed more charcoal to make it work because of the impurities. I broke up the briquettes inside the leg of an old pair of jeans with a hammer first, then poured some of that into a blender and ground it up more. Finally, I sifted that through some silk that I had used for model airplanes that had a very tight weave (better than through nylons). It was a difficult, messy and time consuming process but it resulted in a powder as fine as purchased air floated charcoal. I recommend not wasting your time this way and just buying your chemicals.

Coffee Mill

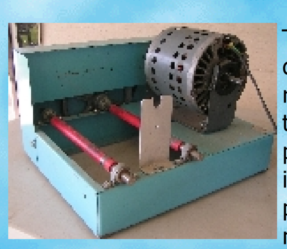
A coffee mill does a job similar to a blender but it works a little better. You can grind a little at a time but it does a better job of keeping the material pulled into the blades. It was designed to grind solids so it is a better choice. A new coffee mill (a cheap one) can be purchased for about $15. It has the same problem of cleaning but with its low price, a person could have more than one if he needed to grind more than one ingredient. It is also a little faster, even though you can only grind a little at a time, you can do it quickly and get a sizeable amount of ground chemicals in a reasonable time through multiple batches. Check for lumps that haven't been reduced to powder in both a blender and a coffee mill before using. You might want to put it through a fine screen to insure you don't have lumps.

Ball Mill

The ball mill is the best way to grind and you can also grind all the ingredients for black powder together. A ball mill is really a rock tumbler. The rock tumbler is usually made of hard rubber at least on the inside. Mine has an aluminum plate inside the rubber lid to help give it rigidity but when it is closed up, there is no exposed metal. When polishing rocks, the tumbler is filled about three quarter full of rocks, then water and the abrasive is added to that. When grinding chemicals or powder, a similar process is used except there is no water added. David Sleeter in his book prescribed brass bar stock. I checked into that and when I saw the price, I decided there IS another way. I tried some rocks (after all, it really is a ROCK tumbler). I used those for milling potassium nitrate. That worked fine so I also used the rocks to mill charcoal (after washing them). That also worked fine. I still had a little concern about using the rocks to grind black powder with all the ingredients (explosive) because some rocks can still produce sparks, though unlikely. Since I had already rejected brass bar stock, I thought about glass marbles. They are cheap, round, totally spark free. They worked GREAT creating dust consistency for everything I tried in it--charcoal, potassium nitrate and black powder.

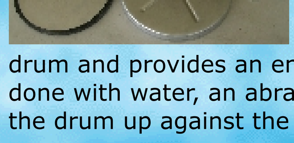


This is my ball mill. It is a 1 gallon rock tumbler I got in Seattle from a lapidary supplier about 30 years ago. The motor is out of a washing machine.



There is one driven rubber roller attached to the large pulley. There is a small pulley on the motor. It is a double reduction system. The drum actually turns at about 2 rpm. The drum has a grooved plastic nut. The groove runs in the slot at the top of the white angle bracket to keep it from moving along the roller axis and off the machine.

The drum is all rubber and as can be seen has multiple flat sides. This helps the contents to tumble rather than roll. The white residue is KNO_3 residue left from my last milled batch which was milled to a talc like powder using 400 standard size glass marbles that I got at a Dollar Store for 100 for $1.00. This has a capacity of 1-1/4 gallons and will mill about two pounds in a batch. Starting with lumps about half the size of the marbles and smaller, it takes about six or eight hours to mill to dust.



The lid is composed of four parts as can be seen in the left picture: the inner lid, the outer lid, a washer and plastic grooved nut. The inner lid is rubber with an aluminum disk molded into it for stiffness. The bottom or rubber side of the inner lid can be seen in the picture on the right. The inner lid fits snuggly inside the drum and provides an entirely rubber milling area and also is water tight. (Rock tumbling is done with water, an abrasive and the rocks). When the outer lid is placed on, it helps snug the drum up against the inner lid.

Dry Compressed

Black Powder

This method is mainly used for black powder. Whatever components are not already in a fine powder need to first be ground. Usually the sulfur is already a powder, at least if you have "flours of sulfur" or "sulfur flour" or something similar. If you are making your own charcoal from chunks, then it will need to be broken up into small pieces first and then milled to a fine powder. "Air floated" charcoal can be purchased and that doesn't need to be milled at all. Finally, the potassium nitrate is probably not a fine powder and will probably need to be milled. The individual components are usually first milled separately. The mill needs to be thoroughly washed between uses of different chemicals. Then the right proportions of each are milled together. Last, the powder is mixed with just enough water (alcohol or acetone can be used because they dry faster) to moisten the whole batch and if it is to be used in a rocket motor, it can then be loaded directly and rammed in place by blows with a mallet on a rod in the paper rocket tube. It can also be let dry first and then re-ground and loaded dry. See the 1979 manual for details (pay attention to it's revision)

Sugar and Potassium Nitrate

As mentioned above, the same formula for melted caramel candy propellant can be milled separately then mixed together and loaded dry into a paper motor tube in the same way as black powder. It is difficult to get these to be consistent and they don't have as much total power (specific impulse) as using the heated method.

Zinc-Sulfur

This is the third type of compressed propellant but is not considered a dependable fuel now since there is so much information and chemicals available for other fuels. The method would be the same as for Sugar and KN. The Zinc would have to be purchased already in a powdered state since it can't be milled. It would then be dry mixed and compressed with hammer blows on a dowel.

Dry & Wet Heating

These methods are used exclusively for caramel candy propellants so are detailed on that page.

Cold Mixing

This method takes in all other propellant types that have at least one non-liquid component and includes especially composite propellant and Epoxy propellant. These are just mixed together thoroughly and then a hardener is added which will cause the liquid slurry to harden over a short period of time, usually half an hour to several hours.