

## .... Composite Rocket Fuels ....

### 1.) Introduction

Composite propellants are solid rocket fuels that are composed of separate fuels and oxidizers mixed together in one homogenous mass. This propellant is then either molded into a grain to be inserted in an engine or cast in an engine casing and left to harden. The fuels and oxidizers taken separately are generally unreactive. Composite propellants are used in a number of engines. There are engines that use water for fuel and an oxidizer, air for an oxidizer like a ramjet, and a liquid/solid engine that can be throttled. The rocket motors discussed here are best built by the amateur with propellant weights below 2 lbs. and preferably under 1 lb. This is still powerful enough to shoot a sizable rocket to well over 4 miles altitude.

Before I get into propellant mixtures a few terms to learn are:

Specific Impulse - Defined as the impulse (force \* time) delivered by burning a unit weight of propellant in a rocket engine.

Volume Specific Impulse - The product of specific impulse and density. This is expressed in pound-seconds per cubic inch. If the propellant's weight is kept constant, a propellant with a lower Isp but a higher density may outperform one with a greater Isp but a lower density.

Specific Force - This is a measurement of the ability for a gas to perform work. Specific force (F) is expressed in foot-pound per pound.

### 3.) OXIDIZERS

Composite propellants contain both an oxidizer and a fuel. The oxidizer may be a monopropellant and as such contributes power to the propellant mix. The ideal oxidizer should decompose into totally gaseous exhaust.

Oxidizers used in composite propellants : Potassium perchlorate (KClO<sub>4</sub>). Potassium perchlorate was one of the first used oxidizers. One of its drawbacks is the product of decomposition ( potassium chloride ) is not a gas at regular temperatures and does not contribute as a working gas. The KCl appears as a dense smoke in the rockets exhaust. Burning rates of propellants made with KClO<sub>4</sub> are usually high at 0.8 - 0.9 in/sec at 1000 PSI. Densities of fuels made with KClO<sub>4</sub> also tend to high at 1.8 - 2.0 gm/cc. Specific

impulses are usually below 200 lb-sec/lb. Potassium perchlorate is hardly ever used in modern propellants.

Ammonium Perchlorate  $\text{NH}_4\text{ClO}_4$ . This is the oxidizer of choice when possible. The products of dissociation of  $\text{NH}_4\text{ClO}_4$  are 100% gas. The specific impulse of propellants using this oxidizer reaches 250 lb-sec/lb. Depending on the percentage of  $\text{NH}_4\text{ClO}_4$  the burning rate may reach or exceed 0.5 in/sec. The products of exhaust are  $\text{N}_2$ , CO,  $\text{CO}_2$ ,  $\text{H}_2$ ,  $\text{H}_2\text{O}$ , and HCl. The HCl may pose some problem if the engine is used in high humidity as the HCl vapor may form visible hydrochloric acid fumes.

Ammonium Nitrate  $\text{NH}_4\text{NO}_3$ . This oxidizer is useful as it is usually available in bulk weight. The products of dissociation of  $\text{NH}_4\text{NO}_3$  are 100% gas. However the temperatures produced by the propellant are low. For this reason, the specific impulse of  $\text{NH}_4\text{NO}_3$  propellants are usually no greater than 180 lb-sec/lb and low percentage propellants have an Isp of 75 lb-sec/lb. The products of exhaust of  $\text{NH}_4\text{NO}_3$  propellants are  $\text{N}_2$ , CO,  $\text{CO}_2$ ,  $\text{H}_2$ ,  $\text{H}_2\text{O}$ . These gases cause no special problems. The burning rate of  $\text{NH}_4\text{NO}_3$  Propellants are low, ranging from 0.05 in/sec to 0.27 in/sec. The higher burning rates are possible if catalysts are used in the propellant. Prussian blue, chromium compounds (ammonium dichromate), or cobalt compounds are catalysts that are used. Ammonium nitrate is hygroscopic and undergoes a phase change if the temperature goes above 90 deg./F. Because of this phase change, some grains may crack if the temperature cycles about this temperature. The burning temperature of  $\text{NH}_4\text{NO}_3$  propellants are lower than any other propellants especially at low percentages of oxidizer.

Lithium Perchlorate  $\text{LiClO}_4$ . Some work has been done using lithium perchlorate as an oxidizer. The lithium chloride formed in the exhaust is a gas at high temperatures. Lithium salts are hygroscopic and must be protected from high humidity. Burning rates of  $\text{LiClO}_4$  propellants are similar to  $\text{KClO}_4$  mixtures.

#### 4.) FUELS

Fuels Used in Composite Propellants : Since most rubbers and polymers are not available to the general public, some adjustments have to be made. A good source of plastics is an auto supply store. There you can find epoxy resin which can be used as a fuel. You will also find fiberglass resin. This is a liquid made from polystyrene and polyester resin. It is catalyzed with a few drops of hardener. PVC plastic can be dissolved in tetrahydrofuran to make a thick paste. This can be mixed with an oxidizer and allowed to dry for an extended time to form a propellant grain. Asphalt was used in some JATO units about 30 years ago but it was found lacking when used at high temperatures. Some fuels used in commercial engines are polyurethane rubber, polysulfide rubber, and butadiene-acrylic acid. Non ferrous metals are added to propellants to increase the temperature of combustion and consequently the Isp. The metals most used are aluminum, magnesium, and copper. The metals are usually added in amounts of 5% - 25%. In engines designed to breath water as an oxidizer, metal amounts to about 50% to 80% of the weight of the propellant. The

other components are usually ammonium perchlorate and a polymer.

Propellant Grain Geometry : If the grain is ignited from end on, like a candle burns, the thrust will be steady or neutral. If the grain has a hole in it extending end to end and the combustion takes place from the inside out then the thrust will rise to a peak or be progressive. This is because the surface area of the grain becomes greater as it burns whereas in a neutral grain the surface area remains the same. A cruciform shaped grain produces a large amount of thrust first then tapers off because the surface area becomes smaller. If the grain is tubular and the combustion takes place from both the inside out and the outside in, then the thrust will be neutral but fast burning.

Wherever you wish the grain not to burn, it must be coated with a retardent. Epoxy works well as a retardent as does Elmers white glue. At least two coats of retardent should be used. An epoxy retardent can be used to retain a grain in a rocket engine. When tubular grains are used, the igniter is usually put towards the nose of the rocket and fires backwards towards the nozzle. This insures the grain is ignited completely.

Inspect the propellant grain for any cracks or imperfections. A crack can cause the surface area of the propellant to increase astronomically. This can cause an explosion because of the increased pressure.

## 5.) PROPELLANT MIXTURES

The ratios of oxidizers and fuels depends on the type of engine desired. The amount of oxidizer can be as high as 90% as in some ammonium nitrate mixes to as little as 20% ammonium perchlorate as in some water breathing engines.

A fast burning mixture: Potassium Perchlorate 20%

Isp=200      Ammonium Perchlorate 55%  
                 Epoxy Resin/Hardener 17%  
                 Powdered Aluminum 8%

This is very fast burning but the exhaust makes a fairly heavy smoke.

A slow burning propellant. Great for sustainer engines.

Isp=165      Ammonium Nitrate 70%  
                 Ammonium Perchlorate 10%  
                 Polyester Resin 18%  
                 Powdered Charcoal 2%

Not very powerful but useful. The charcoal helps keep the combustion steady.

A very powerful mixture: Ammonium Perchlorate 75%

Isp=250      Powdered Aluminum 10%  
                 PVC in THF 15%

All the ingredients should be dampened with THF (tetrahydrofuran) before

mixing. Do this in an area with very good ventilation and wear rubber gloves to keep from contacting the THF with bare skin. This mixture is best used in a perforated grain to help the solvent evaporate.

An ammonium nitrate based propellant: Ammonium Nitrate 70%  
Isp=160 Powdered Aluminum 5%  
Polyester Resin 18%  
Ammonium Bichromate 5%  
Powdered Charcoal 2%

A good mix when perchlorates are not available.

Do not under any circumstances use chlorates for rocket propellants. You will not make a rocket, just a pipe bomb with fins.

## 6.) COMPOUNDING PROPELLANTS

One thing to keep in mind when making a propellant, the volume of fuel/binder to volume of oxidizer and additives must not be too low. If it is then the mixture will be too dry to mix well. It will also hurt the strength of the grain. You may have to cut down on the amount of oxidizer depending on the fuel you are using.

For rockets weighing 1 pound and less the easiest way to make the propellant is to obtain a suitable container for mixing and put in the bottom of it the correct amount of fuel/binder. The other ingredients are added one at a time to the fuel and mixed in. One thing that really determines the success of a propellant is the particle size of the oxidizer. It should be as finely powdered as possible. Continue mixing the propellant until it is a homogeneous mixture. Now pour it or stuff it into the engine casing taking care to eliminate all air bubbles. Any mandrels needed to form the grain to shape should already be lubricated for release and in place. After waiting a suitable time for the binder to harden, remove the mandrels and place the engine in a warm place to finish curing. Inspect the grain for any cracks or imperfections.

Some large propellant grains are constructed by cementing smaller grains together. Disks of propellant can be glued and stacked to form a long grain. The disks can be drilled with a number of holes to make a progressive or regressive burning grain. The holes are lined up when the disks are stacked. If you construct a press with a number of guide rods to match the drilled holes, so much the better. The cement can be a very thin layer of the polymer used to make the grain. If you are using a PVC based grain, then dampen both mating surfaces with THF and press them together for a minute before adding the next disk.

You can also load a cardboard casing with the propellant. After the propellant is cured, this cartridge is loaded into the engine.

When drilling these propellants or using any power tool for shaping them, use

the lowest speed while checking to make sure no heat is building up on the cutting surface. If care is used, machining propellants is safe.

## 7.) ENGINE CONSTRUCTION

The typical engine is designed to operate at 1000 psi. The casing of the engine should be able to withstand at least 3000 psi as a safety factor. A low carbon seamless steel tube with 1/16" walls can withstand that sort of pressure. If the tubing has a welded seam, test fire a few engines to see if the tubes can take the pressure. One drawback to using steel as an engine casing is if the engine explodes you have some very lethal shrapnel flying around. If you use a high strength/high heat plastic you can eliminate some of this danger. Epoxy can be used to wet down a mat of fiberglass then the fiberglass is rolled around a large dowel to form a casing. The dowel has to be coated with a lubricant to keep the epoxy from gluing the casing and dowel together. Or you can obtain a heavy cardboard tube with the correct ID and coat it with epoxy then wrap epoxy/fiberglass around it. If the tubes are constructed properly they can take quite a bit of pressure before splitting apart.

An rocket engine is equipped with a nozzle to accelerate the exhaust out of the rocket at a high velocity. A nozzle has a convergent section that does this. A divergent section of nozzle is used to lower the exhaust pressure so the exhaust gases accelerate out of the engine at high speeds.

The nozzle of the engine can be machined out of metal or made of a fireproof ceramic. If the nozzle and the casing are metal, they can be brazed together before the engine is loaded. The nozzle can also be screwed into place by using 4 - 6 screws going through the side of the casing into the nozzle. Care must be used to see that the screws don't break through the inside of the nozzle. On smaller rockets, you may be able to get away with plaster of paris nozzles or for more powerful motors try pressing a mixture of 90% kaolin and 10% aluminum oxide into a nozzle shape in the casing. Dampen the mix with a little water before pressing. You can make a nozzle die by turning 2 pieces of hardwood into divergent/convergent sections. This die should be fitted with a dowel guide pin at the mating points to help keep the die straight.

A nozzle can be made from just a divergent section. This can be easily made by drilling the required hole in a section of nozzle. Then by drilling out the first hole with larger drills without completely breaking through, a diverging nozzle is formed. Smooth out the ID of the nozzle after drilling the holes. This type of nozzle is pretty good on smaller engines with a 1" ID or less. By using some ingenuity, you should have no problem in making a servicable nozzle. A rule of thumb to use for the ID of the nozzle is to use a hole that has an area (repeat-area, not diameter) 1/3 the area of the ID of the rocket engine casing.

Most propellants burn unsteadily at low pressures. Solid rocket engines are equipped with a blast plug that allows the pressure to build up in the engine before being blown out like a cork in a bottle. Sometimes the ignitor is

combined with the blast plug in a single unit. A stiff plastic disk makes for a good plug. It should have a thickness of about 1/16".

The engine is sealed with a plug in the fore section. Depending on the construction of the engine this plug may be made of wood, plastic, or metal. It is held in place with either screws or epoxy. This plug must make the casing gas tight. Remember most rockets develop 1000 PSI.

The ignitor is simply an electric match. It can be made with nichrome wire or a small light bulb. The match is used to ignite a small charge of black powder that in turn ignites the propellant. The ignitor's leads should be shunted together to eliminate premature ignition. A fuse can be used instead of electric ignition. If you go this route, be sure of the burning time of the fuse and allow yourself enough time to retreat to safety after igniting the fuse. I cannot recommend using a fuse because you cannot stop a fuse from burning if someone walks into your launch area. With electric ignition, everything is under your control until the time of launching.

## 8.) Engine Design

It would be nice to be able to give you the complete info on designing rocket engines. However, the required math would be a file about 300K in length. Also this file is mainly about propellants. The other info is gravy.

The best I can offer is to check out your local library for design and engineering books. If you want to build a rocket to simply shoot off to stroke your pyro perversions, build a small engine containing no more than 4 oz. of fuel. Use a paper casing to keep the danger down and chances are very good that if your construction is sound you'll get the thrill of seeing your rocket go out of sight. If you plan to hoist a payload into suborbital projectory however, learn about thermodynamics, interior ballistics, and propellant chemistry.

I recommend trying to get the book *Amateur Rocketry Handbook*. This book is out of print but it was put together by the Fort Sill Artillery School and contains a lot of valuable info.

## 9.) Testing and Firing

You should construct a few engines exactly the same and test fire a number of them to find out what to expect when you finally do launch a rocket. The engines can be buried nozzle end up in the ground and fired. Time the burning of the engine to figure out the rate of combustion of the propellant. Inspect the casing to see how it stood up. If everything seems okay you can construct a static testing fixture to measure the thrust. Keep in mind that even a small engine can put out a few hundred pounds thrust for a split second. When you do launch a rocket, keep people away from the launch site and under cover. Check out the skies for airplanes or other traffic. Don't launch rockets under conditions of low visibility or heavy winds.

