Technique...

Clay Rocket Nozzles

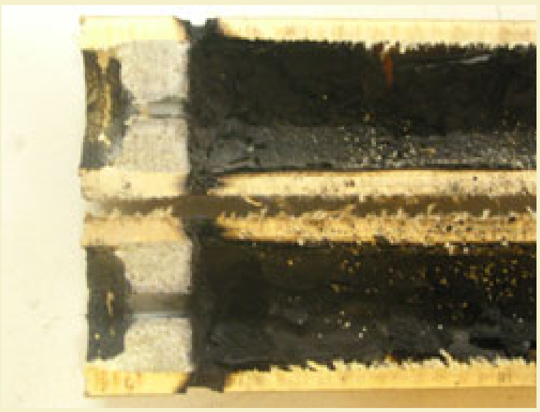

Figure 1: Burn-through just above the nozzle when the inner surface of the clay plug is flat.

Figure 2: The same rocket with a curved inner plug surface suffered no signs of burn-through.

Introduction:
There are many options for materials to use in making rocket nozzles, and rocket builders seem to always be coming up with new nozzle formulas. The most popular and widely used nozzle material for general purpose fireworks rockets is fire clay, also known as bentonite. This is a fire proof clay that is loaded in powdered form, then rammed under pressure to form a fairly hard plug that adheres to the tube wall with enough traction to endure substantial pressure inside.

Rocket failures fall into two general categories: case failure and nozzle failure. Case failure occurs when the tube ruptures under pressure or burns through on the sides, while nozzle failure occurs when the nozzle is blown out from the tube. Widening of the nozzle hole during flight, a term called "erosion," is another type of nozzle failure that can cause a rocket to lose pressure over time. Correcting case failures is just a matter of finding a tube strong enough to hold the pressure, which usually means seeking out virgin kraft tubes or rolling your own tubes from high quality paper. Nozzle failures can be more problematic, and are often the limiting factor in how strong you can make your rocket engine. This article discusses a few common techniques for making your clay nozzles more reliable.

Nozzle Geometry
The shape of the nozzle plays a large roll in its performance. Obviously the exhaust diameter plays a crucial role in determining operating pressure, as does the thickness of the plug and the curvature on both the inside and outside surfaces. These are all easy parameters to control, but it helps to understand the effects of each.

The thicker a plug is, the more holding force it will have in the case, allowing it to withstand higher pressures and thus produce stronger rockets. However, increasing the length of the nozzle hole has the same effect as decreasing its diameter. The longer the hole your exhaust gases must travel through, the more friction there will be on the gas as it tries to escape. This extra friction will increase the pressure to a point that either the case will pop or the nozzle will blow out. This is why controlling the clay increment size is so crucial when ramming your nozzles. It doesn't take much of an increase in nozzle thickness to make the difference between a rocket that flies and one that explodes on the pad.

One trick to gaining the stronger holding force of a thicker plug without suffering the consequences of a longer exhaust hole is to make the plug concaved on one or both ends. This reduces the thickness at the center while allowing more clay to contact the case walls at the edges, as seen in Figure 2.

Figure 3: Supplies required for adding wax moisture resistance to bentonite clay.

Another problem which can plague your rockets is having the hot gases burn a hole in the side of your driver mid-flight, which will drastically reduce the nozzle pressure and send your rocket into an arching dive. This problem can be frustrating if you don't know the simple trick for eliminating it.

Burn-through almost always occurs just above the clay plug, as seen in Figure 1. The problem is symptomatic of clay plugs that are rammed with a flat nosed rammer. What happens is that the hot gases traveling down the tube in search of an exit will slam into the flat plug and split off in all directions. Some gases will find their way out the exhaust hole, while others will bounce off the case wall before finding their way out. It doesn't take long for the continued head-on assault of the case wall just above the nozzle before these gases manage to blow-torch their way to freedom. The engine shown in Figure 1 burned with 500g of thrust for a total of 7 seconds, with the first case breech occurring only a few seconds into the burn.


Figure 4: The yellow liquid resulting from wax dissolved into naphtha in a heated bowl.

The engine shown in Figure 2 was constructed exactly as that in Figure 1, with the exception of the curved inner plug surface. The curved surface tends to guide the hot gasses toward the exit hole rather than scattering them along a single plane, and eliminates the burn-through issue. The engine in Figure 2 burned for 10 seconds and doesn't show any signs of case wall erosion around the nozzle or anywhere else.

Moisture Absorption

One characteristic of clay rocket nozzles that can cause problems is that clay absorbs moisture, which can cause it to expand slightly. If a clay nozzle expands, the nozzle hole will actually get smaller. Rockets that are built "on edge" to give maximum power for a specific nozzle size can fail with even the slightest decrease in the exhaust diameter. A rocket that works fine in one climate under one humidity level can suddenly explode on ignition when transported to a different climate, say at a distant PGI convention in another state.


Figure 5: Working the wax solution into the clay.

Some rocket builders will carry around a set of drill bits to fine tune their nozzles at the firing location. If a test rocket blows up, the next larger size drill bit is twisted into the exhaust hole to widen it slightly. Other builders choose to avoid building their rockets so close to the edge of self destruction, sacrificing some thrust for peace of mind.

Another technique you can use to battle moisture absorption is to treat your nozzle clay with a small amount of wax. This is done by dissolving about 5% wax into a solution of naphtha and working it into the clay. A good source of cheap wax is the toilet bowl gaskets found in the hardware store, which can be seen in Figure 3. A chunk of wax is cut off and weighed to get 5% of the clay weight, then dissolved in Naphtha or Coleman's camping fuel. Heat can be used to greatly accelerate dissolving the wax, but do not use open flames as you will surely ignite the flammable naphtha fumes. The best procedure is to take two metal bowls as seen in Figure 4, with one fitting inside the other, and float the inner bowl in a pool of boiled water. The solution in Figure 4 shows about 25% of the toilet wax dissolved into a yellow liquid. This liquid is then worked into the clay by hand and spread out on newspaper to dry.

Figure 6: Drying the clay on newspaper.

Blowout Prevention

Nozzle blowouts are frustrating, and sometimes the only solution is to cut back on thrust by reducing the fuel strength or opening up the exhaust diameter. However, there are a couple of tricks to try keeping your nozzle locked into the case before sacrificing thrust.

When using recycled kraft tubes as seen in Figure 9, the case wall will actually bulge out where the nozzle is rammed. This is actually a good thing, since it makes the nozzle considerably harder to blow out. You must be sure your nozzle is not flush with the end of the tube, however, otherwise the bulge will actually have the opposite effect and make the nozzle even weaker. The nozzle must be set a little into the tube so that the tube restricts back to it's normal size just in front of the nozzle.

While recycled tubes will hold your nozzle really well, the case itself will tend to blow apart when making rockets of any respectable strength. This forces you to use harder virgin kraft or hand rolled manila tubes that can handle the pressure. Unfortunately you usually lose the bulging plug benefit when using harder tubes, unless you have a hydraulic press that can really apply some serious loading pressure. You can see that the plugs rammed in Figures 1 and 2 don't show any signs of bulging in the case wall, despite the fact that they were rammed with a 10 lb impact hammer (i.e.- the Maltese Driver Rammer shown here).

Figure 7: Grinding up floor tiles with a steel rod in a box to reduce flying shards.

Using just plain old bentonite clay in a rock hard tube will usually result in blown plugs unless you are making very weak drivers or using a very strong loading device. The trick to giving your clay more bite on the case wall is the use of a gravel like additive commonly known as grog. Grog is a type of gravel in the 25 to 40 mesh range and has the effect of biting into the paper to help the plug hold stronger. This material can usually be purchased at pottery supply stores, but you can also make your own by crushing up ceramic material like flower pots or floor tiles. In fact, I find that the home made variety actually has sharper edges and more holding strength than commercial grog.

Making your own grog is simple but not the least bit enjoyable. The process involves taking a pile of your material to be pulverized and placing it on concrete with some kind of barrier around it to reduce the amount of flying fragments. I find it easiest to stand above it with a 1" diameter iron rod and drop-mill it while wearing safety glasses and a respirator (it's a dusty process). After crushing for a while, screen the chunks out using 1/4' hardware cloth, then run the results through a 20 to 30 mesh screen. Take what falls through the screen and run it through a 40 to 50 mesh screen. What little you have left sitting on the final screen is the keeper, which you mix into your clay one part for every three parts of clay.

NOTE: grog and ceramic fragments are spark producing materials that should not be drilled through with an electric drill after the case

Figure 8: Close-up of 25-40 mesh tile fragments showing the sharp edges.

Figure 9: Weaker tubes will allow the clay plug to expand beyond the inside diameter by bulging out the case wall, which locks in the plug and makes it much more difficult to blow out.

is charged. If you need to drill out a nozzle on a loaded case, slowly hand twist the bit in the chuck of your press without turning on the power.

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