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COMBUSTION AND CHEMICAL PROPERTIES OF BLACK POWDER

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1 What is Black Powder

Black Powder is a “high-energy material” and is intimate mixture of potassium nitrate (75 %), charcoal (15 %) and sulfur (10 %). There are of course deviations from the 75/15/10 ratio that will lead to substancial changes in performance. One merely cant’t just mix these materials together and light it. The mixture will be difficult to light and burns quite slowly. This is often refered to as “green meal” mixture. To produce high-quality Black Powder you need the right “stuff”, such as high purity Potassium Nitrate and the right type of charcoal and sulfur.

1.1 History of Black Powder

The use of chemicals to produce heat, light, smoke, noise and motion has existed for several thousand years, originating most likely in China or India. Some time, before 1000 AD. a “scientist” saw the potential to blend Potassium Nitrate, charcoal and sulfur. Marcus Graecus (Mark the Greek) reported a formula quite similar to the one used today in a 8th century work “Book of Fires for Burning the Enemy” (not a very pleasant title). Black powder was first familiar to europeans in the 13th century.

The use and discovery of Black Powder is perhaps the most important discovery of all time as stated by Tenney L. Davis in his classic book, “The discovery that a mixture of Potassium Nitrate, charcoal, and sulfur is capable of doing useful work is one of the most important chemical discoveries or inventions of all time...the discovery of the controllable force of gunpowder, which made a huge engineering achievements possible, gave access to coal and to minerals within the earth, and brought on directly the age of iron and steel and with it the era of machines and of rapid transportation and communication ¹”

1.2 Black Powder Manufacture

There are three factors that is critical in producing high-performance Black Powder. These factors are particle size, purity of starting materials and mixing time. Particle size is a very important factor when making Black Powder because of the surface area of the burning materials. The more surface area per volume the faster it will burn.

The manufacture of commercial Black Powder is a pretty heavy task. Following text is written by Tenney L. Davis,

¹T. L. Davis, The Chemistry of Powder and Explosives, John Wiley & Sons, Inc., New York, 1941

“During the eighteenth century, stamp mills for incorporating the ingredients of black powder largely superseded the more primitive mortars operated by hand. The meal powder, or pulverin as the French call it, was made into gunpowder by moistening slightly and then pressing through sieves. The powder grains were not uniform with one another either in their composition or their density, and could not be expected to give very uniform ballistic results. The use of a heavy wheel mill for grinding and pressing the materials together, and the subsequent pressing of the material into a hard cake which is broken up into grains, represent a great advance in the art and produce hard grains which are physically and ballistically uniform”².

As you can see this is a pretty heavy task for us amateurs, so we use a device called Ball Mill. This is a rotating barrel that grind the materials into fine powder. This is done by loading the barrel with lead media (sphere or cylindrical) or stainless steel media (only use this types of media as they are non sparking) and the Black Powder. The media grind the Black Powder into finer particles and increase the surface area, hence a faster burn rate. In Fig 1 you can see a ball mill that and the open barrel with lead media and Black Powder.



Figure 1: 3 Lb capacity Ball Mill designed by United nuclear

1.3 Burn rate of Black Powder

We usually use two types of Black Powder or as we called it a 12 HBMBP (Hour Ball Milled Black Powder) and a 32 HBMBP. This is a typical 75/15/10 BP that is ball milled for 12 and 32 hours. The burn rate of 12 HBMBP is approx. 0.16 m/s and the burn rate of 32 HBMBP is approx. 0.70 m/s. 12 HBMBP is used

²T. L. Davis, The Chemistry of Powder and Explosives, John Wiley & Sons, Inc., New York, 1941

for coating of the propellant grain to ease ignition and 32 HBMBP is used for recovery charges. Burn rate increases significantly when pressure increases as



Figure 2: [Click here to watch burn rate test of 12 and 32 HBMBP](#)

given by Shidlovskiy equation

$$\text{Burning Rate} = 1.21P^{0.24} \quad (1)$$

where **burn rate** is in m/s and P is pressure in atmospheres. This equation is only valid for the pressure range 2-30 atm. In Fig 3 you can see pressure vs. linear burn rate of Black Powder.

2 Chemical Properties of Black Powder

The burning of Black Powder does not correspond to any simple chemical reaction between stoichiometrical proportion of the ingredients. A study done by Noble and Abel³ showed that 74.430/14.286/10.093 Black Powder produce (average results) 42.98 % of its weight of gases, 55.91 % solids, and 1.11 % water.

2.1 Combustion Volume and Pressure of Black Powder

A much simplified chemical equation for combustion of 78/16/6 Black Powder is



With this information we can calculate the volume of gas that is produced per gram of combustion at various temperature. First we calculate the molar weight

³Noble and Abel, Phil. Trans., 1875, 49

2.1 Combustion Volume and CHEMICAL PROPERTIES OF BLACK POWDER

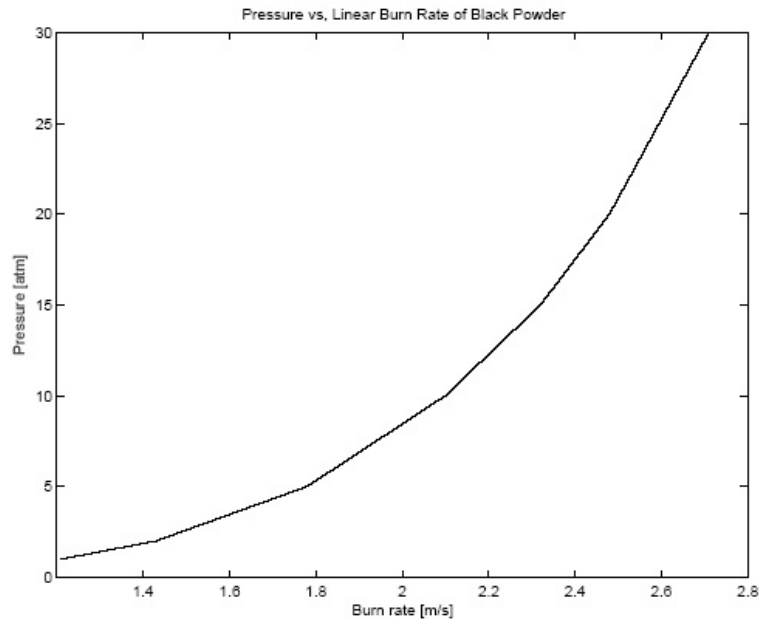
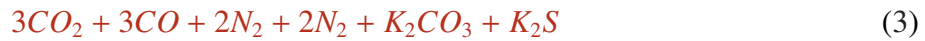


Figure 3: Linear Burn Rate for Black Powder

g/mol for the right side of the reaction (the products)



$$3(44.01) + 3(28.01) + 2(28.02) + 138.21 + 110.3 = 520.61 \text{ g/mol} \quad (4)$$

So for 1 gram of Black Powder there is 520.61 g/mol of gas and solid products. Now we need to know the weight of each gas product.

$$3CO_2 : \frac{132.03}{520.61} = 0.254 \text{ g} \quad (5)$$

$$3CO : \frac{84.03}{520.61} = 0.162 \text{ g} \quad (6)$$

$$2N_2 : \frac{56.4}{520.61} = 0.108 \text{ g} \quad (7)$$

Now we can calculate the moles of the gas product.

$$CO_2 : \frac{0.254}{44.01} = 0.0058 \text{ mol} \quad (8)$$

$$CO : \frac{0.162}{28.01} = 0.0058 \text{ mol} \quad (9)$$

$$N_2 : \frac{0.108}{28.02} = 0.0039 \text{ mol} \quad (10)$$

$$0.0058 + 0.0058 + 0.0039 = 0.0155 \text{ mol of gas products} \quad (11)$$

No we know how many moles of gas product there is for combustion of one gram of Black Powder. We use “The Ideal Gas Law” to calculate the volume produced for combustion of 1 gram of Black Powder. The ideal gas law states that

$$PV = nRT \quad (12)$$

where P is pressure in atm, V is volume in L, n is mol, R is the gas constant or 0.082058 L atm/mol K and T is temperature in Kelvin. Using the ideal gas law gives us

$$\text{@ } 25 \text{ }^\circ\text{C and 1 atm} : V = \frac{nRT}{P} = \frac{0.0155 \cdot 0.0821 \cdot 298}{1} = 0.38L \quad (13)$$

$$\text{@ } 3500 \text{ }^\circ\text{C and 1 atm} : V = \frac{nRT}{P} = \frac{0.0155 \cdot 0.0821 \cdot 3773}{1} = 4.8L \quad (14)$$

This shows that at 3500 °C the increase in volume is about 5000 fold the volume of 1 gram of black powder, and that’s a lot! Why did I use 3500 °C as a reference? Because this is close to the combustion temperature of Black Powder in confined space.

We can also calculate the combustion pressure for 1 gram of Black Powder in a controlled volume of 10 cm³. We use of course the ideal gas law again and get

$$P = \frac{nRT}{V} = \frac{0.0155 \cdot 0.0821 \cdot 3773}{0.01} = 480 \text{ atm!!} \quad (15)$$

With these calculations in hand it is no wonder that you here a loud bang when Black Powder is burnt in a confined space. It may also be noted that Black Powder “explodes” in an open area. You just have to dump about 250 kg at the ground and light it. The combustion gases work as a shield and confine the unburned Black Powder which will lead to an “explosion”. So be aware if you see 250 kg of Black Powder lying on the ground!

3 Uses of Black Powder in Rocketry

In Amateur Experimental Rocketry (AER) there are at least two main uses for Black Powder. Black Powder is used to blow out the recovery device when needed and also to ease the ignition of the Propellant. We use our 32 HBMBP to blow out the parachute in our rockets with good success. When testing motors it is very important that all the surface of the propellant ignite simultaneously. We use our 12 HBMBP to coat the Propellant segments (Grain) with great success. This help the propellant to “start” burning at the same time and gives a better thrust curves.