An Oxidized Bisque Firing by Steve Davis / Aardvark Clay & Supplies

Many clay and glaze faults in ceramic wares are caused by incomplete burnout (oxidation) of carbon during the bisque firing. This can be attributed to a kiln operator's lack of understanding about the chemistry that occurs during this first firing.

Carbon

Many materials used in ceramics contain carbonaceous matter, including organic carbon and binders, and inorganic carbon from clays, whiting, and dolomite. This carbon must be burned out (oxidized) during the bisque firing to ensure the best results possible in glaze firings. Bloating, black coring, pin holing, blisters, and poor color development are all the result of incomplete carbon burnout. To achieve the complete burnout of carbon (oxidation), you must have the following elements in place: oxygen, time, and temperature.

Oxygen

Oxygen is the most critical element. Without sufficient oxygen in the kiln chamber, carbon in the clay will have difficulty forming carbon dioxide and vacating the clay as a gas. If oxygen is in short supply, carbon will take oxygen from oxygen sources including red iron oxide (Fe_2O_3) that comes from ball clays, kaolins, fireclays, and particularly red clays. When carbon atoms strip oxygen atoms from red iron oxide (Fe_2O_3), the red iron oxide is converted into black iron oxide (FeO), a powerful flux. ($Fe_2O_3 + C \rightarrow 4FeO + CO_2 \uparrow$) Starting at 1650°F, the walls of the wares become progressively sealed by the fluxing action of the black iron oxide. When this same clay is then fired for a second time in a glaze firing to maturation, it can be over-vitrified and soft from the fluxing action throughout the clay body. Gases that are trapped in the soft clay wall will expand to form pockets (Bloating).

In low fire ceramics, temperatures are not high enough for bloating or melting to occur, but the carbon can cause faults such as black coring in the clay wall, pinholes, blisters, and poor color development in glazes and underglazes.

Time

Carbon burnout requires time for the oxygen to penetrate the ware and form carbon dioxide gas. Much thicker pieces, dense loads, and high iron clays require substantially more firing time for proper oxidation of the carbon. Sometimes the carbon content of the ware can be much higher than normal due to changes in raw materials. This increased carbon content can cause problems that would not normally occur with established firing procedures.

Temperature

Organic carbon burns out (oxidizes) from 300°F-600°F. Inorganic carbon from clays and ceramic materials burns out (oxidizes) from 1292°F-1652°F. Sulfur in various forms will oxidize from 1292°F-2102°F. Kilns must be well vented throughout these temperature ranges, especially from 1292°F-1652°F and the firing should proceed slowly through this temperature range to allow oxygen time to oxidize all of the carbon in the clay.

Venting Electric Kilns

Just because a kiln is electric does not mean that it is oxidizing during firing. There are too many carbon sources coming from clays and glazes. Oxygen must be supplied to the kiln through venting by one of two methods. One method is to install a kiln vent, which is the most effective way to introduce oxygen. The other method is to prop the lid open at ¾" and remove all of the peephole plugs. This venting should be done from the start of the firing and continued until the inside of the kiln chamber has achieved a bright, orange glow. A good prop for the lid is a 10" x 10" x ¾" kiln shelf. If placed on the rim of the kiln wall directly below the lid handle, it will shield the lid handle from the heat and corrosive vapors from the kiln. After a bright orange glow is achieved (1500°F), the lid can be closed and all of the peepholes left open. The lid is closed at 1500°F because any hotter will overheat your control box. (Get a kiln vent…………)

Bisque Firing with a Gas Kiln

In a gas kiln, oxygen supply is a little trickier. Gas fired kilns are basically a box where air and fuel are mixed and ignited. The air-fuel ratio is what we are concerned with. In natural draft kilns, fuel comes through the body of the natural draft burner under pressure. This flow of gas entrains 50% of the air requirement (primary air) through the burner. Air and fuel are mixed in the burner and the kiln chamber. The other 50% of the required air comes through the burner ports (secondary air). The damper on both up draft and down draft kilns controls this secondary air and the atmosphere of the kiln.

To achieve a reliable, oxidized bisque firing with a gas kiln, a **kiln chart** that list the gas pressure and corresponding damper settings, must be employed. As the kiln temperature increases, a greater expansion of the gases occurs in the kiln chamber. The air-fuel ratio will change towards a reduced atmosphere (lack of oxygen), due to the greater pressure of the fuel verses the pressure of the air.

In order to guarantee that there is always ample oxygen supplied to the wares, a firing chart should be established at a temperature equal to, or above the bisque temperature. It is critical to use repeatable methods of measuring the gas pressure and damper settings. Start by cleaning out the kiln, burner ports, and burners. Check the orifices for spider nests, and inspect the flue area for obstructions. Debris in the burner port can cause an area of local reduction within the kiln that may not be noticed during a firing. Next, install a gas gauge between the burners and the gas control valve. Make marks indicating the location of the damper openings of inch or half inch increments. Fire the kiln empty up to cone 04 and make notations on a kiln chart. Notations should include “time, temperature, gas pressure, damper setting, and comments”.

At cone 04, note the maximum amount of gas pressure used. Then push the damper in until a flame is visible in the damper area. If the damper area is not visible, observe the flame coming out of the peephole. Now incrementally back out the damper until the flame disappears. It may take a minute for the kiln to adjust to the new atmosphere. A peek-a-boo flame is a neutral flame and the kiln is not quite in oxidation. Once the kiln is in an oxidizing mode, make a note of the damper setting that corresponds with the gas pressure reading. Turn down the gas pressure a ½” and follow the same damper adjustments to establish the corresponding damper settings for the lower gas pressure readings. Continue this process until you are down to one inch of gas pressure.

This chart is created at a temperature that guarantees your kiln atmosphere will be oxidizing at lower temperatures. It is best to make the kiln chart at night when the flame is more visible. Once this chart is established, it should be easy to achieve a well, oxidized bisque.

Remember that “oxygen, time, and temperature” must be taken into account when bisque firing.

Kiln Chart

Time	Temp	Gas	Damper	Comments

Steve's Bisque Firing Program for a Skutt KM Controller

Controller Display	Push	Push	
"PROG"	1	Enter	
"SEGS"	6	Enter	
"RA 1"	60	Enter	
"F 1"	180	Enter	(Water forms steam at 212°F)
"HLD 1"	12.00	Enter	(Variable depending on water content and thickness of the wares)
"RA 2"	200	Enter	
"F 2"	600	Enter	(Organic carbon burnouts from 300-600°F)
"HLD 2"	0	Enter	
"RA 3"	240	Enter	
"F 3"	1300	Enter	(1300°F is start of inorganic carbon burnout)
"HLD 3"	0	Enter	
"RA 4"	60	Enter	
"F 4"	1650	Enter	(Inorganic carbon burnouts from 1300-1650°F)
"HLD 4"	0	Enter	
"RA 5"	360	Enter	(At this point you can push the "Cone Table" button,
"F 5"	1850	Enter	enter cone 04, and press "Enter".) This will allow you
"HLD 5"	0	Enter	avoid a 6th segment.
"RA 6"	108	Enter	
"F 6"	1922	Enter	(Cone 04 Bisque temperature is 1922°F with a
"HLD 6"	0	Enter	rate of climb of 108 degrees per hour)
"ALRM"	9999	Enter	
"IDLE"	START		

A segment (SEGS) includes a rate (RA), a temperature (F), and a hold (HLD) setting.
Alarm and Delay can be set after you have inputted a program.

The rate (RA) is the rate of temperature climb per hour.
The (F or C) is the temperature that a segment will fire to.
The hold (HLD) is how long the temperature will be held for that segment.

Heat Transfer

1. **Radiation**: When electromagnetic waves travel through space, they transfer heat to objects they come into contact with. The sun and kiln elements produce these waves. Radiation is the primary source of heat in electric and gas kilns.
2. **Conduction**: The transfer of heat between substances that are in direct contact with each other.
3. **Convection**: Heat transfer caused by the up and down movement of gases and liquids. Flues gases moving up a kiln chimney is an example of convection.

Pyrometric Cones measure heat-work, not a set temperature. If you fire to Cone 04 at a rate of 108 degrees an hour, Cone 04 will drop at around 1922F. If you fire to Cone 04 at a rate of 270 degrees per hour, Cone 04 will drop at a higher temperature of 1940F.