KILN LOADING AND FIRING

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The <u>bisque</u> temperature is generally cone 010 (earthenware), 06 (stoneware) and cone 04 (porcelain), depending upon the clay body used and the finish fire techniques desired. In general, the fired bisque ware must be hard enough to endure normal handling in the glazing process, while remaining sufficiently absorbent to permit glaze adhesion. The stacking of a bisque kiln is quite different from that required for a glaze fire. In electric kilns, one inch of free space is recommended between the electrical elements and the ware. In gas firings, some separation is desirable to allow free passage of heat thus avoid hot spots. Please remember; from raw clay to bisque, the clay will expand and shrink in the bisque firing process, please load accordingly.

Raw ware must be completely dry before it is loaded in the bisque kiln. Since there is no problem of glaze sticking, kiln wash (50/50 - E.P.K. & 200 mesh silica) is not needed and pieces may touch each other. It is possible to stack one piece inside or on top of others, building to a considerable height. Care must be taken to make foot rims coincide. Best practice is to load foot-to-foot & rim-to-rim for support. Avoid placing heavy pieces on more fragile ones. Large shallow bowls, which might warp, are better fired upside down on their rims with several smaller placed beneath. Covers/lids should be fired in place in the bisque fire to help prevent warping, and tall knobbed covers can be reversed to save space. Use discretion when bridging the shelves with your ware.

Gas or Electric kiln - Even though apparently dry, the raw clay contains much moisture and the firing should proceed at a low rate for several hours. 100-150^{o} F heat increase per hour is standard temperature rise for most of the firing. A slower rate of increasing heat should be followed from 0- 1300^{o} F. Kiln peepholes should never be removed for moisture to escape. Positive pressure out the bottom peep should always be present. Kiln turbulence and pressure will create evenness of heat and render moisture control. Positive pressure is especially essential for large, heavy pots or sculptural pieces with an even rate of temperature gain. Large work must be fired at a slow speed to prevent the moisture contained in sealed interiors and hidden air pockets from being converted into steam, which would cause the pieces to explode. Good air circulation and positive pressure will aid in controlling all free and chemical water issues.

Chemical changes in the body during the firing are slight at first. Greenware is prone to blowing up if fired too quickly past the point where water turns to steam (212°F), When the temperature reaches 350° to 400°F (175°- 200°C), all atmospheric moisture should have left the ware, causing little or no shrinkage. Most of the chemically combined water will leave the ware at temperatures between 950° and 1300°F (510° to 705°C). During this ‘water smoking’ period, considerable shrinkage occurs, so both the chemically combined water and gases from organic material leave the body. The firing should not be too rapid, for the body is very weak. As the temperature approaches 1750°F (950°C) and continues to 1850°F (1010°C), needlelike crystals of alumina-silica ($3A1_2\ 0_3$, $2S10_2$), called mullite begin to form, but they are not fully developed until stoneware temperatures are reached. These crystals give toughness to the body and as the temperature increases, additional free silica forms a glass around these crystals. Because of impurities and varying compositions, clay bodies achieve maximum hardness at different temperatures. Earthenware clay matures at about 2000°F (1090°C), stoneware at about 2350°F (1290°C), and pure clay (kaolin) at about 3000°F (1650°C).

Most ceramicists use cones to measure the cone 010 to cone 04 bisque fires, but some judge maturity by the bright red color of the ware. A uniform bisque temperature is necessary to create the proper absorbency for glazing. When the correct temperature is reached, the kiln (electric or gas) is simply turned off and allowed to cool. In the fuel-burning kiln, the chimney damper must be closed immediately to prevent a cold draft of air from being sucked through the burner ports, which might crack both the ware and the shelves. Just as the kiln must be fired slowly, it must be allowed to cool naturally. Consistency is an important key. The damper can be opened after cooling over night, but the door must not be opened until the temperature is below 400°F. Best Practice is to allow the kiln to cool until the unloading can be done without gloves. The use of gloves when you load and unload is recommended to protect hands from scrapes or cuts. (Slower cooling may be desirable for extremely large or heavy pieces. A kiln is one of the largest studio investments, which should give over 10 years service before any repairs are needed, if the kiln is not built properly your investment may be ruined after a short time by careless firing and cooling.

The glaze fire differs in several respects from the bisque fire: the loading is different, the kiln atmosphere may be varied and the final temperature must be carefully controlled. Since mishaps may occur from glazes, all kiln shelves must be coated with a kiln wash. This is made of equal parts of silica (flint) and kaolin (E.P.K.) in a creamy mixture. Each coat is applied before the last is completely dry. A new shelf can be sprayed with aluminum paint before the kiln wash is painted on. Additional protection can be obtained by dusting or sieved on a thin layer of coarse crushed silica sand. The shelf edges must be cleaned to prevent this sand from sifting down onto the ware below. All glazed ware should be ‘dry footed’, that is, all glaze cleaned off the base and about 1/4 inch up the foot rim. Glazes that are problematic, such as crystalline, fake ash and copper reds, can be placed on a slice of insulating brick to soak up the excess glaze.

A uniform load without tight spots will more likely produce an even firing. Uneven temperatures are almost certain to occur in the critical heating & cooling phases if partial kiln loads are fired. Staggering the shelves in a large kiln tends to create a better heat flow. Cold spots will develop in any firing if shelves are placed too close to the ware or to close to the bottom or the top of kiln. Test tiles must always be stacked in a middle/middle position, since there is usually some temperature variation from top to bottom. A center support is desirable for larger shelves. Damp clay wads are used to level uneven posts. Wads should be dusted first with dry flint to avoid stickling. Uneven shelves can create unstable kiln stacks. Unleveled shelves can cause warping and uneven glaze flow. If the shelves are of moderate size, three posts will eliminate leveling problems. As in the bisque fire, glazed covers/lids are best fired in place, but one must make certain that the contact areas are clear of glaze. Placing glazed ware too close to the bag wall may results in flame contact. Flame contact on glazed ware can cause glaze separation and warping clay forms. Glazed pieces should be at least 1/4 inch apart because heat radiation can also cause shininess.

Reduction firing means that part of a firing cycle that is conducted with an inadequate amount of air /oxygen required to burn the fuel. As a result, the free carbon in the air unites with and thus reduces the oxygen content of the metallic oxides in both the body and the glaze, thereby altering their color. Reduction is accomplished by cutting down on the primary air supply. Excessive reduction (black smoke) is undesirable in any firing. Excessive reduction will cause a rapid temperature drop, can produce blisters, bloat or even weaken or “black core” the body. Over reducing will dull most glazes. All that is necessary for a reduction is a pressure blue flame out the bottom peep. The blue flame should have an orange to yellow tip, not the belching of flame and smoke. Because of atmospheric pressure built up during reduction, one should not pull out the peep plugs/bricks with her/his face near the opening, for the flame will shoot out at least a foot in the top peeps. If you are using a brick up door, make sure you are using header courses every fifth or sixth course. In a bricked-up door, the door bricks may lean outward as the firing reaches higher temperatures, repositioning the top few courses may be needed to stabilize and secure the door.

The atmosphere should be oxidizing during the first part of the firing cycle, in order to ensure the most efficient heat rise. Reduction at body reduction temperature is needed to produce a rich body color and is most effective between cones 016 and 010. To ensure a good body reduction color (warm, rich, golden brown) and draw the iron to the surface. Minimum heat rise must be experienced during body reduction. The 20-40 minute time elapsed during body reduction (with minimum temperature gain) should be followed with an equaled time in a neutral cleansing atmosphere before increasing gas and resuming the firing. Neutral atmosphere should be experienced before and after body reduction (cone 010). For copper reds, begin reduction at 1650°F and maintain a reduction atmosphere throughout the duration of the firing. For normal reduction glazes after body reduction, at 1850°F atmosphere should return to neutral atmosphere until reduction is resumed around 2000°F through duration of fire. To provide a glaze reduction when the maximum firing temperature is reached, the air is adjusted to a preheat setting, the damper is adjusted to control length and color of pressure flame at the bottom peep. The usual practice is to cut back the air on the burners after the cone 9 is down and cone 10 begins to tip. Allow 20-40 minutes for a final glaze reduction that will set the color of glaze and acts as a soaking heat in which temperature variations can be stabilized and glazes become smooth.

(note from Pete Pinnell) I have been quite interested to read the traffic concerning copper red glazes. Up until a year and a half ago, I worked exclusively in porcelain, and for a period of seven years at least half of all my work was glazed with copper reds. During that time I tested hundreds of different formulas and tried a number of different firing schedules in order to produce better reds, and also to better understand the mechanisms involved in their production. Frankly, I was certain that the red color itself formed during the body reduction, the first reduction I did from about cone 012 to cone 04. Last week Richard Burkett wrote that he thought the red formed during the cooling cycle and since Richard knows his stuff, I thought I should put this to the test. I no longer work high fire (I have seen the light-- EARTHENWARE!) But one of my neighbors is Victor Babu and I knew he was firing this week. He very graciously allowed me to include some tests. I placed a number of porcelain draw rings just inside the top peephole. The rings were glazed with Pete's Copper Red from Victors supply. I dipped them at the same time his canisters were dipped, so I would know the glaze was well mixed. The firing consisted of three very large canisters (up to 2 ft. diameter), two of which were glazed in copper red. This particular glaze batch had already been used with great success in two firings over the last few weeks, so we know both the glaze and firing cycle were good. The rings were pulled form the top peephole at various times during the firing, and the results were as follows: Cone 012 (before reduction) - Color: white. Surface: dry Cone 04 (after body reduction) - Color: gray with just a trace of pink. Surface: a bit less dry Cone 2 (light reduction) Color: light gray. Surface: satin matt. Cone 5 (light reduction) - Color: light gray. Surface: semi-gloss. Cone 91/2 (end of reduction, begin 1 Hr. of re-oxidation) -Color: Clear with a very slight gray tint. Surface: Glossy. Cone 10 down (kiln off) - Color: none. Surface: glossy transparent. I did not include any draw rings for the cooling cycle - just one last one to remain in the kiln until it was unloaded. Well, I was perplexed. Victor was, well, nervous. At this point I decided to do what I should of done in the first place: consult Robert Tichane's excellent book: Reds, Reds, Copper Reds. Sure enough, Richard was right. According to Tichane, the glaze must reoxidize during the cooling cycle in order for the reduced copper metal in the glaze to return to the cuprous oxide state, and for the reds to nucleate and form. Since, I had two nervous days to wait until Victor could unload his kiln, I decided to run a further test. I placed the last two (cone 9 and 10) draw rings in my electric kiln and fired them to cone 08 in oxidation. RED!!! Both are a bright, deep, semi-transparent ruby red, but the one that went to cone 10 and was reoxidized is slightly better in color. I wondered how this would effect an already fired red, so I broke an old teapot lid of mine in two and put half in the same cone 08 firing. It changed the color from an almost opaque orange-red to a deeper more transparent ruby red. It is a definite improvement in quality - the color is now very similar to Ching Dynasty reds. I am now very curious. The only person I know who fires down is John Neely. John, how far down do you keep the burners on, and have you ever included any copper reds in your reduction-cooled firings? By the way, Victor's canisters are stunning. It is amazing to see such huge red pots. I also was curious about what the tiles would look like which were pulled from the kiln before cone 10, so last night I fired the rest of the draw rings to cone 08 in the electric kiln. Results: Cone 010 ring: White, dry Cone 04 ring: Pink, dry Cone 2 ring: pink, satin matt Cone 5 ring: darker pink-red, semi-gloss I think the results show that the copper in the glaze is reduced enough at even cone 04, but the glaze has not matured enough to dissolve the copper, so it does not have the intensity of a mature glaze. This raises an interesting question: if the glaze were mature at cone 04, it looks as if a true copper red would be possible. I do not name my glazes after myself- I originally called this cranberry red, but my KCAI (Kansas City Art Institute) students dubbed it Pete's, and that's the way I keep seeing it on all the photocopy glaze sheets that float around. This glaze works best if it's reduced early, beginning at cone 012 and continuing until cone 04. From then until cone ten we keep it in a light reduction. The exact color seems to depend primarily on how heavily it's reduced: its different colors are distinct enough that I (and my students) use it as a measuring stick after the firing to judge the intensity of reduction. In case you are interested: Oxidation: glossy, crazed, very light green Neutral: clear (no color) crazed, slight pigskin (dimpling) on surface Light reduction: very dark burgundy, almost black- heavy pig skinning on surface Medium to heavy reduction: bright cherry red, semi-transparent, smooth glossy surface. Beautiful! Heavy reduction: some blue appears, surface can mottle, or begin to take on a matt appearance-also quite nice. Extremely heavy reduction: matt surface some bubbling, lots of blue mixed with the red. Of all the reds I tried, this one seems to be the most dependable as a standard around here.)

The term reduction first must not be confused with reduction glazes. The latter are glazes especially formulated to produce copper-red and celadon colors. In the firing of these glazes there is no real change in body color but rather a reduction of the coloring oxides in the glaze from an oxide to a metallic form. Thus, copper green becomes a rich red, and the iron brown-red is transformed into a gray-green. In the reduction fire, the glaze begins later than the body reductions but it must occur before the glaze begins to melt. Reduction causes the heat rise to diminish; there is usually an increase in reduction as the fire progresses. Too much oxidation will bleach out the color. Copper variations in color range from a mottled blue-green and red to a deep purple-red or a pale pink, depending upon the reduction sequence, the glaze thickness and the body color.

A <u>localized</u> <u>reduction</u> can be obtained by adding 1/2 of 1% of silicon carbide (carborundum @ forty mesh or finer) to a copper alkaline glaze. The result is usually a speckled red and purple color. Its only real advantage is its stability to the electric kiln. Popping a few mothballs through the peephole can reduce an electric kiln. The kiln should have heavy elements, which have a good oxidized coating from many previous firings. Continuous reductions will eat away the elements, but an occasional one will do little harm to the kiln. **This mothball procedure yields toxic gases. Make sure your kiln and the kiln room is well ventilated for health & safety! M.S.A. with proper filter is strongly suggested.**

The single-fire salt glaze is fired to the maturity of the body. Any form of salt can be blundged with water will product a brine solution. Mix three pounds of salt to forty pounds of water. (Approximately 5 gallons of brine for a 50 cubic foot load). An addition of 5% borax to the brine solution will render a glassier/shiner glaze surface. The brine solution is atomized into the kiln atmosphere at peak temperature in salt ports (**not burner ports**). A twenty-minute soaking or clearing time is allowed at the conclusion of the process. Draw rings of clay are commonly used to check for desirable build up of salt. Draw rings are placed in peepholes and extracted during firing after salt/soda is atomized. Clay rings can also be used to measure kiln temperatures. Clay rings are the only method of determining actual salt buildup in a salt or soda kiln (see high temperature salt handout).

Striking (reducing) the kiln in the cooling process is advisable for richer earth tones. New kiln wash is applied to kiln furniture and removed at the conclusion of each firing. A complete coating of kiln wash is applied every second or third firing cycle. Salt kiln wash and Wood kiln wash is (50% **alumina** and 50% **E.P.K.** with a 10% addition of **Epson Salt**. Wadding – (wood and salt) – for leveling the kiln furniture and elevating ware is the same formula as the kiln wash.

Pyrometric cones provide the ceramicist with his most accurate method of measuring the working heat in the kiln. The name is inaccurate, for the pyrometric “cone” is actually a tetrahedron or pyramid shape 1 3/4 inches high, with a base that is 1/2 inch across. Cones are compounded of a material similar to a glaze. When softened by the heat, they bend and when a complete arch is formed, the temperature in the kiln is that of the cone number. The base is beveled to indicate the proper angle at which to press them into a pad of clay. The usual practice is to use body and glaze set of cones, for example: body (010-04-01- 3) glaze (6-8-9-10) if the firing is to reach cone ten. Cones should be placed in front of all peeps, not too close but allow some distance for a clear view with a large object behind cones to help silhouette the cones. The bending of cone 8 and 9 warns that the kiln is approaching the proper temperature and the burner or damper adjustments are made to stabilize the heat at this point. As cone 10 starts to bends, the air to the burners can be adjusted and final damper setting made for a soaking period. The softening or tipping of cone 10 indicates a completed firing. Most glazes can be formulated to allow a temperature range of a full cone for an acceptable surface; this usually allows most kilns from top to bottom & front to back to even out.

Kilns can fire slightly hotter in some areas, so knowing the sweet spot in the kiln can be valuable acquired bit of information. Damper control should control and compensate any temperature variance from top to bottom. If the cones are difficult to see, blowing into the peephole through a tube, or inserting a metal rod near the cones or temporarily opening the damper will reveal them more clearly. Caution: wear protective eyewear.

A slower rise in temperature with the resulting longer period of chemical reaction will permit a glaze to mature at a lower temperature than if the heats rise is rapid. This relationship between time and temperature is called the working heat ratio and it is recorded by the pyrometric cone but not by the pyrometer. The pyrometer consists of a pair of welded wires of dissimilar metals, called a thermocouple, which is inserted into the kiln. When the kiln is heated, a minute electrical current variance in thermocouple metals which indicates a variance that is translated to temperature change on a millivolt meter that is calibrated in °F or °C. A pyrometer is convenient to have when the ceramist is making adjustments to produce the most efficient heat rise, or when he wishes to determine the proper time to begin a reduction or hold temperature. However, unless one has an exact and unvarying firing schedule, it is not completely dependable. In time, corrosion of the thermocouple tips affects the accuracy of the reading; this can be adjusted to the proper cone by moving a tiny screw on the meter face. Thermocouples and pyrometers are available in both low and high fire models. The rather inexpensive ones are seldom reliable over a wide range of temperatures, that is, if the cone 10 reading is correct, the cone 06 may be inaccurate. Optical pyrometers are also available; these are quite accurate, but rather expensive. Glazed draw rings, which were common before the introduction of cones, can also be used to measure kiln temperatures. Such clay rings are the only method of determining glaze buildup in a salt kiln.

KILN MATERIALS

Firebrick is made in a number of special compositions, but the common alumina-silica hard refractory firebrick is satisfactory for most purposes. Hard firebricks are used in corrosive atmospheres. High alumina or high silica is additional selection for duty in H.F.B. or I.F.B. Different grades are produced for operating temperatures: 1600°, 2000°, 2300°, 2600° and 2800°F (870°, 1093°, 1250°, 1427° and 1638° C). Some can be used at temperatures as high as 3000° and 3200° F (1649° and 1742° C). The bricks used for higher operating temperatures are denser and lose much of their insulating ability. In operation H.F.B. have a cold face temperature of 700°F. / I.F.B. have a cold face temperature of 200°F. Temperature is wicked through the brick to the cold face, the cold face temperature is maintained. The increase of temperature in the kiln chamber must always answer the wicked heat equation before temperature is increased. It takes more energy to fire on cold days vs. warm days. I.F.B. are more expensive but shipping can turn the cost upside-down. Therefore, one should not purchase a higher-grade brick than is needed. A 2600°F brick is generally used for kilns firing from cones 8 to 10. Special shapes (arch, wedge, skewbacks can be ordered for the curve of the kiln arch. A kiln constructed entirely of hard firebricks will consume a lot of fuel, since the bricks absorb and conduct a considerable amount of heat. Insulating firebricks are also made, which have an insulating value from 3 to 5 times as great as the brick. Insulating firebricks are also available in a similar temperature range as a hard brick, but the cost is higher. They are most often used as a backup layer next to the hard brick, although kilns made entirely of insulating bricks are common. Although more expensive, they require less fuel and the insulating bricks can be easily shaped with a coarse tooth saw, such as an inexpensive pruning or bow saw. All Brick dust is hazardous and protective eye-ware and M.S.A. Respirator is recommended.

KILN FURNITURE

Kiln furniture includes the shelves, posts and other props used in the kiln. Special plate and tile sitters are common. The heavy fireclay shelves that were formerly used have disappeared in high temperature, as better materials have replaced them. Mullite/Cordierite/Sillimanite shelves are suitable for the earthenware temperatures, but the more expensive silicon carbide shelves or even the lighter/thinner nitrate bonded shelves give longer service and are compounded for use at various temperatures. A 3/4-inch thickness is adequate for standard 200 lb. duty per shelf loads. A center post is necessary to avoid sagging and possible breakage in spans of 24 inches or more. Since it is less subject to strain in cooling and heating, a rectangular shelf gives longer service than a square one. If the length exceeds the width by two then the shelf is potentially weak. To accommodate the weakness the thickness of the shelf should be increased to 7/8” or to one full inch. A slow heating and cooling cycle, will not only minimize damage to the pots but will prolong the life of the kiln furniture, especially the shelves.

Posts that are made of fireclay are available in various sizes. They often have a center opening to promote a more even expansion. High temperature insulating bricks can be cut to make satisfactory posts. Dipping the ends of the fireclay posts into aluminum paint will lessen their tendency to stick to the bottom of the silicone carbide shelves. This problem does not arise with triangle slip-cast posts made of porcelain-like material. Triangular stilts (porcelain) with nichrome wire tips can be used for some covers or for small pieces that must be glazed all over. The small contact blemishes are minimal.