REDUCTION FIRING

Reduction is firing where the kiln atmosphere has insufficient oxygen for complete combustion (more fuel than air to burn it). At high temperatures, this produces carbon monoxide gas, which will steal loosely-bonded oxygen from other materials, in ceramics mainly iron and copper.

SAFETY NOTE: 
carbon monoxide gas is TOXIC. Do not remain in a closed kiln room during reduction.


China. Qing dynasty celadon cups

This changes the molecular form of the material and produces color changes. In oxidation, iron generally produces tan, brown, or rust colors. **In reduction, small amounts of iron give celadon colors: green, blue, olive, or grey-green colors.** Copper in oxidation is green or blue-green. **Small amounts of copper in the appropriate base glaze in reduction produces copper reds** in shades known as *sang-de-boeuf* (oxblood - red toward a plum-red), peach bloom (pink-to-peachy reds), or flambé (orangish-red). Chinese historic ceramics are particularly famous for these colors. While reduction can be done at other temperatures than high-fire (cones 8-11), it is held by many clay artists that high-fire reduction has the best color response, with richer tones, than reduction at lower temperatures.


China. Qing dynasty *sang-de-boeuf* vases

Bisquing work before glazing

Work may be raw-glazed and once-fired. This is not the most common procedure because bone-dry greenware is fragile, may split or crack from being wetted by glaze, and contains carbonaceous matter that will burn out in firing, possibly causing pin-holing in the glaze. Greenware is also prone to blowing up if fired quickly past the point where water turns to steam (212°F), and pieces of exploded ware would be trapped in glaze. Glazes for once-firing must be balanced for shrinkage with the raw pot, and usually contain a much larger % of clay than glazes for bisque application.

Industry sometimes bisque-fires pottery to maturity so that it may be supported during the firing (e.g. translucent porcelains). This vitrified ware is no longer porous and special binder and application methods must be used to apply the glaze.

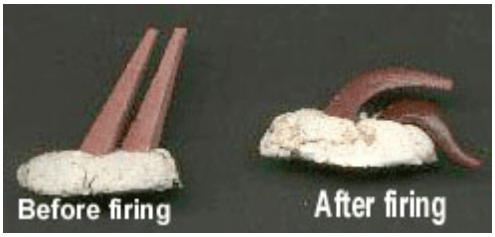
Studio potters usually bisque to a temperature below the maturing point of the clay, then apply glaze to the porous bisque and glaze-fire to maturity.

Pyrometers measure temperature, usually through a probe inserted into the kiln. This tells us the temperature at the place of the probe and the time read. This may not indicate whether the materials in the kiln have sufficiently melts.

Pyrometric cones measure work-heat (the effect of time and temperature on materials) and are the usual indicators for firing. Cones were developed by Seger. American cones are manufactured by Orton. Cones are a combination of clay and glaze materials, calibrated to melt at a specific temperature. The interval between cones is about 32 degrees F. Cones are made in large and small format. Melting temperature is somewhat different between large and small cones of the same number. Small cones are often used in electric kilns for visual cones because peeps are small and it's hard to see several large cones. Small cones are used in electric kiln kiln-sitters.

See Appendix 2 in Hands In Clay for color and temperature equivalents. Lower-firing cones are numbered with a "0" in front of the number, and read like a negative number (e.g. 022 is cooler than 06). There is no cone zero. Numbering goes from cone 01 to cone 1. Cones numbers w/o a "0" in front are hotter in ascending numerical order: cone 1 is cooler than cone 6.

Cone packs should be made to put in front of both top and bottom peeps of the gas kilns. Clay wads are used as a base to support a series of cones: theoretically, a **guide cone** (tells you when you are getting toward temperature desired), a **firing cone** (the desired temperature), and a **guard cone** (to gauge the limits you may fire to).



Bisque cone packs, cone 05. Left, 06, right

Cones should be tilted at a slight (8 degree) angle so that you will see them soften and bend before melting. Place cones close to each other so the group may be easily seen through the peep, flat side facing forward, number facing you, **cone that melts soonest first** (if cone order is reversed, the first cone to melt will knock the others over). It is difficult to get 2 wide cone packs on a support in front of the peep, so balance the need to catch the drips with the logistics of placing 2 cone packs next to each other. Note that the cones in the bisque illustration are junior-sized lowfire cones fired close to their melting point. In the cone 10 reduction cone pack, you will be firing way beyond the lower cone pack, and the cones will melt into a liquid and run. Make a big boat on the front of the cone packs. Make cone-packs ahead of time and dry them. Glaze kilns are usually heated faster than bisque (gas burners are often harder to control at low temperatures), and wet cone packs may blow up, scattering bits of clay onto glazed ware.

Cone 10 reduction cone packs after firing. Back cone pack , l to r, cones 011, 010, 09, 4, front, l to r, 6, 8, 9, 10. Note that packs are faced in opposite directions to make sighting cones more definite. In spite of a boat, the cones ran. Helps to put on a kiln shelf shard for easier clean-up.

For high-fire you will need **2 sets of 2 cone packs:**

1. **Lower cones for determining when to begin reduction.** Usual low cones are 011, 010, 09, 4 or similar. ***MAKE A BIG BOAT ON THE END OF THE LOW CONE PACK***. THESE CONES WILL MELT DOWN TO A PUDDLE IN FIRING AND RUN IF NOT CONTAINED. It is not fun to chip this off of shelves, or find it in glazed work.

2. **Glaze maturity temperature cones.** Glaze cone pack should contain 6, 8, 9, 10. While the #6 cone is not necessary, it gives a guide part-way through the firing to temperature and kiln evenness top-to-bottom and is a helpful indicator. Please make sure to fill in a kiln chart and label the numbers of the cones in the cone packs so the firers know what they're looking at.

Placement of cone packs

Cone packs are placed in front of the peep holes, usually with the reduction cones to the front (they will melt out of the way before the glaze cones are needed) facing in one direction, and the glaze cones in back facing the opposite way. Check position for visibility with the kiln door closed using a flashlight or a paper torch in the kiln.

Glazing

Most high-fire glazed benefit from even glaze application. This is most easily accomplished by dipping. See information on glazing and high-fire shop glazes.

Pot bottoms should be waxed (dry-footed, i.e. unglazed) to resist glaze application, as well as lid seats and lid edges if you plan to fire with the lid in place to reduce warping. High-fire glazes tend to move (run) during the firing, and 1/8 to 1/4" should be left between the pot bottom and the beginning of the glazed area to prevent runs onto the kiln shelf. Many potters consider this when making work, and make a deep bevel on the foot that creates

a shadow so the piece visually sits gracefully and also lifts the pot the ¼" area needed above the kiln shelf w/o showing a ring of bare clay at the foot.

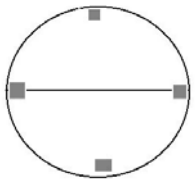
If glaze sticks the piece to the kiln shelf, it may break the piece as it contracts in cooling, and the work's owner will be asked to chisel the glaze off the kiln shelf. Thicker glaze applications tend to run more than thin ones. Combinations of glaze (e.g. double dips) may form a **eutectic** be runnier than either one alone. **If you feel you are using a thick glaze application and/or doing experimental combinations of glaze, please make sure you work is loaded into the kiln with a clay waster of a piece of broken kiln shelf under it to catch any runny glaze drips.**

Loading

Before you load check that the kiln is free of debris around the ports and behind the bagwall. The target brick behind the bagwall is there to deflect the flame and should remain in place, but check for shards of work, etc. Check to see that all the gas valves are closed and the blower system are OFF. If you have any reason to suspect a problem with the kiln, test-light it before loading to make sure it is working properly.

Use the black silicon carbide shelves for the gas kilns. THESE SHELVES ARE HEAVY. THESE SHELVES ARE EXPENSIVE. Please be careful and do not prop them against movable items. Find help if you have trouble lifting and placing higher shelves in the kiln. Check each shelf for proper kiln wash. This protects the shelf from glaze drips and makes it easier to chisel off any glaze runs. Kiln was should be mixed up in a container by the sink in the kiln room. Dry mix is in the cupboard underneath. Apply w/a brush or paint roller. Kiln wash should be the consistency of cream. Several thinner layers stick better than one thick one. WASH ONLY THE TOP OF THE SHELF. Wash on the sides or underneath may pop off and fall into the work below. Kiln wash for low-fire and regular reduction is 50 silica + 50 EPK by weight.

WARNING: if you are using the thin, black **bonded silicon carbide shelves DO NOT EVER fire them wet or damp.** If they need to be kiln-washed, they must be completely dried before using them. **If these shelves are heated wet, they may EXPLODE.**



Post the first shelf several inches off the kiln bottom for adequate heat/air circulation. Generally shelves are tri-posted, sharing end posts. **Posts are always put above each other when loading subsequent levels so that the posts, not the shelves, bear the weight of the load.**

Ware is grouped by height, and similar heights are loaded on the same shelf to use the space efficiently. Very tall pieces are often put on the top shelf so that multiple posts don't have to be used to achieve tall heights. The ware selected for the bottom shelf should be at least 6" high. A very low first shelf (say, plates or tiles) sometimes does not let heat and gasses circulate well, and may result in under-fired or under-reduced works on the bottom. Check the bottoms of all ware as you load to make sure there is no glaze. Also check to make sure the clay does NOT look like terracotta. If lowfire clay is accidentally fired to cone 10, it will melt into a pancake, stick to the kiln shelf, and has the potential to ruin adjacent works. If anything looks like it may run too much, put it on a piece of broken kiln shelf or a brick to protect the kiln shelf. Glazed ware may be placed to the edge of the shelf, close together, but not touching. **Make sure you note the position of the peeps and leave room for the cone packs.**

Firing

When you are done loading, check the kiln chart and make sure the cones for the cone packs are noted. With the damper open, the air off, light the pilots. We generally candle the gas kiln on very low heat overnight to get them fired off at a reasonable hour the next day. It's safe to have the pilots on. Turning the burners on low setting is a judgment call. If this is done early and the next person watching the kiln comes in late, you could heat the kiln enough that you miss the right time to do reduction. Generally, we turn the burners on very low overnight only if the kiln is turned on late in the evening, and someone is coming in early to check on it.

Glazed ware holds less physical water than greenware, and the chemical water has already been fired off, so it is less likely to explode from water turning to steam at 212° F than bisque. However, recently glazed pieces, especially thick ones that are still cold to the touch, may hold water. Temperature should be increased gradually

until the kiln is past red heat (about 1000° F), which is also quartz inversion, where silica changes shape and gets 2% bigger.

OXIDATION is complete combustion of fuel in the presence of adequate oxygen. The flame will appear blue, short and bushy, the kiln atmosphere will look clear, and the kiln makes a roaring sound. No back pressure (flames) from damper or peeps. The gas combusts at the burner tips. This is the most efficient combustion and will cause temperature to rise the fastest. Oxidize until reduction (about 010). It is helpful for smoother, brighter glaze surfaces to oxidize for 15-30 minutes at the end of the firing (begin around cone 9 soft for a cone 10 soft firing).

REDUCTION is incomplete combustion of fuel, caused by a shortage of oxygen, which produces carbon monoxide. Reducing flames will appear soft, licking, long, orange/yellow. The kiln atmosphere will be murky. Back pressure (incompletely burned gasses) will be seen (visible orange or yellow flames at the damper and peep holes). Black smoke indicates too much gas (waste), and can cause black-coring of clay bodies and dull glazes. It is not necessary to reduce this much. During reduction, the lack of sufficient oxygen for combustion in the kiln causes the whole kiln to become a combustion area. This is inefficient combustion, slows the temperature climb, but will help even out the kiln temperature. **You should do reduction about cone 010, and reduce for 20-30 mintues.** If you begin reducing later then 06, you may have missed reduction and will not get any.

NEUTRAL or slight reduction atmosphere will produce greenish flames and conditions between oxidation and reduction. After reduction, it is common to leave the kiln in a neutral atmosphere til cone 9, then oxidize.

Kiln Control
Controls on the kiln consist of the **GAS** valve (generally a meter is attached, altho on some kilns you may register just the position of the handle to indicate amount of gas), the **PRIMARY AIR**, which is the blower on forced-air kilns, and **SECONDARY AIR**, or the air sucked in around the burner ports and controlled by the **DAMPER** on the flue.

These controls work together to produce the desired effect. To produce an oxidizing flame, turn of the gas to the desired level. You may open the damper and/or increase the primary or forced air or reduce the amount of gas to produce a blue, bushy flame.

To put the kiln into reduction, close the damper partially and/or decrease the primary air, and/or increase the gas pressure to produce reducing conditions. Make sure that you get back pressure, or at least can see swirling gasses in the kiln at the bottom peep for good reduction.

The firing is oxidized from the beginning up to about cone 010. The kiln is reduced, then put into a neutral atmosphere until cone 9 is down. As cone 10 begins to move, the kiln should be put into complete oxidation to finish the firing (usually the last 20 minutes or so). This will allow glaze materials to settle down. Once the kiln reaches the glaze maturity point (for our shop glazes someplace between cone 10 beginning to bend and cone 10 over), turn off the kiln. If you **turn the electrical switches off**, everything will turn off. **Close the gas valves**. Note the time on the kiln chart. **Close the damper** to keep cold air from blowing through the kiln. Most glazed benefit from slow cooling, and all need time after firing in a molten state to allow bubbles to smooth out. Cold drafts can cause uneven cooling during quartz inversion or cristobalite inversion may cause **dunting**, or cracking though the body during cooling, from stresses.

Safety
Please tie long and/or fluffy hair back before checking the kiln. Remove and replace peep plugs from the side to avoid any back pressure. If you have trouble viewing the cones w/back pressure coming out the peeps, reduce the back pressure by turning down the gas and\or opening the damper a bit. When viewing kilns above orange heat, **use protective dark glasses intended for eye protection**.

TROUBLE-SHOOTING

You need to review the kiln conditions to make appropriate judgments for adjustments. Downdraft kilns react somewhat differently than updrafts, and each kiln had it's own personality. Differences in loading and weather may also affect firing. Generalizations below are for the updrafts.

IF you have the damper wide open, you may be losing so much heat out the flue that the bottom will be cold in spite of a low, busy, oxidizing flame. If the bottom seems cold (often the case early in the firing as the kiln heats), close the damper a bit.

IF you have very high primary air you may cause a great deal of turbulence in the kiln and such a strong draft and intake of secondary air that the bottom stays cold. Reduce the primary air (blower) and adjust the gas and damper for proper flame.

IF you have the damper closed too much, you may find it difficult to get a clean, oxidizing atmosphere w/o back pressure. Open the damper a bit and/or reduce the gas.

IF you do not have enough turbulence in the kiln, you will have difficulty getting good reduction of the bottom. Increase the primary air and/or open the damper a bit. Turbulence helps the heat and kiln gasses circulate to all parts of the kiln.

IF the kiln seems to stall toward the end of the firing, check the gas. Sometimes very high gas and enough air for a neutral atmosphere causes too much draft and heat is lost. Turning down the gas a bit for better combustion with the desired amount of air may actually increase the rate of climb.

REMEMBER that **any change you make may take 15-30 minutes to show** in overall effect. Constantly changing the kiln settings may slow firing. Note all changes and results on the kiln chart.

When you reach the desired temperature, turn off the gas valves, flip off the electric system, turn off the blowers, and shut the pilot valves. Close the damper so that cool air does not continue to flow through the kiln. Note the time on the kiln chart.

Cooling/Unloading

Although it is possible to speed-cool a kiln by leaving the damper open from the end of firing through red heat, this is hard on the kiln structure and may not produce the best glaze surfaces, especially in crystal-surface glazes (the crystals form during cooling, and slow cooling promotes more crystals). Around red heat quartz (1000 deg F) goes through **QUARTZ INVERSION**, and the piece becomes about 2% smaller. This should happen slowly to avoid **dunting** (cooling cracks). Free silica in the clay can be converted to **cristobalite** when fired above about 1940 deg F. This will invert and get about 3% smaller on cooling at 439 deg F. This can also cause dunting if it happens quickly. A classic test for whether a kiln is cool enough to pull the peeps and crack the door/lid is to put paper into a spy hole. When a paper no longer ignites (paper burns at 451 degrees F), you may pull the peeps and open the damper a crack. Unload when cool.

Persons unloading should note any unusual results from reduction or lack of while the kiln is still loaded and note positions of any un-reduced or under-fired work (note this on the back of the kiln chart for reference). Unload the work onto a cart. Remove shelves. Chip any glaze runs off with a chisel and hammer and/or rub off w/a piece of black silicon carbide shelf. To avoid cracking the shelf when chipping glaze off shelves, it is helpful to put the shelf on a resilient surface (e.g. wood), or lean against an immovable object at an angle and/or chip at an angle, not straight down. Re-apply kiln wash and stack. **PLEASE WEAR SAFETY GLASSES TO PROTECT YOUR EYES FROM FLYING CHIPS OF WASH.** Replace the shelves in the holder, stacking the shelves face-to face and back-to-back (to prevent wash chips on the backs of shelves that could fall into the work in stacking the kiln). Re-stack kiln posts. Sweep out the kiln if needed. Sweep up the area around the kiln.

Bibliography

Hamer, Frank and Janet, *The Potter's Dictionary of Materials and Techniques* 4th ed, Univ. Of PA Press, A & C Black, 1997. Thorough discussion of cristobalite, reduction, and many other topics