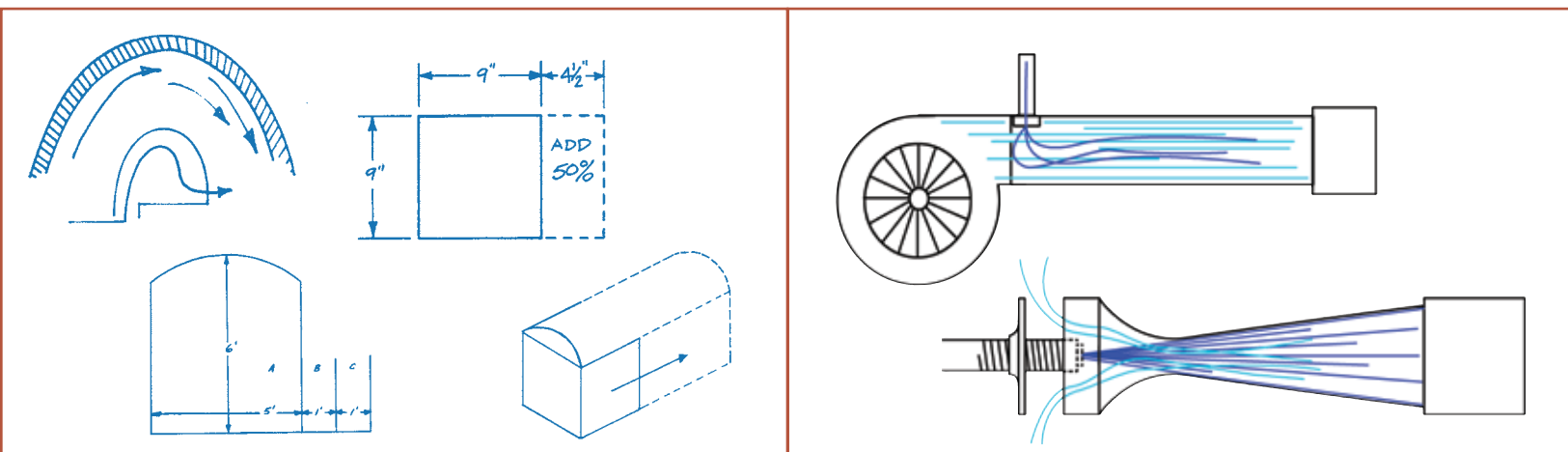


gas kiln design & firing



integrating material and energy
efficiency into gas fired kiln plans

Gas Kiln Design and Firing

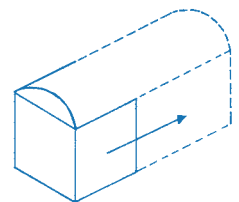
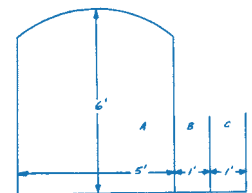
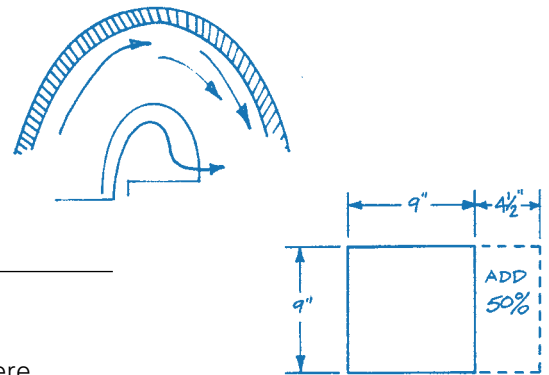
Integrating Material and Energy Efficiency into Gas Fired Kiln Plans

If you want to build and/or fire a gas kiln, there are several things you need to know before diving in. Whether you plan on doing oxidation, neutral, or reduction firing, and regardless of the type of gas fuel you will be using, knowing how a kiln is designed and put together helps you understand what is happening during the firing. **Gas Kiln Design and Firing Integrating Material and Energy Efficiency into Gas Fired Kiln Plans** provides guidance and information critical to the success of your ceramic work.

Principles of Gas Kiln Design: How to Plan and Build a Gas Kiln That Suits Your Needs

by Frederick L. Olsen

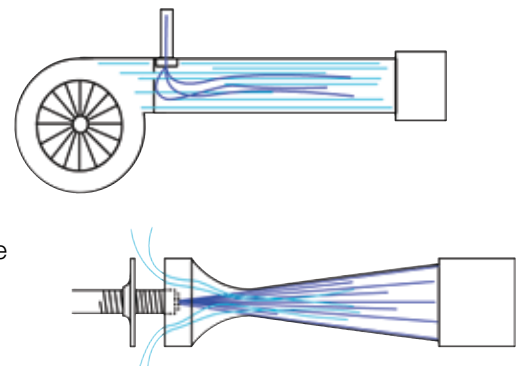
From choosing the size of bricks to stacking them into a finished kiln, there are several critical factors and principles to consider before you begin to build a gas kiln. Olsen guides you through choosing the shape and size of your kiln, calculating flue and chimney size, and even adjusting for oxygen needs at higher altitudes. All of these will require you to make some decisions; some are based on the kind of work you make, and some are based on your workflow and studio capacity. All of these decisions will be guided by the decades of experience provided by veteran kiln builder Fred Olsen.



Efficient Gas Kiln Firing

by Hal Frenzel

Most anyone can figure out how to mix gas and air to produce heat in a kiln. What takes a little more expertise is firing a kiln with efficiency, regardless of what type of firing is being done. Understanding fuel combustion and the kinds of burners and other atmospheric controls that are available will help you understand the processes at work in a gas fired kiln, and will help you determine the best possible approach for your ceramic art.



Principles of Gas Kiln Design

How to Plan and Build a Gas Kiln That Suits Your Needs

by Frederick L. Olsen

Six critical factors must be considered before you begin to design a kiln. This article reviews those considerations, then discusses the principles of good gas kiln design. These basic principles are then incorporated into the four distinct types of kilns discussed in succeeding chapters on crossdraft, downdraft, updraft configurations and multi-directional draft configurations.

Critical Factors

Kind of kiln. Will you build an updraft, downdraft, crossdraft, circular dome, or salt glaze kiln? Will the kiln be 10, 20, 25, 45, or 150 cubic feet or larger? You must carefully calculate your requirements before you begin the design.

Clay to be fired. The type of clay you plan to fire will determine the type of kiln you need, its size, the fuel to be used, and so forth. Kilns may be planned and built specifically to fire terra cotta clay, sewer pipe clay, earthenware, stoneware, porcelain, or any of a number of possibilities. In fact, the potter should know the clay and ware so well that he can design the kiln to enhance the pottery and to control the effects of firing.

Atmospheric conditions. The chamber shape will depend on whether the kiln is intended for oxidation, reduction, or perhaps middle fire. Burners and dampers can greatly affect the ability of the kiln to oxidize or reduce. This, in turn, affects clay bodies and glazes and their outcome.

Available fuel. It may be foolish to build a wood-burning kiln in the city; it's a romantic idea but impractical. Therefore, the relative availability of natural gas, propane/butane, oil, wood, coal/coke, and electricity must be considered. Since propane/butane and electricity are available almost anywhere, and are clean burning, they can be used anywhere except where natural gas is provided. Natural gas is a perfect fuel for use in cities or highly populated neighborhoods; however, before one

proceeds, ascertain the amount of gas available to the site. Wood, coal/coke, and oil should be reserved for use in the country.

Location of kiln. Whether city, suburb, backyard, garage, manufacturing area, or countryside, all locales tend to "self design" a kiln. By this I mean that each location tends to dictate what kind of kiln is feasible, a wood kiln in a garage is not the best idea, nor is an anagama in a suburb. Many areas will have building code restrictions that affect what kind of kiln you can use. Be sure to check local regulations before spending any money.

Shelf size. Be sure your kiln is designed to accommodate one of the standard shelf sizes.

Design Principles

Once the basic requirements are determined, according to these critical factors, the following nine principles become an integral part of every kiln design:

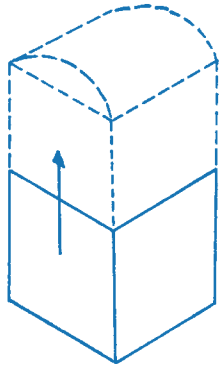
PRINCIPLE 1: A cube is the best all-purpose shape for a kiln.

The best design for an updraft kiln has the arch on top of the cube, not contained within (*figure 1*). This allows for the best stacking space. Also, the volume of the arch



1

A cube is the best all-purpose chamber shape.



2

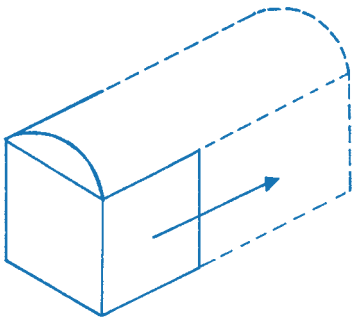
Increasing the height of a cube chamber decreases firing efficiency.

serves as a collection area for the flue gases. Increasing the height of the cube chamber with a fixed width decreases the efficiency of even-temperature firing (figure 2). I do not know what the ratio factor is between increasing height and uneven temperature. From experience in firing an updraft kiln (2x3-foot base x 5-feet+ high stacking space) with burners in the floor, I have found from 1/2 to 1 cone difference between top and bottom, no matter what firing schedule was used. However, on the same kiln 1 foot shorter (2x3x4 feet) it can be dead even top to bottom. In a similar kiln (3x3x5-foot stacking space), I found a constant 1/2 to 1 cone difference in the firing temperature between top and bottom but if the width and length was increased to 4 feet, the temperature evens out perfectly. My conclusion is that equal height and width is extremely important to even temperature when using

floor level burners. From my experience, the same findings also apply to the downdraft and crossdraft kiln design. Increasing the length of the cube has no effect on the even firing efficiency of the kiln, hence the development of tunnel kilns (figure 3), and other long tube-type kilns used commercially. In circle or round-dome kilns, (figure 4), the diameter and height should be nearly equal, depending upon whether it is an updraft or a downdraft kiln. Most small downdraft kilns tend to include the dome in the height measurement, while updraft beehive types tend to add the dome to the height measurement. For firing tall kilns (figure 2), the burner becomes important and should be placed up the sides of the kiln. There are other specialty kiln designs, not based on the cube, like the tube, groundhog and derivative kilns, but follow other principles listed here.

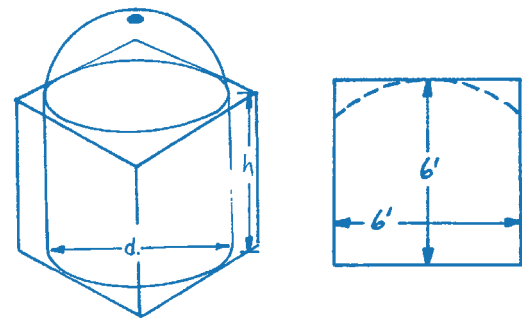
PRINCIPLE 2: The chamber shape is determined by heat direction and ease of flame movement to allow a natural flow.

Two important rules to remember are: (1) the flame and heat direction should follow the arch (figure 5), and should not be at right angles to the arch (figure 6); and (2) the flame movement and heat direction should have only two right angles to negotiate within the chamber, usually located at the firebox inlet flue and bag wall and at the exit flues. Right angles can cause irregular heating or hot spots, which could lead to refractory failures and firing inefficiency. Figure 6 also depicts the basic groundhog kiln design which is an effective kiln design.



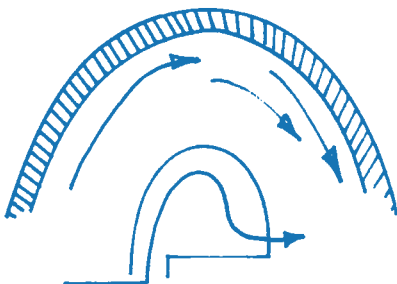
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Increasing length does not affect firing efficiency.



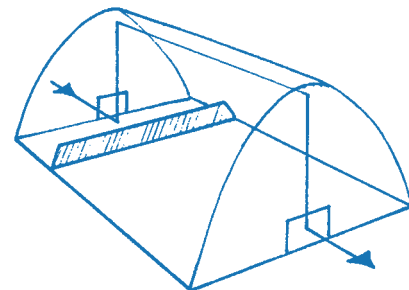
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Diameter and height should be nearly equal in circular or round-dome kilns.



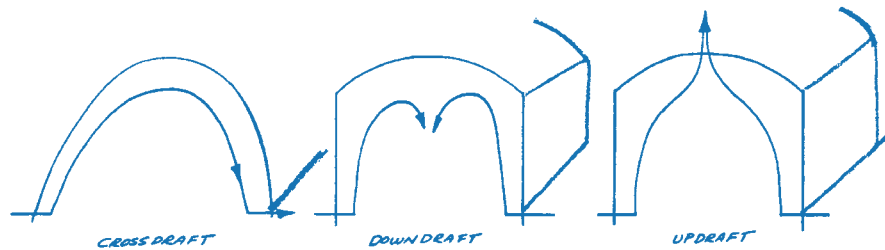
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Heat direction should follow the arch.



6

Configuration forces heat direction to flow at right angles to the arch.



7 Cross sections of three chambers showing proper heat direction.

Nevertheless the fact remains it produces hot areas along the crown following the directional arrow which leads to cool areas along the bottom back side wall and refractory failure at the back wall. If the design runs contrary to the arch then the transition should be curved or shaped from the firebox up into the volume and then into the chimney wall or chimney flue. This is possible with the use of lightweight insulation castables. Kilns that run contrary to this principle are the Nils Lou Minnesota flat-top kiln design and some professionally made gas-fired pseudo-downdraft kilns. They show that any shape can be fired if there is sufficient heat produced and a correct flue-to-chimney ratio is used. The box, which is the easiest shape to build, becomes their primary kiln shape. There is merit to this style of design and they do work and should be researched. However, a more traditional approach based on natural draft is used here. Three kiln chamber cross sections with proper heat direction and flame movement are shown in figure 7.

PRINCIPLE 3: A specific amount of grate area or combustion area is needed for natural draft.

Grate area (fire box or fuel combustion area) depends upon the fuel used, following these approximate guidelines to get started:

Wood: 10 times greater than the horizontal section of the chimney, or put another way, the grate combustion area to chimney cross section area at the base ratio is 10 to 1.

Coal: 1 square foot of grate to every 6 to 8 square feet of floor space.

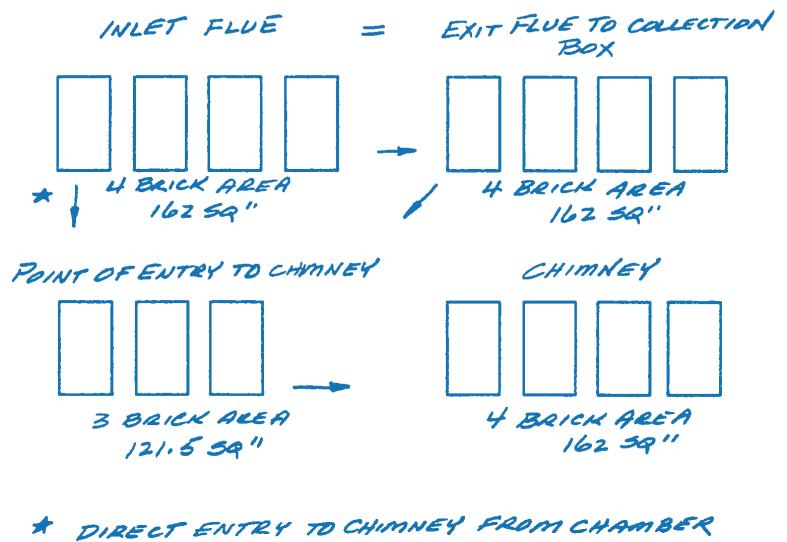
Oil: 1 square foot of combustion area to every 5 square feet of floor area.

Gas: 4½-inch minimum channel combustion space between ware and wall, usually the length of the wall.

This is the most difficult principle of kiln design to apply, but it is the real heart of the kiln, for it determines the draft rate. When in doubt, be generous. It is also better to have a chimney area on the large side instead of too small. When designing kilns the fireboxes or combustion area and chamber are usu-

ally designed first, then the chimney matched to the size of the grate area or combustion area and chamber. If your calculations come out short of brick sizes, then opt for increasing the area up to match the brick sizes.

In natural-draft kilns the inlet flue areas must be equal to exit flue areas for the simple reason, “what comes in must go out.” If exit flues are too restricted, this will slow down the flow and retard combustion efficiency, thereby affecting the temperature increase. The combined area of the inlets should be equal to the chimney section. If the latter is 162 square inches, then the inlet flue area should be about 162 square inches. Since the normal flue size is a brick size (9×4½ inches), four flues of this size would equal 162 square inches, adequate for a chimney with a cross section of 162 square inches. At the point where the exit flues enter the chimney, they should be restricted so that the chimney cross-section is larger than this flue area. This can be done by using a flue collection box behind the chamber and in front of the chimney. See figure 8. In the fastfire design the exit flue is restricted because of the direct connection into the chimney. If the chimney cross section is made much larger than the inlet and exit flues in



8 Flue-to-chimney relationship.



9

An updraft gas kiln must have equal inlet and exit area.

a natural draft kiln, tapering of the chimney must be done to ensure proper draft. To make matters simple without jeopardizing the kiln design, make the inlet and exit flue areas and the chimney cross-section area all equal, with the chimney point of entry slightly smaller. It is far better to make these areas too large than too small, for they can easily be altered by plugging them up.

When using pressurized gas as a fuel, the inlet flue area should equal the exit flue area. An example: For an updraft gas kiln with 10 bottom burner ports with 2½-inch diameters (inlet floor flues) which will equal approximately 4.9 square inches per hole or a total of 49 square inches, the exit flue in the arch should equal approximately 49 square inches. See *figure 9*. This is a safe rule of thumb to use, remembering in the case of a downdraft or pseudo downdraft one can block the exit flue. In the updraft the exit flue or flues (if two holes are used) can be made smaller by about 5 percent, but the option to enlarge if needed is possible. Remember, making a hole smaller is a whole lot easier than enlarging.

For a downdraft or crossdraft kiln using pressurized gas (forced draft), the inlet flues can be the size of the burner tips or slightly larger since the oxygen is supplied through the burner with secondary air pulled in around the burner port hole. In most cases, the inlet flue will be brick-size then reduced in size to add adjustability to the flue. If a

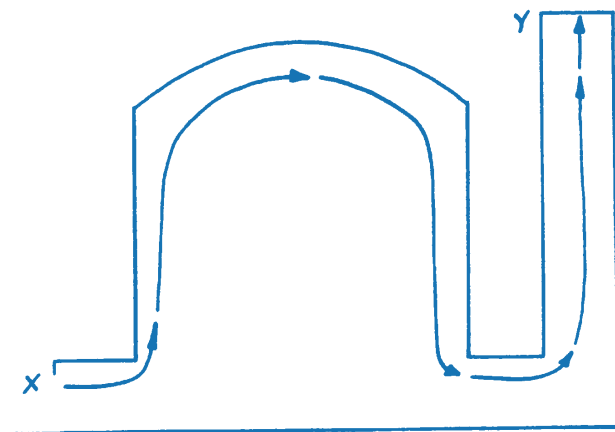
combination of wood was to be used also, then an auxiliary air source must be provided. Exit flues should be built brick-sized (can be reduced in size if needed) and follow the natural draft relationships from flues to chimney. The difference with forced draft is that the height of the chimney is reduced by at least 25 percent.

PRINCIPLE 4: The taper of a chimney controls the rate of draft.

Tapering reduces atmospheric pressure and increases the speed of draft, thereby controlling the rate of draft, which ideally should be 4 to 5 feet per second for natural draft kilns. The draft rate is measured periodically throughout the firing of the kiln, and, in the beginning, it will be very slow. The 4 to 5 feet per second is the rate of draft at most efficient operation, usually after 1093°C (2000°F) in cone 10 kilns. The draft rate measurement in feet is determined by the inside circumference of the chamber up the front wall, over the arch, down the back wall, through the flues and up the chimney (which is 45 feet in *Fig. 10*). For this kiln to fire at the proper draft rate, gases would take about 10 seconds to travel from X to Y. One way to determine the draft rate is to throw an oily rag into the firebox and count the number of seconds it takes for the smoke to come out the chimney. If it is too slow, tapering the chimney could increase the rate. A kiln chimney that is between 16 and 20 feet, with a base section of 12×12 inches, would normally taper to a minimum of 9×9 inches. In a natural draft kiln, seldom would a chimney be less than 9×9 inches at its base cross section.

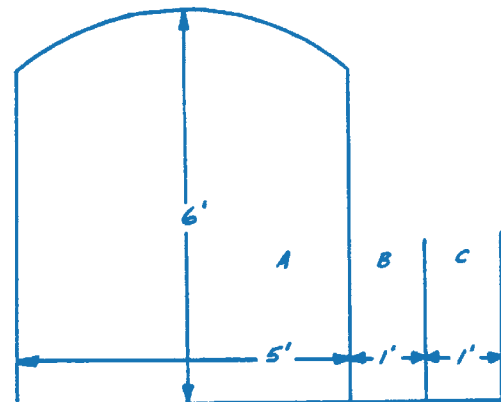
PRINCIPLE 5: For natural draft kilns there should be 3 feet of chimney to every foot of downward pull, plus 1 foot of chimney to every 3 feet of horizontal pull.

The height of the kiln chamber in *figure 11* is 6 feet. Therefore, there are 6 feet of downward pull (dp); and



10

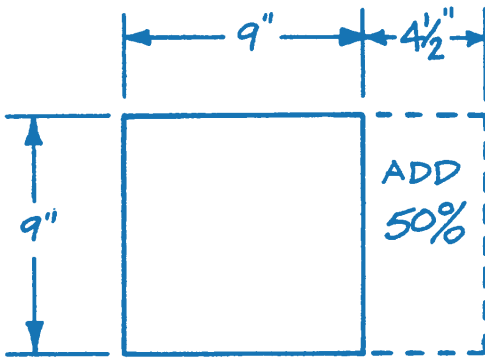
It requires 10 seconds for gases to travel from x to y (45 feet) in this kiln.



11

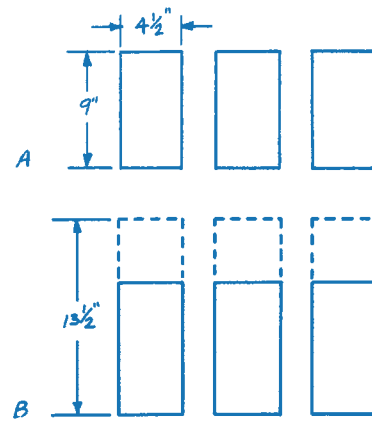
Three feet of chimney length are added for every foot of downward pull, plus 1 foot of chimney for every 3 feet of horizontal pull: A, chamber; B, flue collection box; C, chimney.

12



Chimney diameter is increased by 50 percent in high-altitude adjustment.

13



High-altitude adjustments for inlet and exit flues: A, normal; B, flue height increased by 50 percent.

for every foot, 3 feet of chimney are added: Thus, $3 \times 6 = 18$ feet of chimney. Then add 1 foot of chimney for every 3 feet of horizontal pull (hp), which in *figure 11* equals the chamber width (5 feet), plus 1 foot of collection box, plus a 1-foot-wide chimney, totaling 7 feet. Thus, $7/3 = 2.3$ feet; added to 18 feet, we find that this kiln requires a 20.3-foot chimney. To calculate chimney height for any natural draft kiln chamber: When using pressurized gas, the draft is forced and does not need the same height requirements as natural draft does to pull the draft through the kiln.

PRINCIPLE 6: Chimney diameter is approximately one-fourth to one-fifth of the chamber diameter.

If a chamber is 5 feet in diameter, then the chimney must be at least 1 foot in diameter. This principle, when used with Principle 3, can give a more specific chimney dimension for natural draft kilns.

PRINCIPLE 7: A tall chimney increases velocity inside the firing chamber.

Too high a chimney can cause irregular heating by pulling the heat out of the kiln, not allowing it to build up within the chamber, thereby prolonging the firing. On the other hand, too short a chimney can protract the firing by decreasing the draft rate, which allows build-up in the firebox and does not pull enough oxygen into the kiln to allow proper combustion for temperature increase.

PRINCIPLE 8: Critical areas of a kiln should be planned and built to be altered easily.

If in doubt as to flue sizes, grate area, or chimney size, bigger is better. Plugging excess space with bricks is an easy matter. Also, for ease of construction, all dimensions should be based on the standard $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ -inch brick, or the large standard, $9 \times 4\frac{1}{2} \times 3$ -inch. Perhaps 80 percent of the time, normal flue dimensions will be one brick standing on end ($9 \times 4\frac{1}{2}$ inches). These should be spaced 9 inches apart.

There will be no problem in the kiln you can't correct if you remember to make flues adjustable, planning so

that you can add or knock out a brick, make the chimney entrance flue adjustable, and build the chimney so that the height is readily adjustable.

High-Altitude Adjustments

Building a kiln at high elevations necessitates adjustments to compensate for decreased oxygen per cubic foot of air. The difference is very apparent in hot desert elevations over 3800 feet, and in mountain elevations from 5000 to 10,000 feet. Outside air temperature, as well as elevation, has a direct effect on the amount of oxygen present. For instance, in Aspen, Colorado, the elevation is about 8600 feet. However, at an outside air temperature of 22°C (72°F), the density of oxygen per cubic foot of air is equivalent to the amount found in air at 10,000 feet. Thus, kiln firing is more efficient at night, when the air cools and becomes denser, and more oxygen is present.

There are five steps in the procedure for making appropriate alterations to a natural draft kiln to compensate for high altitude and low air density.

- 1). Design the kiln according to standard principles, figuring out the chimney diameter, the inlet and exit flue sizes, and the chimney height.
- 2). Increase the chimney diameter by roughly 50 percent (so it works into the closest bricklaying combination). Thus, a chimney with a diameter of 9 inches would be increased to a diameter of $13\frac{1}{2}$ inches (*figure 12*).
- 3). Increase the inlet and exit flues by 50 percent. If you have three inlet and exit flues measuring 9 inches high and $4\frac{1}{2}$ inches wide each, increase the height by $4\frac{1}{2}$ inches to make them $13\frac{1}{2}$ inches high by $4\frac{1}{2}$ inches wide (*figure 13*).
- 4). Increase the chimney height by at least 30 percent to pull the greater volume of air needed.
- 5). It is not necessary to increase the grate area in relation to the chimney (for wood) or to the floor area (for coal and oil). Remember, it is not more fuel that is needed, but more oxygen to burn the fuel.

Efficient Gas Kiln Firing

by Hal Frenzel

What is perfect combustion? By reading the description in the North American Combustion Handbook, it seems rather simple: Perfect combustion exists when one carbon atom is combined with two atoms of oxygen to form one carbon dioxide molecule, plus heat. But when you are firing a kiln to achieve a certain consistent atmosphere, it becomes a little more complicated.

To achieve complete combustion, the exact proportions of fuel and oxygen are required with nothing remaining. In a gas kiln firing this is often difficult to attain because of the many variables in fuel and oxygen (which is derived from the air) and the equipment used to mix the two.

The most common fuels used today are natural gas and propane. These are hydrocarbons and when they are properly mixed and ignited, they produce heat, carbon dioxide and water vapor.

Air is a combination of approximately 75% nitrogen and 25% oxygen by weight. Unlike oxygen, the nitrogen does not react (combust) but it still absorbs a portion of the heat and therefore creates a cooler flame.

During the firing of a gas kiln there are a trio of atmospheres that have to be controlled to achieve both a rise in temperature and the desired glaze results. The first, and most important, atmosphere is neutral. It is only in a neutral atmosphere that perfect combustion can be attained. A neutral atmosphere is the most fuel-efficient firing possible.

If the amount of air is increased, or the amount of fuel is decreased, from a neutral firing, the mixture becomes fuel-lean and the flame is shorter and clearer. The kiln

has now entered an oxidizing atmosphere and the rate of temperature rise will decrease.

If the fuel supply is increased or the air supply is decreased the atmosphere becomes fuel-rich and reduction begins. The flame becomes long and smoky and incomplete combustion occurs. The result is an excess of carbon, which combines with the remaining oxygen and creates carbon monoxide. To convert back to its natural state of carbon dioxide, the carbon takes oxygen from the metal oxides in the glaze, thus altering the finished color of the glaze. The rate of temperature rise will also diminish under these conditions.

Regardless of the atmosphere necessary for the results you desire for your work, a higher level of efficiency and fuel savings may be attained by firing to a neutral atmosphere whenever possible (see diagrams on page 38). With the enormous increases we have seen and will continue to see in fuel costs, it might become highly desirable to buy an oxygen probe and maintain a neutral atmosphere for at least part of your firings.

In the early stages of a firing, excess oxygen helps in the decomposition of the organic and inorganic carbonates and sulfates. In researching this article, I was unable to find a potter/ceramist who could explain exactly how excess oxygen during the glaze maturity period enhances the glaze finish or color. This raises the question as to whether the results would have been the same if fired in a neutral atmosphere during this period. If, by chance, the results are the same, then an oxidation potter would save both time and fuel if he or she fired in perfect combustion during this period.

Firing Atmospheres

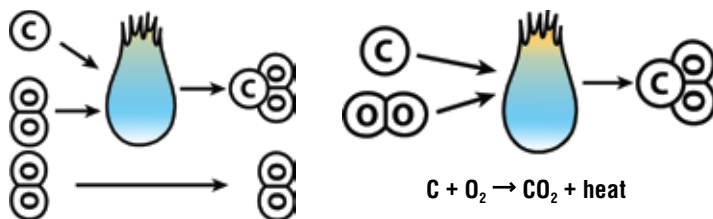
Oxygen to burn fuel in an artist's kiln comes from the air. The air, however, is not all oxygen. Rather, it is far from it. By weight, air is approximately 77% nitrogen and 23% oxygen. What this means to the artist is that for every ONE pound of oxygen from air that is heated to kiln temperature to burn fuel in a kiln, THREE pounds of nitrogen have to be heated to kiln temperature. This is why using "excess" oxygen is expensive. Using a minimum amount of excess air in an oxidation firing saves both energy and money.

DEFINING THE TERMS

Oxidation Atmosphere: A mixture of fuel and air where there is a significant excess of oxygen from the air relative to the fuel; defined (somewhat arbitrarily) as more than 3% excess oxygen.

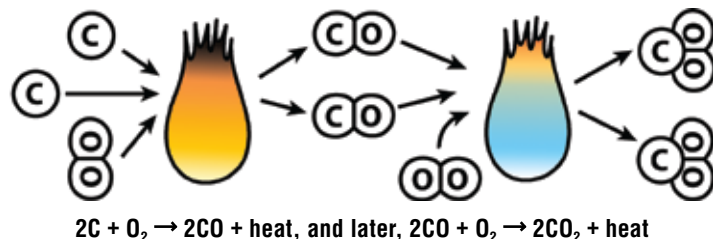
Neutral Atmosphere: A theoretical mixture of fuel and air where there is a perfect balance between the amount of fuel and the amount of oxygen from air necessary to burn that fuel.

Reduction Atmosphere: A mixture of fuel and air where there is more fuel present than there is oxygen from the air to burn the fuel. For complete combustion to occur in a reducing atmosphere, the fuel must react with all the oxygen from the incoming air and with oxygen from other sources. For a ceramics artist, the important "other" sources of oxygen are oxides of iron and/or copper in the ware being fired, as those oxides are reduced (relieved of their oxygen molecules) by oxygen-hungry fuel. This typically results in a color change.



Oxidation: When excess oxygen is present in the kiln, it plays no part in combustion. However, it does absorb heat energy that would otherwise help fire your ware. In this way, it does contribute to fuel consumption.

Neutral: When exactly two oxygen atoms are present for each carbon atom, neutral (or perfect) combustion occurs, creating carbon dioxide and heat. Perfect combustion assumes that turbulence and circulation in the kiln is so complete that every atom finds a partner. This is difficult in even the most efficient kilns, so some excess oxygen is typically necessary to avoid reduction.

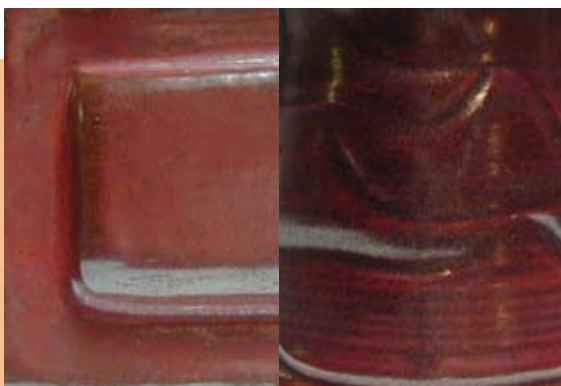


Reduction: When an excess of carbon (fuel) or a shortage of oxygen (air) is introduced, incomplete combustion takes place. Carbon monoxide (as opposed to carbon dioxide) is produced along with heat, though not as much as would be produced during complete combustion. The carbon monoxide then looks for more oxygen, which it takes from oxides in the clay and glaze in the kiln. This is also the reason yellow flames shoot out through spy holes when a kiln is in reduction—the carbon-rich fuel is following the oxygen supply.

recipe

MODIFIED OHATA KHAKI (Cone 10)

| | |
|---------------------|-------|
| G200 Feldspar | 50 % |
| Silica | 21 |
| EPK | 6 |
| Talc | 6 |
| Whiting | 7 |
| Bone Ash | 10 |
| | 100 % |
| Add: Red Iron Oxide | 13 % |



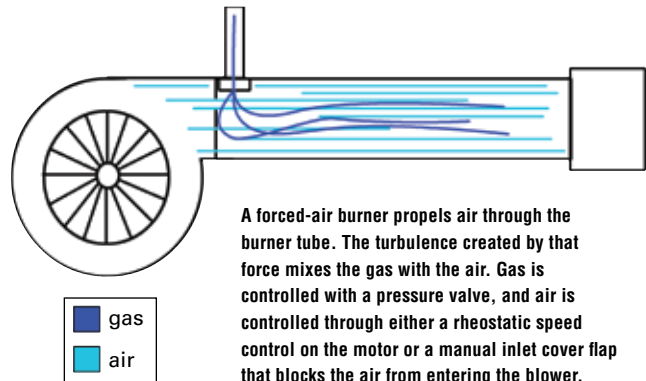
Both of these surfaces were glazed with Modified Ohata Khaki, an iron saturated glaze. The piece on the left was fired in oxidation, and the piece on the right was fired in reduction.

Atmospheric Controls

The two most common types of burners used today are forced-air and atmospheric venturi burners. How these burners mix the fuel and air is of vital importance in accomplishing complete combustion.

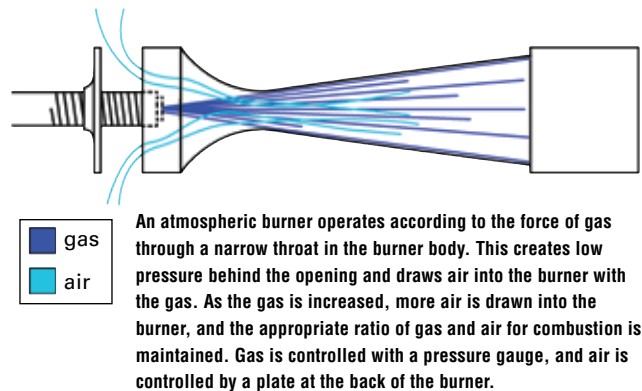
FORCED-AIR BURNERS

There are many types of forced-air burners, most of which are used in industrial applications with sophisticated proportional fuel-air control. The typical forced-air burner used on a kiln is not as complex. Typically there are two burners that enter the rear of the kiln, which have either individual blowers or one central blower with some form of rheostatic speed control. When adjusting the gas during the firing process you must also adjust the air flow. Initially, this might require some guesswork or prior experience in determining the proper fuel to air ratio. But if there is an oxygen probe available you'll be able to measure the ratio more precisely and achieve the particular atmosphere necessary for your glazes. (See CM September 2002, for more details on the oxygen probe.)



ATMOSPHERIC BURNERS

Atmospheric venturi burners are often mounted under the kiln in a vertical position. There is an air shuttle on the inlet side of each venturi burner that allows adjustment of the primary air flow into the burner. The venturi burner is called an inspirator and utilizes the energy in the gas jet coming out of the burner orifice to draw in air for combustion. The jet of gas from the nozzle produces a high velocity in the throat of the venturi, and the resulting low pressure pulls air in and around the gas jet. If the rate of gas is increased, more air will be induced. Thus the air and gas are proportioned for combustion.



DAMPERS

There is one other piece of equipment on every kiln that is absolutely necessary in controlling the kiln atmosphere and that is the damper blade in the chimney stack. Even the smallest adjustment in either direction could change the atmosphere from neutral to either reduction or oxidation. By moving the damper in, you create back-pressure in the flue gases, which reduces the flow of air into the kiln and thus causes a reducing atmosphere. By moving the damper out, you create more draft, which pulls more air into the kiln and thus causes an oxidizing atmosphere.

