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.
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.

**recipe**

**MODIFIED OHATA KHAKI**

(Cone 10)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>G200 Feldspar</td>
<td>50</td>
</tr>
<tr>
<td>Silica</td>
<td>21</td>
</tr>
<tr>
<td>EPK</td>
<td>6</td>
</tr>
<tr>
<td>Talc</td>
<td>6</td>
</tr>
<tr>
<td>Whiting</td>
<td>7</td>
</tr>
<tr>
<td>Bone Ash</td>
<td>10</td>
</tr>
<tr>
<td>Add: Red Iron Oxide</td>
<td>13</td>
</tr>
<tr>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>

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.