➤ Each part of the firing curve, as well as the atmosphere required, must be evaluated in order to design a successful combustion system.

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To the neophyte, a kiln may look like a big box with burners and an exhaust system. Those with a little more skill know that kilns require a combination of combustion technology and refractory design to reach a desired temperature. But kilns can only be outstanding in performance when all of the operating criteria are designed to adhere to the critical requirements associated with their use. To produce high-performance kilns, the sales and engineering team must consider several factors to make sure that the new kiln is a successful investment.

Of the many factors considered when producing a kiln concept, the mission-critical design goal is to provide a well-insulated structure that will adhere to the time, temperature, and atmosphere requirements with precision—not only during the heating phase, but also during the cooling segment. Arrangement of burner locations, exhaust locations, air jets, etc., can be determined empirically through a large database of kiln designs, as well as scientifically with modeling software, so that the temperature uniformity throughout the setting space will be nearly perfect.

A fair amount of digging is often required to determine a client's kiln requirement parameters; sometimes a client's knowledge is traditional ("But we've always done it this way!") rather than scientific. With effort and experience, however, the appropriate parameters can usually be defined in order to develop the best design for an application.

Traditional Ceramics

The curve shown in Figure 1 (p. 20) represents a typical whiteware curve. Starting at ambient temperature, the time/temperature curve gradually rises to a point where oxidation begins. During this period, heating is slower, to provide time for the oxidation of the volatile materials inherent in clays. Following oxidation, a fairly quick run-up to soak occurs, followed by very fast cooling. Slower cooling is needed during the beta to alpha quartz inversion, and then rapid cooling to the end of the cycle. This cycle is normally around 60% heating and 40% cooling.

Unfortunately, more specific data is needed. Adjectives like "gradual" and "fairly quick" are not useful when trying to determine the exact heating and cooling system necessary to accomplish the goal of producing the ideal system.

Developing a simple heat balance to select the burners to accomplish this cycle is easy, but because the oxygen curve affects efficiency of heating, having a valid O_2 curve is imperative. In addition, the selection of the combustion system that can accurately perform the heating segment of the cycle is dictated by both the temperature and O_2 curves.

To match the curve in Figure 1, it would be helpful to select a system with continuously variable excess air controls, so that

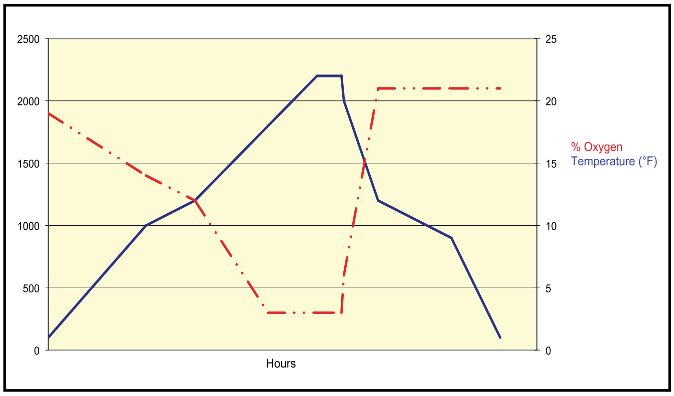

Figure 1. Typical whitewares firing curve.

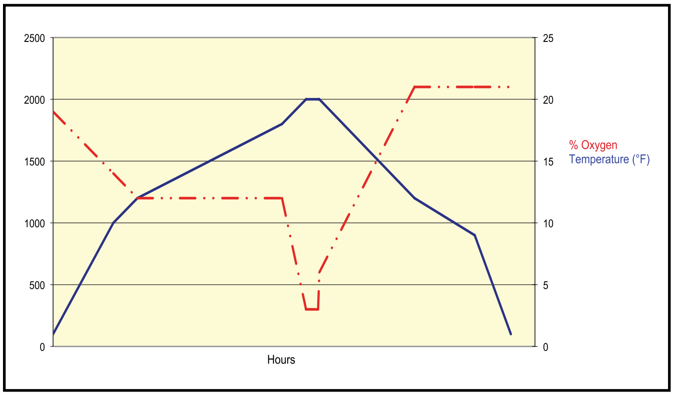

Figure 2. Typical structural clay firing curve.

just the right quantity of excess air could be used to produce the desired oxygen curve. This, combined with accurate heating rates, allows the burners to be sized perfectly, with extra margin for faster curve development. In kilns of this type, special attention must be given to the cooling cycle. The necessary cooling air volumes frequently need to be quite high to match the cooling cycle.

Structural Clay

Another segment of ceramic manufacturing is structural clay, which includes brick, pipe, red-body tile and other red structural products. At first glance, the typical structural clay time/temperature/atmosphere curve is similar to the whiteware curve, but it differs in subtle, but critical details (see Figure 2). Raw materials for structural clay are a lot “dirtier” than those used in whiteware bodies. Impurities consist of carbon, a range of sulfur compounds and, occasionally, high levels of quartz.

A consequence of these impurities is that more time is required to oxidize them. Therefore, in kiln design, the firing system must be set up to allow for more time in heating for the oxidation period, which often results in a cycle that will require 70% of the total time for heating. Burner and combustion system selection will also require special analysis. The need for

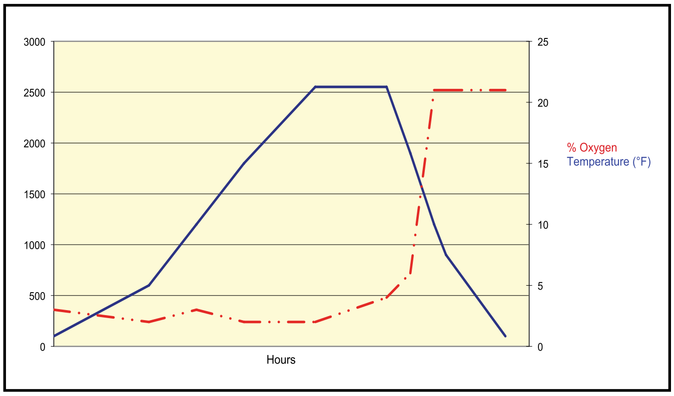

Figure 3. Typical firing curve for specialty ceramics with high binder content.

high volumes of air for oxidation, combined with strong circulation, will help define the appropriate system.

Specialty Ceramics with High Binder Content

Figure 3 shows a curve and atmosphere that is significantly different than the whiteware and structural clay cycles. Building a firing system for the curve shown is a real challenge. A kiln that is suitable for whitewares would be unsuitable for products with high binder content.

A variety of binders are used in ceramic bodies to improve green strength. These include inorganic binders, organic binders, bentonite, sodium silicate, polyvinyl alcohol, methylcellulose and paraffin. These binders must be oxidized at low temperatures (typically 150-600°C, depending on the binder material). Analysis of binder removal temperatures, and the depressed oxygen necessary to limit exothermic heating, is imperative.

In the case of ceramics with binders, such as those used in catalysts or substrates, the binder burnout can take place at 150-600°C. To prevent thermal cracking during the exothermic reaction, the kiln atmosphere is accurately controlled at a depressed oxygen level, and the heat-up rate is reduced (see Figure 3). It is important to select a combustion system control scheme that can provide a low oxygen atmosphere with very slow heating rates during the binder burnout while still providing the high degree of circulation needed for temperature uniformity. Proportional or pulse firing systems are potential combustion solutions to meet these firing requirements, especially when combined with recirculation of kiln atmosphere, injection of inert gases, or both.

After the binder removal is completed, the product is rapidly ramped to its peak temperature at higher oxygen levels with increased volume to promote temperature uniformity. A propor-

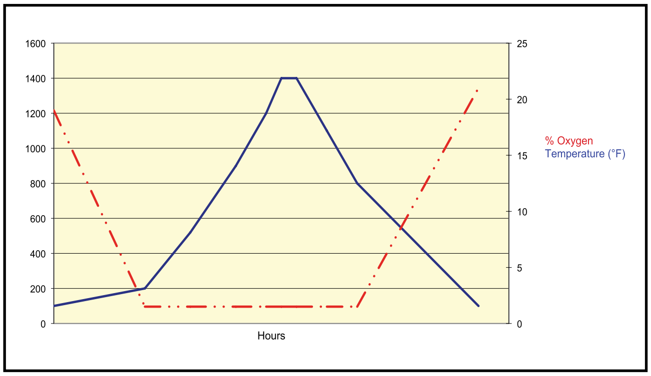

Figure 4. Typical firing curve for carbon-based products.

tional system would not meet the firing requirements without the ability to automatically change the burner air-to-fuel ratio.

Depending on the final ramp rate to the peak temperature, the higher oxygen levels limit the net heat input as the available heat value diminishes. This could require the use of larger burners or preheated combustion air to achieve the desired ramp rate at the higher temperatures.

Cooling is generally 30% of the overall cycle. The initial cooling can be achieved by firing down with the combustion system or by directly injecting air. The initial cooling is usually rapid, with ramp rates limited by the kiln furniture. The cooling rate is slowed through the alpha to beta quartz inversion when substantial free quartz is present.

The kiln designer must consider requirements for the final temperature exiting the kiln. Does the product exit the kiln (batch or continuous) to an intermediate holding area, or does it have to be at a certain temperature for immediate unloading? Extremely low exit temperatures may require additional cooling equipment, such as auxiliary cooling nozzles, a cooling chamber, recirculation systems, etc.

Carbon-Based Products

Many types of carbon products are produced, including cathodes, electrodes, contactors, brushes, carbon foam and fine-grain carbon stock. Depending on the type of product, the cycles are highly variable and can range from two to 60 days. The size of the furnace can also vary considerably, with loads ranging from a few thousand pounds to a million pounds. As seen in Figure 4, control of oxygen is crucial; in fact, if the oxygen curve from a whiteware kiln was applied to this type of firing, the entire payload of product would oxidize during the firing, and there would be no product to sell.

Carbon is commonly baked in a car bottom furnace (batch) or a ring furnace (continuous). In the design of a carbon baking furnace, the primary concern is the ability to maintain a low oxygen level throughout the majority of the cycle, including the cooling cycle (as shown in Figure 4).

In order to maintain such a low oxygen level, the furnace must be designed to be airtight. Common design considerations include continuously welded structure, water sealing of the car to the kiln, airtight door seal and stringently controlled kiln pressure. These design considerations are not typically considered in traditional ceramic products fired in oxidizing atmospheres.

For electrode first baking, the furnace could have a payload of 500 tons on a single car; the use of multiple cars would provide a potential for air infiltration. It is not uncommon that the furnaces are designed for outdoor operation and require special considerations for the elements.

Baking of electrodes requires two different firing processes: first baking and rebake. The customer frequently desires one furnace for both processes. The challenge is to provide a combustion system capable of cycles ranging from three days (rebake) to 15 days (first fire). The system must have extremely low turndown for the very slow ramp rates required for first bake. It must also have enough firepower for the fast re-bake rates while maintaining an oxygen level below 2% from the beginning of binder burnout until the furnace goes to below 600°C during cooling.

In both processes, the electrodes contain a volatile binder (coal tar pitch) that is released between 200-700°C, and must be thermally oxidized. The heat value released during volatilization is sufficient to sustain the firing process, forcing the burner outputs to near minimal inputs and creating a potentially explosive atmosphere. This creates a temperature uniformity issue for a standard proportion firing combustion system. High-temperature recirculation fans and/or pulse firing systems are used to enhance temperature uniformity.

Special safety systems must be designed to ensure safe relighting conditions (much lower than the lower explosive limit, or LEL) during volatile release to prevent an explosion in the event of a relight. If a burner fails, equipment must be provided to shut down the combustion air to the burner as well as the gas.

During the cooling phase, the oxygen level must remain below 2% to prevent oxidization of the product. For this process, water injection to create steam or nitrogen may be used.

Curve is Key

Designing a great kiln demands accurate details before work is started. Determining the combustion system that will meet the product requirements in terms of time/temperature/atmosphere will help guarantee excellent results in product performance and efficiency. With these crucial variables defined, the kiln system can be a productive asset instead of a cumbersome liability. ⊕

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