Low-Mass Kiln Furniture

Ceramic manufacturers can reduce their energy consumption and operating costs by taking advantage of the low-mass, high-strength properties of SiC kiln furniture.

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The ever-present possibility of a sudden increase in the cost of energy became a reality at the beginning of 2001, when natural gas prices spiked to almost $10 per MMBTU (million BTU) for a short period of time. This event sparked renewed interest in improving kiln energy efficiency. As noted by Ralph Ruark in his “Kiln Connection” column in the March 2001 issue of *Ceramic Industry*, any reduction in the “dead load” (kiln furniture and car mass) will reduce kiln fuel usage. A simple kiln energy analysis shows that both energy savings and a significant return on investment can result from using low-mass kiln furniture.

Low-mass kiln furniture significantly reduces the “dead weight” of a kiln car.

Kiln Energy Analysis

In the ceramic industry, shuttle (periodic) and tunnel (continuous) kilns are used in the vast majority of firing applications. The overall energy balance for a shuttle kiln is shown schematically in Figure 1. As indicated, the energy input and gas flows generally vary during the course of the firing cycle (except for the soak time at peak temperature). The fundamental objective is to subject the kiln load to the required firing curve, but only a fraction of the total energy input goes to this use. The bulk of the energy input leaves a shuttle kiln in the exhaust gas flow, which consists of the products of combustion of the fuel, the excess combustion air, and the air infiltration (if any). Unless some form of energy recovery (recuperation) is employed, this energy is totally lost. Additional energy is lost in re-heating the kiln lining during each firing and by convection and radiation from the external surface of the kiln.

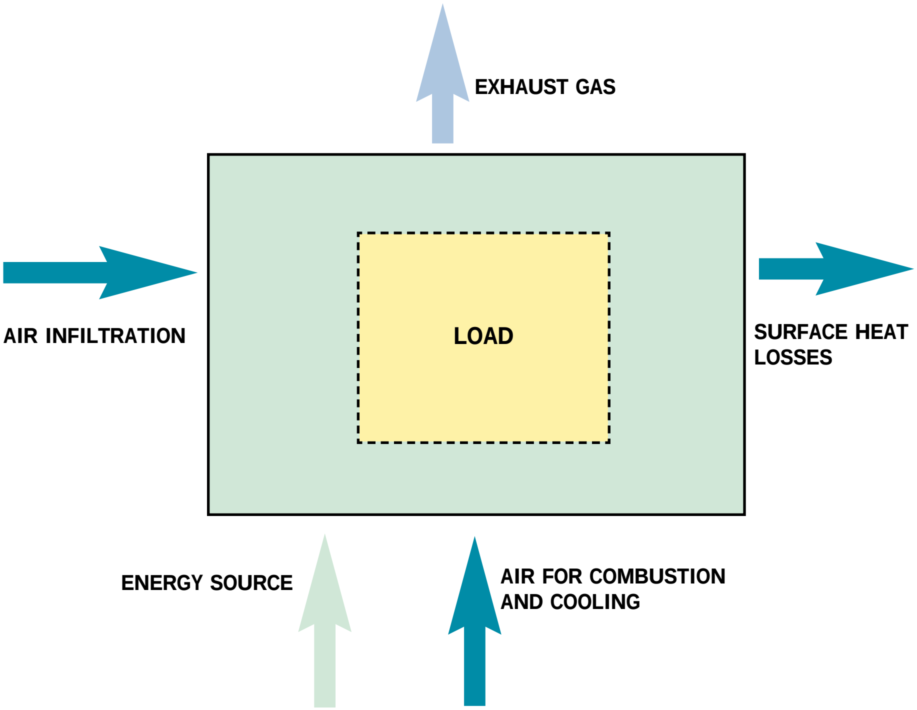

Figure 1. The energy balance of a shuttle kiln.

The overall energy balance for a tunnel kiln is shown schematically in Figure 2. This is a more or less continuous process, with essentially constant energy input and gas flows for a given firing curve and firing cycle (cold-to-cold) time. Again, energy is lost in the exhaust gases and from the kiln external surfaces. However, because the process is continuous, it is possible to draft the kiln so that a portion of the energy in the exhaust gas stream is used to heat the incoming load. Therefore, tunnel kilns are generally more thermal-efficient than shuttle kilns.

Kiln Thermal Efficiency

Kiln thermal efficiency is defined as the ratio of the energy delivered to the load (product plus kiln furniture) to the total energy input (x 100). Using the sanitaryware industry as an example, some typical values of kiln thermal efficiency are shown in Table 1. For a tunnel kiln, the longer the firing cycle, the lower the kiln thermal efficiency. This is due primarily to the fact that the kiln surface heat losses are essentially the same for a fixed firing curve, regardless of the firing cycle time. As the cycle time increases (and the kiln throughput decreases), those losses represent a greater portion of the total energy input. For sanitaryware applications, tunnel kiln thermal efficiencies are generally in the range of 35 to 45%.

As indicated above, shuttle kiln thermal efficiency is lower because all of the energy in the exhaust gas is lost and because the kiln lining must be re-heated during each cycle. For sanitaryware applications, shuttle kiln thermal efficiencies are in the range of 20 to 25%. Shuttle/periodic kiln thermal efficiency falls rapidly as peak firing temperature increases. For example, a periodic kiln firing to 3000°F could have a thermal efficiency as low as 13 to 15%.

Table 1. Kiln thermal efficiency values for sanitaryware applications.

Type of Kiln	Cycle Time	Thermal Efficiency
Tunnel – First Fire (1260°C)	12 hours	46%
	16 hours	39%
	20 hours	34%
Tunnel Kiln – Refire (1200°C)	20 hours	44%
	26 hours	37%
	32 hours	33%
Shuttle Kiln – Refire (1200°C)	20 hours	25%
	26 hours	24%
	32 hours	23%

Low-Mass Kiln Furniture

Low-mass kiln furniture is produced from several types of silicon carbide (SiC) refractory materials. The important characteristics of those SiC refractories are summarized in Table 2, with the properties of the traditional refractory, cordierite, shown for reference.

The conventional nitride-bonded silicon carbide is a cost-effective SiC alternative for plates and lavatory setters in the sanitaryware industry. Plates and setters produced from the advanced nitride-bonded SiC will have minimum thickness and mass, while beams extruded from the reaction-sintered, silicon-infiltrated SiC have exceptional load-carrying capability up to the use limit of 1350°

The SiC refractories are 10 to 100 times stronger than cordierite and thus allow major reductions in the thickness and/or cross section of kiln furniture components such as plates and beams. The corresponding mass reduction translates directly into energy savings. In addition, the SiC refractories have significantly better oxidation resistance and thermal shock resistance than cordierite. These advantages result in longer life and

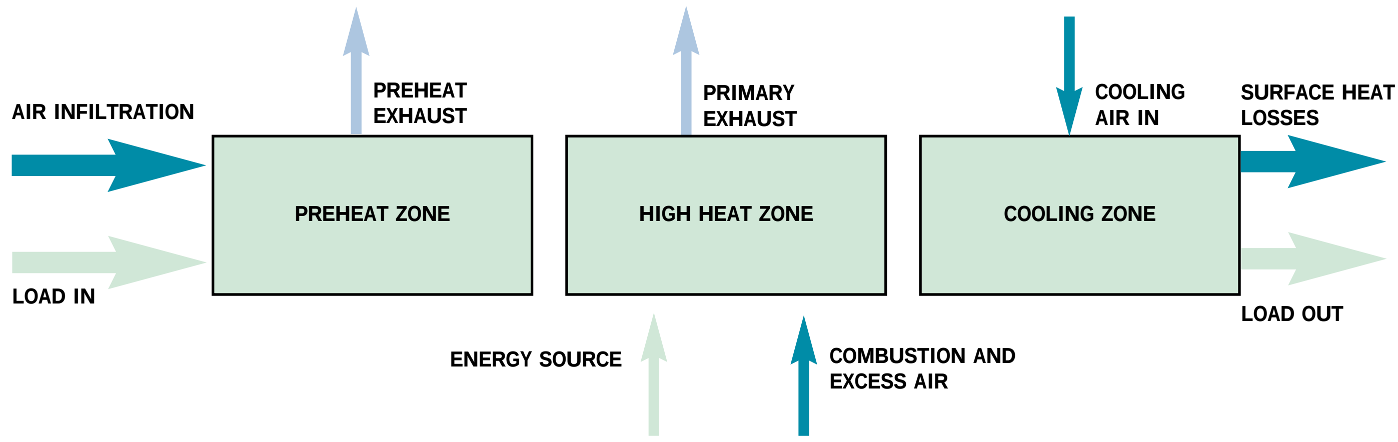

Figure 2. The energy balance of a tunnel kiln.

Table 2. Characteristics of kiln furniture materials.

Property	Cordierite[1]	Nitride-Bonded SiC[2]	Advanced Nitride-Bonded SiC[3]	Reaction-Sintered, Silicon-Infiltrated SiC[4]
Max. Use Temperature, °C	1280-1300	1550	1450	1350
Density, g/cc	1.9-2.1	2.6	2.8	3.0
Open Porosity, %	20-30	15	<1	0
Modulus of Rupture (Hot), MPa	10-20	62	175	260
Modulus of Elasticity (RT), GPa	20-40	160	235	300
Thermal Conductivity[5], W/mmK	1-1.5	14	18	40
Coeff. of Thermal Expansion, $°C^{-1}$	$2.5\text{-}3.0 \times 10^{-6}$	5.0×10^{-6}	4.3×10^{-6}	4.5×10^{-6}

1. Typical properties
2. Cryston®, manufactured by Saint-Gobain Industrial Ceramics
3. Advancer®, manufactured by Saint-Gobain Industrial Ceramics
4. Silit SK®, manufactured by Saint-Gobain Industrial Ceramics
5. At 1000-1200°C

reduced life-cycle cost. Although low-mass SiC kiln furniture has a higher initial cost than cordierite, a thorough economical analysis typically indicates a rapid return of that additional investment.

An illustration of the reduction in kiln furniture mass via low-mass construction is shown in Figure 3 (p. 45). In this example, for a shuttle kiln firing sanitaryware, the baseline carload with all-cordierite kiln furniture consists of 43% product mass and 57% cordierite kiln furniture. As indicated, the alternative low-mass construction with SiC plates and beams and cordierite posts results in a 33% reduction in the total mass of the load. This means the ratio of product mass to kiln furniture mass (higher is better) increases from approximately 1 to 1 for cordierite to 2 to 1 for low-mass construction.

Low-Mass Construction Economics

A typical traditional kiln furniture arrangement for a sanitaryware shuttle kiln, consisting of heavy cordierite posts, is shown in the photo on page 45, while the low-mass version is shown in in the opening photo on page 41. The mass of the cordierite kiln furniture is approximately 7000 pounds per car, while the mass of the alternative SiC furniture is approximately 3000 pounds per car. Since there are four cars in the kiln during a firing, the reduction in “dead weight” is almost 16,000 pounds per firing.

The economics of this example are summarized in Table 3 (p. 44). It should be noted that two important assumptions are made in calculating the gross energy consumption. First, since energy is consumed only during the heat-up and soak portions of the firing curve, only that portion of the curve is considered. Second, we need only consider the energy consumed by the heating of the kiln furniture itself

Table 3. Economic analysis of a shuttle kiln firing sanitaryware.

	Cordierite	Low-Mass	Difference
Number of cars in kiln		4	
Price of natural gas (US$ per million BTU)		5	
Firing cycles per month per car		16	
	Cordierite	Low-Mass	Difference
Energy consumption per cycle - kiln furniture only* (BTU)	223,852,129	94,973,880	128,878,249
Cost of natural gas per cycle - kiln furniture only* (US$)	1,119	475	644
Cost of kiln furniture for 8 cars (US$)	43,234	103,735	(60,501)
Monthly savings in natural gas cost (US$)		10,310	
Time to return additional investment in 8 cars (months)		5.9	
Time to return total investment in 8 cars (months)		10.1	

*Rationale for considering kiln furniture only: Product load, heat storage and heat losses will be similar for the same firing curve.

when estimating the energy savings for the low-mass design versus the traditional design. This assumption is valid because, for the same firing curve, the gross energy consumed by the product load, the heat storage and the surface heat losses will be the same regardless of the type of kiln furniture. Regarding the specific efficiency of energy consumption (combustion efficiency), this is a function of the process temperature and is computed incrementally and reflected in the gross energy consumption values.

As shown in Table 3, based on a natural gas price of $5 per MMBTU, the monthly fuel savings for low-mass construction is approximately $10,000. With respect to the return on investment, two cases are considered. The first case considers the time to return the *difference in cost* between the cordierite and low-mass designs and would be applicable for a new kiln, when one or the other of the kiln furniture systems is to be purchased. The second case considers the time to return the *total investment* in the low-mass kiln furniture and would be applicable for a complete replacement of the cordierite kiln furniture in an existing kiln.

For this example, the time to return the additional investment in low-mass kiln furniture was determined to be about six months, and the time to return the total investment was found to be about 10 months. In the current economic climate, projects generally must show payback times of 12 months or less to be given serious consideration, and the low-mass conversion in this example certainly clears that hurdle.

Recent economic analyses of other shuttle kiln and tunnel kiln applications indicate similar economics, with the investment in low-mass kiln furniture returned in less than one year. All of these analyses have assumed fuel costs in the range of $4 to $6 per MMBTU. Clearly any increase in fuel cost only makes the economics more attractive.

Other Advantages

Low-mass kiln furniture can be justified based on energy savings alone, but it also has the following additional advantages relative to traditional cordierite kiln furniture:

- Longer life and lower life-cycle cost
- Plates remain flat longer (better product quality)
- More open construction (better circulation and temperature uniformity in the kiln)
- Less air required for combustion and cooling (electrical energy savings in blowers)
- Possibility of increased kiln capacity due to reduction in “dead load” (shorter firing cycle)

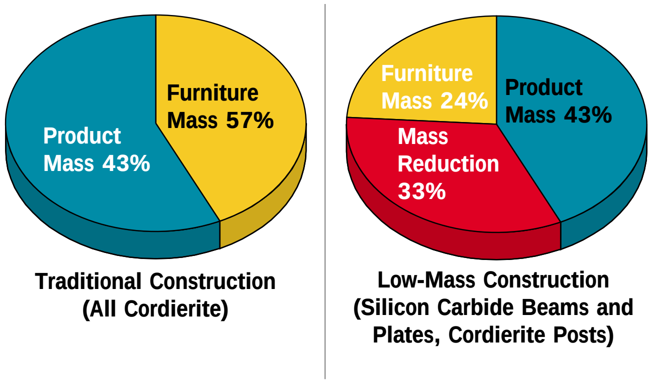

Figure 3. Traditional vs. low-mass kiln furniture.

A typical traditional kiln furniture arrangement for a sanitaryware shuttle kiln.

Preparing for the Future

While energy prices have dropped in recent months, the market is cyclical, and prices are likely to rise again in the near future. Additionally, the current economic climate requires that each plant optimize its production operations to make them as efficient as possible. Each case must be analyzed individually to determine the optimum low-mass design and the extent of low-mass conversion for existing kilns, but the investment in low-mass kiln car construction is generally returned in less than one year at today's energy costs. And the benefits last for years to come. ⊕

Editor's note: This article was adapted from a paper presented at the XXIII Convention of the Mexican Ceramics Society in Manzanillo, Mexico, July 13, 2001. While that paper was directed toward the traditional whiteware ceramics market, similar economic benefits are often possible in other applications

About the author: Mac McGinnis has a Ph.D. in Mechanical Engineering and more than 40 years of experience with kilns, industrial furnaces, and thermal processes. He formed Supratec, Inc. in 1983 and serves as a technical consultant to kiln and industrial furnace builders and end-users. He can be contacted at (214) 890-1341 or e-mail supratec@sbcglobal.net.