by weight, not volume

by Matthew Gaddie with Ryan Coppage, PhD

Firing an anagama or noborigama kiln is often a group effort that requires a lot of pots and considerable time and labor over the course of numerous days. Kiln owners typically charge artists for space in the kiln; however, there are some traditional practices with these community firings that may not actually be thermodynamically accurate.

Defining the Terms

BTU: One of the original calculations for heat content of an object if burned—shortened from British Thermal Unit to BTU. It measures heat content available by mass.

Heat Capacity: The amount of heat energy required to increase the temperature of an object by one degree. Specific heat applies to bulk metals and materials by weight, whereas heat capacity applies to individual objects and their entire mass.

Joule: The energy unit commonly accepted in most physics and chemistry calculations, which is used for thermal energy, work, electromotive energy, etc., and is expressed as $kg \cdot m^2 \cdot s^{-2}$ (kilogram × meter^2 × second^{-2}).

Specific Heat: The amount of heat energy needed to increase the temperature of 1 gram (or kilogram) of a substance by 1 degree Celsius or Kelvins.

Tradition

Like much of the ceramics world, tradition dictates how people perceive art and how they go about many studio and even business practices. As frequent challengers of tradition, scientists often upset traditionalists at every turn. It is not uncommon practice for a community woodfire kiln owner to charge individuals to use space in their kiln—and that is the exact problem with that practice: space. Wood kiln owners (in the US) often charge for space by the cubic foot, but they are also offering some of the most celebrated surfaces in the ceramics world (1). A common price is $30/cubic foot if you take shifts firing the kiln and $60/cubic foot if you don't. Regardless of what you make, this adds up quickly. You can easily have a bill of $120 or $180 for a relatively small number of pots (and multiple 6-hour shifts firing), but these pots will have absolutely unmatched surface richness that is only available in wood firing.

This pricing structure punishes old hands at pottery (who make large, lighter works) and rewards newer patrons who make smaller works that weigh more.

1 A bowl made and fired in Matthew Gaddie's wood kiln—one of a few wood-fired kilns he has built and run as a community effort in Kentucky.

Lessons Learned

Matthew Gaddie (2), assistant professor of ceramics at Hanover College, has built kilns for a number of years for communities and colleges (including the large wood-fire kiln for Baltimore Clayworks in Maryland), and also runs his own community firings. His approach to the fee for firing work in the kiln is similar to the pricing system described above, but with a twist. He often tracked the amount of wood used for each load, with slight variations for weather conditions. It was pretty consistent and could easily be anticipated. And then a small-scale sculptor started showing up to his firings.

Gaddie notes, "I quickly realized for my particular situation, having crew members from all over the region, it was simpler to purchase the wood and have it delivered. The purist in me always wanted to process the wood, but finding a time for all the crew to arrive and equally contribute proved impossible, with many conflicting schedules."

The amount of wood needed varied, as he explains, "Depending on the agreed-upon firing process and plan for that week, the kiln could consume anywhere from 1½ to 5 cords of wood. Each unique firing plan was connected to a particular mode of experimentation, and the result was a fuel-consumption factor that varied wildly. I began to divide this shared economic burden with the crew by following commonly accepted examples. Mainly, I embraced the ideas about kiln loading and firing from what I learned in school as an undergraduate student. I was taught to think about the kiln loading and resulting need for fuel in terms of space. I also had a brief connection to a local clay center that charged for shared electric kiln loads by cubic feet. Thus, for years I charged by space or cubic feet. This involved a fair amount of math and [the use of] three connected boards, each marked with measurements. From these three measurements (height × width × depth) each piece's volume could be estimated with a high degree of accuracy. Combining that information with the known total volume of my kiln, I was able to calculate a percentage of space used by each crew member. I would always have the wood delivered and organized into several smaller stacks of wood, so I could estimate the amount of wood used for the firing and the related cost."

Identifying the Variable

Gaddie explains how and why his thinking changed. "In 2010, my buddy Jim Champion was completing his MFA exhibition at Hood College. His work was a series of large cityscape installations. The cities were made of small buildings that were solid clay sculptures of varied sizes, from the size of a human thumb to the size of a common salt shaker. Each had small windows stamped into them and the resulting sculptures were amazing. Jim arrived to fire with me with a dozen or more recycled clay boxes full of these little sculptures—hundreds of pounds, but a relatively small volume. We arrived at a system where we would load each shelf just as we always had and then step out and let Jim finish the shelf by placing as many buildings as would fit—imagine clay buildings in all of the negative spaces."

"We bricked up the door and began the firing with no expectations of notable variations. Almost from the beginning the firing was noticeably slower. We soon learned that finishing the firing was also going to be a struggle. We finished a full six hours behind schedule and having used way more wood than estimated. The kiln unload went just as slowly, only in reverse order, and as before, we all set on the task of doing the math for our individual cost. We used Jim's clay boxes to roughly calculate the volume of the solid buildings. When complete, the crew and I walked away."

"Weeks later, I was still struggling to understand why the math had been so strange. I had clearly used more wood, and the crew chipped in like always, but it just seemed to me that the cash pool was short. Clearly something was different—and it had to be all of those little buildings; everything else was relatively [the same] as it had been for the last several firings. After that, I began to think of my kiln load in a different way. I began to see the space as being filled with a variable mass of clay and that it was ultimately the mass of clay absorbing my fuel, and not the space."

2 Matthew Gaddie with his wood-fired kiln.

heat, in Joules — specific heat, in J kg^{-1} K^{-1}

$$q = m\,C_{sp}\,\Delta T$$

mass, in kilograms — change in temperature, in K

3

3 Specific heat equation for determining heat requirements of various materials for temperature changes.

$$\frac{\text{total cost of fuel to fire the kiln}}{\text{total pounds of pots in the kiln}} =$$

$$\frac{\sim\$2.25}{\text{lb pots (soda)}} \qquad \frac{\sim\$1.75}{\text{lb pots (wood)}}$$

4

4 The simplest way to come up with your own prices is to look at your total fuel cost and your total weight of pots in the kiln (each person weighs their share and it is added up at the end). A fast, dirty cost÷weight calculation gives you the exact amount to charge by weight. Both kiln owner and renter should agree on a slightly higher premium to account for kiln wear and tear, so that these practices can be continued for all involved. Keeping and maintaining a wood or soda kiln is definitely not a cheap endeavor. The formula above shows the estimated firing cost per pound of pots for a soda firing (gas fuel, left), and a wood firing (wood fuel, right). Costs may vary based on gas and wood prices as well as the kiln's fuel consumption.

5 Matthew Gaddie's wood kiln stacking for atmospheric surface deposition.

Specific Heat

These observations are painfully accurate. There is a specific heat associated with ceramic materials (after quartz inversion). It requires 850 joules of energy to heat up 1 kg (2.2 pounds) of ceramic material by just 1 degree—Celsius or Kelvins. This value is a bit higher for clays that have not yet undergone quartz inversion at 1381 J kg^{-1} K^{-1}. However you choose to look at it, clay and ceramics are effectively giant heat sinks. A bowl that weighs 1 pound, to get to cone 10 (already bisque fired, and having absorbed heat once, undergone quartz inversion and using the "ceramic" specific heat), would need 453,977 Joules of heat (3) to be vitrified and finished at 2192°F (1200 °C). And that is just for one single, relatively light bowl!

Beyond such, there are various woods with differences in BTUs (British Thermal Units) and cord weights. Pine is notoriously snappy and burns fast and hot, but doesn't have the slow energy output that oak does. With the conversion that 1 BTU = 1055 Joules, a cord of pine (2250 pounds) has 15.9 million BTU thermal output, which is 7.46 MJ/pound of wood, whereas a cord of oak has 29 million BTU per cord (4200 pounds), which places oak at 7.28 MJ/pound of wood. Oak just weighs more, burns more slowly, and delivers that heat output over a longer period of time.

Considering that an entire kiln is comprised of brick, with a similar heat capacity to the pottery inside it, and that several-thousand-pound kiln beast (including kiln furniture) (4), must be heated up in order to allow the ceramics inside to absorb enough energy to vitrify at cone 10, much of this comes down to weight conversions and energy absorbances, not cubic footage calculations.

Charging by Weight

After the experience with firing heavier sculptures, and the extra wood and time required, Gaddie explains that he altered his approach. "The next year, when I built my soda kiln and accepted some studio renters, I immediately charged for sharing kiln space by weight of work. Within the first five to seven firings, the correlation between the total weight of pots in the load and the amount of fuel used to fire was clear. What was even better was the time savings on unload day. We had a regular house scale and simply weighed a box full of pots at a time. We would get a total weight and charge each potter's weight in pots as a percentage of total weight. We would then charge for the same percentage of fuel.

"I noticed right away that my students were suddenly economically encouraged to make lighter and better-balanced pots. It was even better that there was no economic benefit or burden when pieces were designed to stack or nest inside each other," states Gaddie.

Cost by Weight

While prices for wood and gas are variable based on location and demand, $75/cord of wood and $2.65/gallon of LP (propane) dictate current prices of $1.75/lb of pottery for wood firing and $2.25/lb of pottery for soda firing for Matthew Gaddie. And while no system is perfect, this seemed to create a more even split of resources for those sharing a kiln.

What It All Means

Sometimes altering tradition helps to create a more accurate and equitable system. It is more scientifically appropriate (and thermodynamically apt) to charge for the weight of the ceramics being fired, since that actually determines the energy consumption of the kiln, aside from the furniture and walls—which would come out as a constant cost among firings. Charging by volume assumes that the mass and heat capacity (the whole entity) over the volume of the kiln would not change over time, which is actually the opposite of what happens!

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