



Kiln Temperature Measurement for Jacks*

OR

How to Make a \$20 Digital Pyrometer

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I'm a newcomer to the world of glass working, but I've been involved in engineering and physics for a long time. In reading the catalogs and "art glass" literature, I have seen that the topic of temperature measurement and control is skimmed very lightly. These remarks on temperature measurement are intended to help you get "more bang for the buck" when monitoring simple kilns and annealers. An understanding of some simple ideas can cut your costs dramatically by letting you build your own system with commonly available parts, or allow you greater accuracy with off-the-shelf systems.

Don't take these suggestions as criticism of the vendors who charge you \$60 to \$120 for a simple meter. They are also providing calibrated temperature outputs (no computations to make), switch-free use, strong connections, a warranty, and selling to a very small market.

You might as well ignore almost anyone's claims to "accuracy" in glass temperature measurements. What you want to know is the temperature inside your glass, and your probe only measures kiln conditions.

Let's start with the following observations about small electric kilns and annealers:

- We really don't care how accurately our pyrometer measures the temperature at the point of the thermocouple. Our concern is with the temperature within our piece of glass.
- Kiln temperatures are seldom anywhere close to uniform.
- Kiln temperatures go up and down a lot as things are added or removed, and as the heating element cycles on and off.
- Radiant heating from the electric elements affects small things (like our thermocouple) a lot faster than thick things (like our glass). That's why, with a Chromolux® (clicking) type controller the apparent temperature bobs up and down.

The fact is, *no* pyrometer, at any price, can tell us the core temperature of the glass. The best we can do is experiment until we know how a particular piece of glass responds to a particular heating or cooling "program."

Thermocouple Principles

Most kiln temperature measurement is done with thermocouple systems. These rely on thermo-electric effects between two different metals. Figure 1 shows a circuit (the electricity flows around a circle) composed of two pieces of wire. The points where the wires join are called the "junctions," and these are usually beads made by heating the junction until the metals fuse.

* In many trades, a Master is a worker who is so highly specialized he can only do one thing - period. As I see it, a Jack is a Renaissance Man of the craft world. It is the Jacks who can take methods developed in one area and apply them in another. On the whole, Jacks have a tradition of sharing techniques, and of teaching "outsiders." Masters, on the other hand, have a tradition of protecting secrets, and forming guilds of exclusion. Jacks are often concerned with "good enough," while Masters focus on "the best." This applies to tools and equipment, as well as techniques and results.

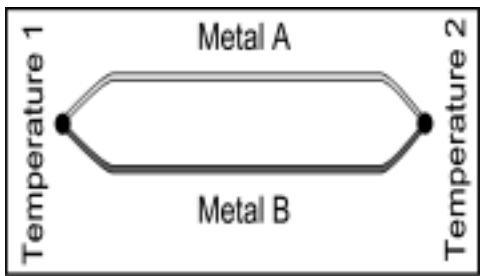


Figure 1. Basic circuit

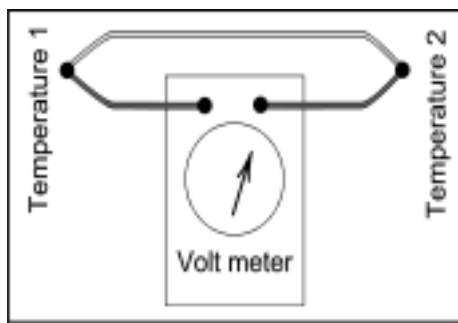


Figure 2. Basic thermocouple pyrometer

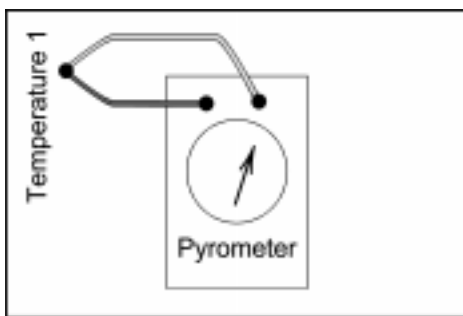


Figure 3. Vendor's pyrometer

If the two junctions are at different temperatures, a small DC electrical current flows in the loop. Different metals, different sized wires, and changes in temperature difference, result in different currents. We can cut the loop and insert a meter, as shown in Figure 2, and measure what is happening.

If we measure current, our results vary with the wire diameter and length, but if we measure voltage, we can find tables which tell us the difference between Temperature 1 (T_1) (which will refer here to the kiln temperature) and Temperature 2 (T_2) (which we will call the reference temperature) corresponding to various voltage readings and metal pairs. For glass kilns, the metals are typically patented alloys called Alumel and Chromel, and one wire of each joined with a weld at one end is called a Type K thermocouple. You can find tables of temperature versus voltage for this combination in a number of engineering, physics, and chemistry handbooks. The voltages involved are very small, typically something like 20 millivolts (0.02 volts) at annealing temperatures, but many simple meters can be used to measure this.

The typical pyrometer sold with kilns looks more like Figure 3. What, you should be asking yourself, *are* the differences between this and Figure 2?

First of all, what is the difference between a “pyrometer” and a “voltmeter?” In reality, only the numbers on the scale, if the sensitivity is correct for the voltages encountered. That being the case, can you use a cheap meter from some place like Radio Shack? Yes, you can. Today digital meters cost about the same as analog (moving needle) ones, so the choice between them might be largely considered a personal one.

You may be an “analog person” who likes needles better than numbers on meters, but the digital ones are much better than analog ones for this job. This is because they have much higher impedance - that is the amount of current they let flow around the loop is very much smaller, and this produces higher accuracy.

How do you convert volts to temperature? Tables are available which give points for Type K thermocouples. I've got one on <http://www.cemr.wvu.edu/~venable/RMI/studio>. The relationship is actually non-linear, but overall it amounts to about 0.023 mV/F°, or 43.7 F°/mV. (1 mV = 1 millivolt = 1/1000 volt and 1F° is one degree on the Fahrenheit temperature scale) You can use these “conversion factors” as multipliers for rough (and maybe most) work. In my shop I always have a copy of the table laminated with Contact® plastic sheet somewhere in the stack of junk on the bench for referral.

What happened to the junction at T_2 ? One way to look at that is to say “It’s inside the meter.” A basic voltmeter reading only tells you the *difference* in temperature between the junctions. Some

expensive digital pyrometers *may* have other temperature measuring circuitry inside the case to measure T_2 and provide the compensation required to make the read out “the real temperature.” If we use analog pyrometers, or volt meters of any kind, we may need to worry about T_2 . We’ll return to T_2 later.

Accuracy, Precision and Repeatability

In general, non-scientists tend to mix up accuracy, precision and repeatability. “Accuracy” is how close a measured value is to the “true” value you wish to measure. “Precision” is how finely that value can be determined. “Repeatability” or perhaps “reliability,” is how closely you expect values of repeated measurements to agree. All three are important, but only up to a point.

In practice, you want to be able to say is something like, “I know this glass anneals well if I heat it to 23 before turning off the kiln, and I know that sheet slumps nicely if I heat it to 39.” What 23 or 39 corresponds to in Fahrenheit or Centigrade degrees really doesn’t matter if you are working glass in your own studio, not reporting to a scientific meeting. What you probably value most is repeatability, getting the same results each time. The way to get this is by careful observation, and by making sure your glass, probes, and heating system always remain in the same relationships.

Taken individually, commercial thermocouples and digital voltmeters can be expected to have accuracies of $\pm 1\%$ or better. Analog meters, whether millivolt or pyrometer, should be expected to be much lower, perhaps $\pm 5\%$ or worse.

You might, at first, worry about the precision of cheap digital meters. These typically have “3 ½ digit” displays. That is, they display everything as numbers between 0 and 1999, with decimal points inserted at the appropriate place. With a Type K thermocouple, this means that a displayed reading is about ± 20 Fahrenheit degrees, but still this is a variation of only about 1 or 2%.

The Reference Temperature

As noted above, a pyrometer circuit measures the temperature difference between two point, not the temperature of either one. If , T_2 the reference temperature is completely unknown, we can not infer anything about our measured temperature, T_1 . We can usually assume that the reference junction is at “room temperature,” but that can vary a bit, particularly near a kiln.

The simplest way of establishing a very exact reference temperature is to place our reference junction in a container of ice water. This probably isn’t necessary most of the time, but if you make a two-junction pyrometer, you always have the option of using the ice bath. The standard tables are based on an ice bath at 32°F or 0°C.

Building the \$20 Digital Pyrometer

To build the pyrometer my way you will need four parts:

- A Type-K thermocouple - 18 inches is a good length
- A digital multimeter
- A junction block
- An ice bucket (any cup will do)

I’ve been buying an 18 inch Type K thermocouples from Sundance Art Glass Center which list at \$7.00 each. (Sundance Art Glass Center, 179 Stierlin Road, Mountain View, CA, 94043, 800-641-6262, <http://www.artglass1.com>) It looks like a pair of wires with fiber insulation. (It is.) One end has been stripped and fused into a small ball. Strip the other end, twist the wires together, and, if you



have a glassworking or welding torch, fuse a ball on the other. About 6 inches from one end, gently remove about an inch of outer insulation, cut one of the wires, and strip about ¼ inch of insulation from the cut wire. The short end is the reference junction.



My digital meters have come from Harbor Freight. Their Cen-Tech Item 30756 7-Function Multitester lists at \$9.99, and they cost only \$4.95 when on sale. (Harbor Freight Tools, 3491 Mission Oaks Blvd, Camarillo, CA 93011-6010, 800-423-2567, <http://www.harborfreight.com>) Radio Shack can provide instant gratification for \$40 or less. Plug the appropriate end of the leads into the meter, cut the probes off the other, and strip about ¼ inch of insulation from the end of the leads.

Next we connect each lead to one of the wire ends we made in the loop. You could twist and/or solder the wires, but I prefer to use a screw connection “barrier” or “terminal strip.” My first choice for a junction block is two sections cut from Radio Shack Cat.No. 274-678 (\$2.19) with Radio Shack Cat.No. 274-656 (2 for \$1.69) as a good second choice. In this application there is no need to worry about fastening the junction block down or wrapping it with insulation.

You can test the system by putting the “hot” junction in your mouth. (Turn on the meter and set it to 200 mV DC first.) This should produce a small meter reading. If the reading is negative, reverse the way the leads are plugged into the meter, or reverse them at the junction block.

Install the “hot” end in your kiln according to the kiln manufacturer’s instructions. Lacking other instructions, drill a hole about 3/32 inches in diameter in the middle of the back wall and shove the wire through until it sticks about 1 inch into the chamber. You can put the meter in any convenient location. Mine rests on the bench, but you could make a mounting bracket or stick it to the wall with double-faced tape. Try to put it where you will not cook it or drop hot glass on it.

A \$50 Computer-Interfaced Pyrometer

For a recording temperature measuring system at a modest price, you could consider purchasing a *Digital Multimeter with Computer Interface* (about \$60 list, but I bought a “model close-out” from RadioShack.com for \$39.95), a Type K thermocouple (\$7 list), and scrounging up any old IBM type PC. You make temperature readings with software included on a disk provided with the meter, or with a few lines of BASIC code.

I have provided sample code for reading in QuickBASIC on my web site
<http://www.cemr.wvu.edu/~venable/RMI/studio/kiln-con/pc-x10.htm>

I’ve gone further, and created a kiln control program (**SIMP-CON**) which records temperature as a function of time, and records each run in a text file which can be imported into a spreadsheet. The program could be used for data logging without implementing the control hardware. It can be downloaded from the same site.