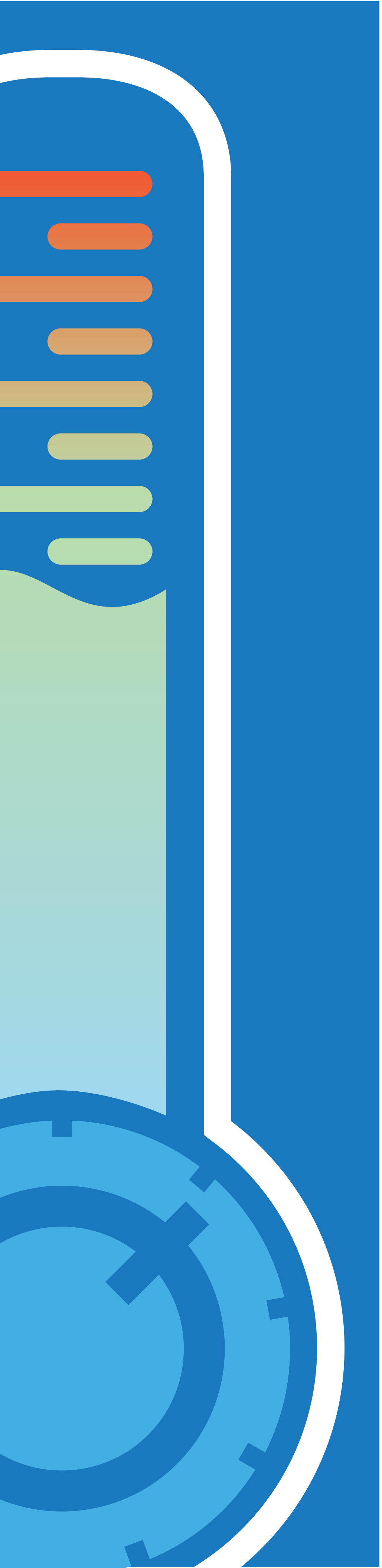

Why TEMPERATURE CONTROL IS CRITICAL IN DENTAL CERAMIC FIRING

FROM FELDSPATHIC PORCELAIN TO LITHIUM DISILICATE

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About
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Why TEMPERATURE CONTROL IS CRITICAL IN DENTAL CERAMIC FIRING

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INTRODUCTION

INTRODUCTION

The goal of this eBook is to explore the many controllable parameters of heating, pressing and vitrifying dental porcelain materials. Any quality control program has the goal of consistent process results. While the goal is admirable in theory, it is not always efficient in practice. A recent LMT survey shows that 66% of dentists switch laboratories based on inconsistency in the quality of the finished product. A comprehensive understanding of thermodynamics, controlling temperature accuracy, and the physical characteristics of the materials used will give the reader the ability to ensure success. So, the implementation of tools to help with consistency in the end product is imperative.

In the ceramic world, isolating problematic issues generally boils down to two phases. First is the preparatory work done prior to firing the ceramic, and second is the firing process itself.

There are so many different things that can go wrong with a case during the preparation and construction phase, and conversely, perfectly prepared cases can be ruined by an unstable firing environment (porcelain furnace). Measuring the critical parameters comprising the ceramic firing process can be challenging and consuming for the dental technician.

If the technician can verify the temperature consistency of the furnaces being used, then any further process instability can be addressed simply in terms of preparatory work or mechanical defect.

The following articles review the importance of temperature control, how to accomplish it, and how to ensure success from conventional ceramic firing to lithium disilicate pressing and/or crystallizing.

THERMODYNAMICS OF THE MODERN VACUUM PORCELAIN FURNACE

THERMODYNAMICS OF THE MODERN VACUUM PORCELAIN FURNACE

"Do you believe **IN MAGIC?"**

JOHN SEBASTIAN OF THE LOVIN' SPOONFUL

We may like to believe in magic but in firing dental porcelains there is only physics. This paper attempts to explain what is happening in the heart of our furnaces, the muffle.

The consistent measurement of temperature accuracy is a critical part of the process. To appreciate how this process functions, it is first necessary to understand the principles of thermodynamics as they relate to the modern furnace.

The most accurate sensor for high resolution temperature is the noble metal thermocouple. Thermocouples consist of two dissimilar metals welded together at one end to form a junction known as the "bead". When the bead is heated by convection (air currents passing across it) or by radiation (which is the case when the furnace is operated under vacuum) the bead will generate a positive electrical charge on one side and a negative electrical charge on the opposite side. Measuring with a meter will tell us the temperature.

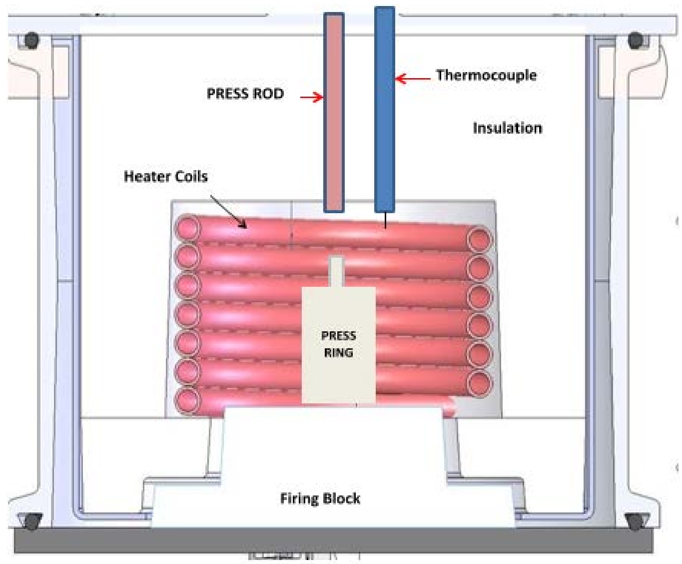


Fig. 1

The measurement of the interior muffle temperature in a Vacuum Porcelain Furnace can be more challenging than the simple sensing of temperature around the thermocouple [Fig. 1]. One of the factors is the position of the thermocouple inside the muffle. Most modern Vacuum Porcelain Furnaces have a spiral wound heating element encased in tubular quartz which covers the inside surface of the muffle. The thermocouple projects downward from the roof of the muffle. Heated air inside the muffle will migrate to the top and force cooler air toward the bottom of the muffle. The difference between the hotter and cooler air depends upon several factors; the level of vacuum, the height of the muffle, the diameter of the muffle and the average air temperature. In addition, the higher the air temperature inside the muffle, the larger the top-to-bottom temperature differential is within the unit.

THERMODYNAMICS OF MODERN VACUUM PORCELAIN FURNACES

Besides the physical factors mentioned above, the ability to control and regulate temperature inside the muffle is influenced by the time it takes the thermocouple to sense the current temperature of the muffle. The furnace must decide whether it is too high or too low and by either turning the heater on or off, reach the desired temperature.

The control circuitry of the furnace must take this thermal time constant (the amount of time it takes to sense the temperature) into consideration or the muffle temperature may wind up oscillating up and down as it constantly hunts for a stable point.

The muffle cavity itself also influences temperature. The muffle is formed by surrounding the heater coils with an insulating material such as Aluminum Oxide, which will slow but not completely stop the loss of heat from the higher interior temperature interior to the lower exterior temperature.

The rate of heat loss increases as the difference in temperature between the inside of the muffle and outside increases. The insulation, when exposed to enough heat over a short period of time, can turn into a ‘heat dam’, which will not allow the temperature to drop until enough time has elapsed to radiate the migrating heat toward and away from the outside of the muffle chamber. Fortunately, most dental porcelains only require a few minutes of process time at high temperatures and return to lower temperatures before enough heat can back up in the insulation dam and adversely affect the firing.

The thermocouple bead and the porcelain restoration are each affected by the radiant energy coming from the heater windings. This radiant energy is directly proportional to the surface area of the heater windings facing the porcelain and the thermocouple. It is also proportional to a lesser degree by the indirect radiant energy that is reflected off the muffle walls. This energy bounces around the interior of the muffle chamber, until it strikes the porcelain restoration and/or the thermocouple.

How a restoration is affected by this radiant energy depends upon the size of the restoration, the surface area and the amount of time it is exposed to the radiant energy. If the restoration is layered ceramic, the speed at which the porcelain absorbs the heat is affected by the amount of moisture in the porcelain and how close the porcelain particles are to each other. In addition, the speed of absorption will depend upon the overall mass of the restoration. This is the case for all ceramic types whether layered, pressed or milled.

Heat (photon density) is subject to the Inverse Square Law which states; 'a work piece which is twice as far away from the heat source, receives one quarter of the energy per square millimeter of surface area'.

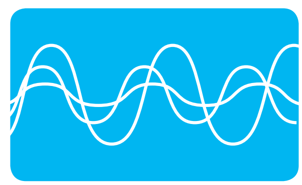
> Where you place the restorations in the furnace, relative to the center of the muffle and firing tray, will have an effect on the amount of heat energy the restoration will absorb at a given temperature setting.

What this means is that where you place the restorations in the furnace, relative to the center of the muffle and firing tray, will have an effect on the amount of heat energy the restoration will absorb at a given temperature setting. The bottom line is: the closer to the center, the better. Also with a smaller muffle, the heat is increased in the same amount of time it would be in a larger one.

We also find that the firing parameters you employ will be different if you are using a 115 Volt furnace versus a 220 Volt furnace, because the exposed heater coil surface of a 115V is less than the 230V furnace, which uses the same wattage. Since the photon density is higher in the 230V it would require less hold time to generate equivalent firings on the same material with the same surface and mass. So published firing parameters will need to be adjusted to accommodate the furnace muffle design you are using.

The wavelength of the photons leaving the muffle coils should be the same to assure a uniform depth of penetration of the ceramic. The physical composition of the muffle coils and the applied voltage determine the spectral heat wavelength. When a muffle coil nears the end of its life, the composition of the wire can change slightly due to "boil off" loss of one of the two metals composing the wire. This can cause a slight spectral shift which would suggest a drift in the firing parameters required to generate an equivalent firing on a given material, wetness and mass. This 'Drift' is often blamed on the aging thermocouple inside the muffle, but in fact can be due to the aging of the muffle coils.

Some attention should be paid to the quartz tubing and the insulation and their affect on heat exchange. The quartz tubing surrounding the heater coils in the muffle is heated at the primary spectral wavelength by the coils and then re-radiates this energy to the muffle cavity at a spectral wavelength characteristic to the quartz. The same is true about the surrounding alumina fiber insulation. The characteristics of these elements do not vary significantly over time so their effects can largely be ignored, therefore the claim of no quartz versus quartz is a non-significant issue.



The measured top to bottom temperature difference mentioned previously is not of particular concern since the relative vertical position of the ceramic inside the muffle chamber is usually held constant by Saggar trays and points and the midline height of the units or bridge never vary vertically more than a couple of millimeters. The ceramic generally sees the same temperature with each firing.

THERMODYNAMICS OF MODERN VACUUM PORCELAIN FURNACES USED WITH PRESSED CERAMICS

The fact that the thermocouple may see a slightly different temperature than the actual work units should not matter since both the restoration plane and the thermocouple plane are simultaneously present in the same place during every firing. The thermocouple helps ensure a preset point of temperature at its location. The ceramic will still need to be inspected visually to ensure that the temperature set point produces the desired effect on the ceramic at the location of the ceramic.

The same is true when using a pressing furnace to press lithium disilicate or other pressable ceramics. There is no thermocouple inside the invested ring to measure the temperature near the pattern molds. Suggested firing parameters are made by the manufacturer of the glass ceramic and in certain cases based on research using their furnace only. Any furnace with the ability to reach and hold an object at the required maturation temperature, whether in one or multiple stages, will be able to properly vitrify any layering/veneering ceramic or pressable material.

Any furnace with the ability to reach and hold an object at the required maturation temperature, whether in one or multiple stages, will be able to properly vitrify any layering/veneering ceramic or pressable material.

A good ceramic technical team should be able to help any furnace user find the best thermal location for their glass.

We have covered a lot of technical and physics related issues in this article.

IN THE END A PORCELAIN FURNACE DOES SIX THINGS:

1

It **ENCLOSES** the work in a sealed heating chamber

2

It heats up at a **SPECIFIED RATE**

3

It achieves a **VACUUM**

4

It **HOLDS** a preset high temperature for a specified amount of time

5

It **STOPS** the heating procedure at a specified time or temperature

6

It **OPENS** the sealed chamber

So, indeed, there is no magic in firing dental porcelains, just pure science. The ceramic and its manufacturer control the firing parameters to ensure that the ceramic **ACHIEVES CONSISTENT SUCCESS**.

THE ADVANTAGE OF THREE POINT FURNACE CALIBRATION

THE ADVANTAGE OF THREE POINT FURNACE CALIBRATION

WHY IT IS IMPORTANT TO THE DENTAL CERAMIST

The calibration of ceramic furnaces in the dental laboratory has a long history tied to Tempill tablets, silver pellets or silver wire. Peering through a window of smoked glass waiting to throw a switch at just the right moment of the melt to set a 1763°F temperature point has been replaced by modern technological breakthroughs. For many years we stretched silver wire between two electrodes and plugged it into our ceramic furnace brain, which sent a current of electricity through the wire. When a muffle temperature of 1763°F was reached, the wire melted and broke the electrical circuit. This set a temperature reference point. Most of the time, this temperature actually went past the reference point we sought before the set. This happened because the temperature of the furnace continued to rise in the moments before we or the furnace brain threw the switch. Some manufacturers are still using this technology in what are called 'self-calibrating furnaces'.

Accurate measurement is tricky enough at a single temperature, but when pinpoint accuracy is required across a broad range of temperatures, as is used in the process of firing ceramic, it is doubly challenging.

The furnace manufacturer begins the calibration process by using a noble metal thermocouple which will withstand the high firing temperatures on modern dental ceramics. Each thermocouple (TC) has a characteristic response curve unique to the two-metal combination of that TC.

The American Society for Testing and Materials (ASTM) publishes ideal thermocouple performance charts for each TC. The charts lists the temperature on one axis of the curve and millivolts of electricity required to achieve that temperature on the other axis. These charts are programmed into the software of the furnace so that the electronics inside the furnace can accurately convert the incoming millivolts from the TC into degrees of temperature. These control the muffle heating response and are displayed to the furnace user.

Unfortunately, there are no perfect thermocouples. The ASTM typically separates noble metal thermocouples into two grades: (1) STANDARD GRADE, which is +/-.2% of the actual temperature and (2) "SPECIAL LIMITS GRADE", which is +/-.1% of the actual temperature.

What this means to you is that the STANDARD GRADE TC will be within +/- 2.4 degrees Centigrade at 1200°C and the SPECIAL LIMITS GRADE TC will be within +/- 1.2 degrees Centigrade at 1200°C. This is at a single set temperature point.

WHIP MIX CERAMIC FURNACE ACCURACY; THE ADVANTAGE OF THREE POINT CALIBRATION

The Calibration process of the modern ceramic furnace (PRO100, PRO200 Series Furnaces) takes into account the values of the ASTM standardized thermocouple used in the muffle. Then a second National Bureau of Standards (NBS) traceable reference thermocouple is placed into the muffle, and connected to an accurate laboratory grade temperature meter. As the furnace goes through the temperature parameter changes, the offset differential, (the difference between the readings of the two thermocouples), is used to correct the future response to internal furnace temperature measurements. It does this by storing the information in the on-board computer of the furnace. This is a very precise means of correcting for the accuracy of response over a range of temperature values.

> The calibration of the entire range of the desired temperature operation is best accomplished by using multiple temperature check points, instead of just a single one.

With single point temperature calibration, the further you are away from that single point to the cold or hot side (+ or -), the more temperature inaccuracy you will encounter. The calibration of the entire range of the desired temperature operation is best accomplished by using multiple temperature check points, instead of just a single one. These temperature points are spaced roughly 30% apart. In Whip Mix furnaces this translates to 850°C, 1000°C and 1150°C. The temperatures encompass the firing range of most ceramics on the market today. The use of three calibration values is very much like wearing tri-focal lenses instead of single vision lenses. You would have clarity close up, at arm's length and on the horizon. Whip Mix furnaces come to you pre-calibrated using this three-point calibration method.

The use of the second thermocouple with a second meter is much like doing an internal audit of your business. You would never ask your accountant to audit his/her own work. You would always go to a second firm to perform this function. Some of the current furnace manufacturers claim a self-calibration feature with a second TC which remains in the furnace all of the time and is read by the furnace brain. Since this TC is experiencing the same environmental conditions as the first TC, is it then capable of performing an independent audit? With the accuracy of the furnace temperature at stake, is this type of system worth the risk?

WHY THREE POINT CALIBRATION IS ESSENTIAL FOR PRESSED CERAMICS

Some of the modern materials being processed in ceramic furnaces, like pressable lithium disilicates, have a temperature variance of as little as five degrees centigrade which can mean the difference between the ceramic becoming molten enough to be successfully pressed or not. With these types of tight tolerances, it is imperative that the furnace you are using has the ability to be calibrated correctly over the total range of the temperatures used in the parameters for the firing dental ceramics. The Whip Mix pressing furnaces offer that advantage.

For a ceramic furnace to be a viable asset as we move into the future of dental materials, it will need to be accurate and correctable for the user. Those furnaces that use the three point calibration system have that ability.

THE PROCAL CALIBRATION DEVICE

AN INVALUABLE TOOL

Historically, the most universally accepted method of verifying furnace temperature accuracy was by melting a silver wire at the known silver melting point. Unfortunately this technique can be significantly inconsistent due to human technique factors. The placement on the posts, the axial orientation and the electrical resistance of the silver wire being used as a fusible link can all contribute to error. In addition, the ramp rate (rate of temperature rise) can also change the point at which the wire breaks. The process can be time consuming, is often subject to trial and error, and must be repeated multiple times if there is any deviation from prior results.

Whip Mix recognized this challenge, so to make and keep its furnaces extremely accurate, it developed the ProCal device. It was conceived to satisfy the need for an efficient, consistent method of checking not only on an individual ceramic furnace but an array of PRO furnaces.

The device had to be more accurate than the furnace itself, highly portable, rugged, offer an easy application of the information acquired by the instrument and not be subject to human interpretation. Lastly, the investment in dollars, time and the ongoing consumable costs (silver wire) had to be minimal.

The device had to be more accurate than the furnace itself, highly portable, rugged, offer an easy application of the information acquired by the instrument and not be subject to human interpretation.

THE PROCAL CALIBRATION DEVICE

There are several off the shelf portable meters used in other industries, so why "re-invent the wheel"?

There are three reasons based on our initial requirements that removed these devices from consideration:

1

the **COMPLEXITY** of the operation,

2

the **COMBINED ACCURACY** of the instruments with their thermocouple, and

3

TRACEABILITY back to the exact same temperature reference standard over a period of years, i.e.; the lifetime of the furnace.

Another issue that was critical for this evaluation was to place the second thermocouple into the muffle in a consistent position without dismantling parts of the furnace to access the factory port for the original calibration. Loose thermocouples are difficult to mount and keep in a stable position during testing. The variations in their height and distance from the muffle center will often cause inconsistent information readings.

The decision was made to embed the second thermocouple into a firing tray just like the one which insulates the base of the muffle and forms a platform for the sagger tray. This allows the thermocouple to be at a repeatable position in the muffle and to be removed and replaced consistently with each use. This also overcomes the problem others have with leaving the second thermocouple in the high temperature environment.

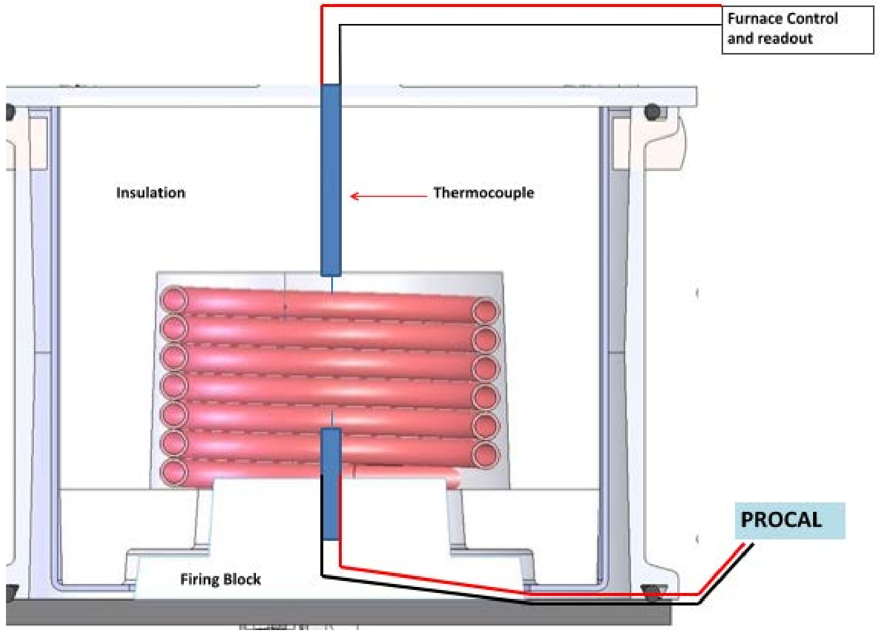


Fig. 2

As seen in Fig. 2, wire connections leave the base of the firing block and connect to an instrumentation box which contains a microprocessor and a system to accurately amplify the low level thermocouple signal with precision.

SO HOW DOES IT WORK?

The TC in the special firing block monitors the electrical signal produced by the heating of the muffle and sends it to the instrument box. The instrument box filters the low voltage electrical 'noise' in the micro and millivolt range. The cleaned signal is then sent to a pre-amplifier with a built-in digital filter to further boost the signal and clean it again. Finally the cleaned signal is presented to a 24bit Analog-to-Digital Converter (ADC) for conversion to digital ones and zeros (10101100) which are transmitted to the furnace computer. Once the information is received, the temperature value is computed and compared to the value being sent by the furnace-reference TC by the furnace computer and the variance is stored. This variance is the correction value.

With this information, each time the furnace is commanded to a specific temperature in a firing parameter, the furnace looks at that 'target' temperature, determines which calibration value is appropriate for that target value and either adds or subtracts the correlation value to produce the accurate muffle temperature desired in real time.

WHY DO FURNACES REQUIRE A PERIODIC TEMPERATURE RECALIBRATION?

Effluents given off by the materials fired in the Ceramic Furnace (alloys, ceramics, investments, metal ceramic stains and glazes) can deposit on the platinum/palladium thermocouple and in some cases react chemically with the noble metals to affect the temperature sensed. In addition, oxide layers can build up on the TC through many cycles of vacuum and vacuum release exposure to air, causing a chemical change to the TC. Prolonged high heat can cause crystallization of the metals in the TC and inhibit the transmission of the electrical registration signal to the computer. Lastly the muffle heater wire itself can become brittle and scaly along its surface, especially after extended usage. This can affect the infrared spectrum heater wire and redirect the angle of the emitted photons so that the ones striking the TC are more diffused and create less of a charge on the TC. With a sub charged TC the furnace computer may think that the temperature of the muffle is different than the actual temperature.

With all of these factors involved in the operation of a modern ceramic furnace, it becomes obvious that these machines need regular maintenance, monitoring and care for long life and consistent results. With that in mind the ProCal Calibration device becomes an invaluable tool and partner in your success.