WBC Procedure for Measurement of Brewing Water Temperature

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gscace

#1: Sep 01, 2005, 10:17 am

WBC Procedure for the Measurement of Brewing Water Temperature in Espresso Coffee Machines

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1. Introduction:

Producing high-quality espresso is an exacting process. Fresh coffee must be ground to a fineness that will produce the correct flow resistance to pressurized (nominally 9 bar) hot water. Immediately after grinding, the coffee is precisely metered into the espresso machine portafilter by the barista, who tamps the coffee into a packed cake prior to installing the portafilter into the machine and brewing the espresso. Since variations in grind fineness, dosing, and tamping affect the end result, baristas strive for precision in their preparation ritual. The espresso machine must be similarly precise, capable of producing consistent pressure and temperature conditions in the hot water used to extract the espresso.

Espresso machine brewing temperatures vary due to changes in duty cycle. It is common practice for espresso machines to heat the brewing water by pumping it through a heat exchanger within a boiler filled with much hotter water intended for steam production. The temperature of this water is usually around 120 degrees Celsius (250 degrees Fahrenheit), much hotter than appropriate for brewing espresso. Under intermittent duty conditions, water within the heat exchanger may be nearly as hot as the steam boiler temperature, although the heat exchanger may be properly configured to produce water at the correct brewing temperature during continuous duty conditions. The temperature of components downstream of the heat exchanger varies with duty cycle changes as well. Downstream plumbing and metal castings are often not temperature regulated. Depending on the machine's design, these components absorb or discharge heat to the brewing water as it passes through on its way to the coffee.

Measurement of brew water temperature is not a trivial exercise. The location of the measurement must be carefully considered for relevance. Temperature measurements of brewing water as it gains and loses heat on the way to the coffee may be informative to the espresso machine's designer, but for the end user, knowledge of the water temperature at the coffee is more important. The measurement equipment itself must not significantly affect the environment one wishes to probe. Care must be taken to insure that heat is not unduly lost to the thermometer, and that the equipment perturbs actual brewing conditions as little as possible. Speed of thermometer response to changes in temperature must be considered as well as accuracy and precision of the measurement.

Interest in measuring brew temperature in espresso machines has increased recently, in recognition of the significant role that temperature plays in the production of the best possible espresso coffee. The following proposed standard for measuring brew water temperature in espresso coffee machines presents a rigorous, technically sound procedure for obtaining meaningful brewing temperature measurements for machine comparison, and improvement.

2. Measurement Location:

Specification: The temperature of the brew water shall be measured within the volume below the housing that supports the portafilter, e.g. the brewhead, and above the packed bed of coffee, or coffee cake. The location of the temperature probe shall be off center, approximately 1/3 of the distance from the center of the volume to the inner edge of the filter basket. During measurement, the sensing portion of the probe shall only contact water.

Technical rationale: This measurement location is chosen for its relevance to the brew process, likely similarity of boundary conditions over a wide range of machine makes, and ease of measurement. A useful and convenient location for temperature measurements, as it pertains to the quality of the espresso produced, is immediately upstream of the coffee cake because the temperature of water within this volume directly affects the extraction rate of various espresso components affecting taste. Measuring water temperature just above the coffee cake eliminates measurement complications due to temperature gradients existing spatially within the coffee cake and varying with time during the brewing process. Such measurements may be interesting, but the results may be strongly dependent on very precise positioning of the thermometer, flow rate of the water through the cake, and on the geometry of the specific filter basket used. These measurements may not be easily reproduced. On the other hand, given consistent filling and packing of the coffee into the brew basket and reproducible infusion rate, the measure of temperature profile differences directly upstream of the coffee cake should provide insight into temperature profile differences within the cake.

3. Measurement Equipment:

3.1 Introduction:
A fast-responding, electronic temperature probe, positioned as described above, senses the temperature of the water. The probe is mounted in a modified portafilter and filter basket, so that the probe may be conveniently inserted in different machines. For ease of use, measurement consistency, and to ensure that the probe contacts only water, the coffee cake is replaced by a plastic insert. An adjustable valve mounted downstream from the insert allows the water flow rate to be adjusted to the required flow rate. The temperature data is read using a suitable readout device, or a datalogger. The requirements of these items will now be discussed in detail. An example of the intended measurement system is depicted in Figures 1 - 3.

Figure. 1 Portafilter thermometer top view, showing the Type T thermocouple probe and the coffee cake facsimile.

*Figure. 2 Portafilter thermometer side view,
showing the thermocouple probe's exit through
the bottom of the portafilter, and the brew water metering orifice.*

*Figure. 3 Installed portafilter thermometer measuring the
temperature of the metered brew water stream.*

3.2 Temperature Sensor:
<u>Specification:</u> The sensor shall be a type T thermocouple probe, with a response time of less than 0.25 seconds in water.

<u>Technical rationale:</u> Thermocouple probes are preferred over other sensor types because they are economical, rugged, fast-responding, and not subject to calibration drift at temperatures expected for espresso production. The type T thermocouple is especially suited for measuring brew water temperature. At temperatures near the boiling point of water, Type T thermocouples are more accurate than other thermocouple types. The ASTM standard wire error for uncalibrated type T thermocouple wire at 93 Degrees Celsius (˚C) is ± 0.8˚C (Ref 1). Regardless of accuracy, a specific thermocouple probe is capable of extremely precise measurements since the chemistry of type T thermocouple wire does not change at temperatures near the boiling point of water. This characteristic assures long-term reproducibility of the probe. Higher accuracy may be obtained by using a thermocouple probe and readout calibrated as a single system. Use of such systems may be warranted in cases where higher accuracy is needed, such as when adjusting brew water temperature for machines used in barista competitions.

Probe response time is specified at less than 0.25 seconds so that the measurements reflect physical reality under rapidly changing temperature conditions. These conditions exist when one initiates espresso brewing. Response time is usually defined as the time required for the temperature probe to indicate 63.2% of an instantaneous change in temperature. After 1.5 seconds have elapsed, a temperature probe with a response time of 0.25 seconds will indicate 99.75% of an instantaneous temperature change. For a jump of 50˚C, this corresponds to a response of 49.9˚C.

3.3 Probe installation:
Specification: The probe shall be permanently installed in a filter basket, which shall be fitted to an appropriate portafilter for the machine under test. The sensor sheath shall be thermally anchored to the filter basket to minimize heat conduction down the sheath of the probe into the room environment. Portafilters may be modified so that the bottom of the filter basket is open to the room (so-called "bottomless", "crotchless" portafilters).

3.4 Simulation of the Coffee Cake:
Specification: The volume of the filter basket normally filled by the coffee cake shall be filled with a solid material having a thermal conductivity of less than 0.5 Watts/meter*Kelvin (W/m*K). The volume of the solid should be approximately the same volume as a coffee cake, but may contain deviations from the actual shape of the cake in order to accommodate the temperature probe, metering valves, etc. The distance between the group dispersion screen and the top of the proxy cake (headspace) should approximate the headspace in the presence of an actual coffee cake.

Technical rationale: A reasonable substitute for the coffee cake enhances practicality. Filling the portafilter with coffee prior to each test run would be wasteful of coffee. Variations in dosing would introduce varying water flow rate, and therefore varying boundary conditions. While tamping the coffee cake is possible if bare thermocouple sensors are employed, use of more robust, sheathed probes complicates tamping by normal means due to the probe position above the coffee cake.

Replacing the coffee cake with a substitute introduces potential measurement errors. However, the proxy cake is located downstream from the temperature probe, and is not likely to affect the temperature of the brew water above the proxy cake, provided that it is not constructed from material possessing high heat capacity. The specified thermal conductivity range from .1 W/m*K to .5 W/m*K encompasses the thermal conductivity of dry wood to wet foodstuffs such as bananas and apples, and is a reasonable approximation for the thermal conductivity of coffee as it transitions from dry to saturated grinds. Many easily machined plastics such as poly vinyl chloride (PVC) fall within the specified range of thermal conductivity.

The proxy cake further deviates from a coffee cake in its water absorption characteristics. This topic will be discussed further in the measurement procedure.

3.5 Water Flow-rate Adjustment:
Specification: A water flow regulator, positioned downstream of the thermometer probe, shall simulate the flow resistance of the coffee cake and provide flow rate regulation as specified in Section 4.3.

3.6 Data acquisition:
Specification: A thermocouple readout device shall measure the voltage generated by the thermocouple probe. Permissible readout devices include digital thermometers that automatically calculate temperature, or digital multimeters, provided that a suitable thermocouple reference junction is employed. The preferred method of recording the data is by datalogger and computer. The precise measurement frequency made possible by computerized observation allows more rigorous interpretation of the results. In addition, data obtained by computer is less likely to be influenced by tester prejudice. Data taken automatically should be acquired at a rate of at least one reading per second. The readout and probe shall be calibrated as a single unit for measurements requiring high accuracy, such as barista competitions.

4. Preparation for Testing:

4.1 Machine Cleanliness:
Specification: The group(s) shall be backflushed prior to performing the tests. If the dispersion screen(s) is removable for servicing, then it shall be removed, cleaned, and reinstalled. After backflushing, the machine shall remain idle until it has again reached thermal equilibrium as specified in section 4.2.

Technical rationale: Cleaning the groups minimizes the chance that stray coffee grinds will clog the flow orifice, affecting the volume flow rate during the measurements. Cleaning the groups may affect the temperature of the groups. Thermal soaking in the idle state is required after backflushing to help insure that the machine is at operating temperature and completely idle prior to the start of testing.

4.2 Espresso Machine Thermal Equilibration:
Specification: The espresso machine to be tested shall be at its normal operating temperature for 1 hour prior to testing. The portafilter containing the thermometer shall be inserted into the group during the warmup period.

Technical rationale: In order to simulate real world conditions and good practice, the machine and portafilter must be hot.

4.3 Adjustment of Brew Water Flow Rate:
Specification: The flowrate of water through the measurement portafilter shall be measured by a graduated beaker and shall be adjusted so that 75 ml of water is collected in an elapsed time of 25 seconds ±5 seconds. The allowable volumetric tolerance of the beaker graduations shall be ±5% or less.

Technical rationale: The specified water volume was determined by direct volumetric measurement, using the Specialty Coffee Association of America (SCAA) standard espresso volume of 60 to 74 ml as the target volume of a double espresso after brewing. An espresso machine was calibrated to produce double espresso shots of 60ml in volume. The amount of water used to produce these shots was measured by brewing a series of "blank shots" into a graduated beaker. The measured volume was approximately 75 ml. The following sections account for the difference in water produced by the blank shots, compared to the brewed espresso.

Water absorption by the coffee cake: A series of measurements were performed, in which a dry portafilter was dosed with coffee and weighed. The portafilter was reweighed after espresso was brewed from the coffee. The measurements show that a dry coffee cake absorbs approximately its own weight in water during the brewing process, about 18ml for a double espresso shot.

Volumetric measurement of crema: A series of 60 ml double espressos were brewed into a graduated beaker, using coffee that had rested for 5 days after roasting. The coffees were allowed to stand for 5 minutes, allowing the majority of the crema to dissipate. The volume reduction due to crema dissipation was approximately 20 ml.

Residual water: Not all of the water that is pumped through the flowmeter percolates through the coffee. During brewing, water fills the space immediately above the coffee, and plumbing within the group. This water is ejected to the drain when pressure is relieved after brewing.

4.4 Steaming Performance:
Specification: If the desired brew water testing includes testing of steam performance, the elapsed time required to steam 300 cc (10 ounces) of milk shall be measured. A normal dial-type frothing thermometer shall be immersed in the milk-filled steaming pitcher. Steaming shall continue until the temperature reaches 60 °C (140 °F).

5. Testing:

5.1 Introduction:

The test procedure measures brew water temperature at gradually increasing frequency, obtaining temperature data over a variety of duty cycles. By slowly decreasing the interval between measurement sets, the influence of duty cycle on various espresso machine designs may be studied. The measurements may be performed with or without steaming, depending on the purpose of the test. The long idling period of ten minutes prior to the first test run should minimize any effects of pre-test equipment setup.

5.2 Test Procedure:
Specification: The intent of the following procedure is to provide a standard procedure for measuring the brew water temperature in a single group. Therefore the test portafilter shall be used in the same group of a multi-group machine for all measurements within a test. Simultaneous testing of more than one group in multi-group machines is permissible by running multiple test portafilters in parallel. These steps shall be followed for each of the 14 test points in the test.

A) *Simulated Idle Period:* The machine shall remain idle with the test portafilter installed into the group for the prescribed period of time between measurements.

B) *Simulated Dosing and Tamping:* The portafilter shall be removed from the machine for approximately 15 seconds. The group shall be flushed with brew water for 2 seconds immediately prior to reinstalling the portafilter to simulate a temperature equalization flush.

C) *Temperature Measurement of Simulated Brewing:* Measurement shall commence upon reinstallation of the portafilter. The brew process shall be activated either manually or automatically, in the manner appropriate to the machine. Measurements shall be observed and recorded over the time interval required to collect the water volume specified in section 4.3.

D) *Data Recording:* During the simulation, the temperature shall be observed and recorded manually, or by computer and datalogger (preferred method).

E) *Simulated Disposal of the Coffee Cake:* Immediately after simulated brewing is complete, the portafilter shall be removed for approximately 10 seconds, during which the group shall be flushed for 2 seconds. The portafilter shall be reinstalled and the test shall proceed to the next idle interval (back to A).

Rationale for the elimination of intermittent use group flushing: Steps A through E specifically ignore the potential requirement for substantial group cooling or heating flushes under intermittent duty conditions. While the authors recognize that flushing rituals are often required as part of the best operational practice for specific machinery, part of the intent of these studies is to discover the need for cooling or heating flushes as part of an intermittent duty cycle regimen, and to discover the consequences, if any, for ignoring this need. Discovery of the best flushing methodology for a specific machine model is beyond the scope of this standard, but is easily determined using the same measurement equipment employed in this standard.

5.3 Testing pattern:
Specification: The length of the idle interval for item A of the Test Procedure shall be:

Test Point	Idle Interval
	(mm:ss)
1	10:00
2	5:00
3	2:00
4	2:00
5	1:00
6	1:00
7	0:30
8	0:30
9	0:10
10	0:10
11	0:10
12	0:10
13	0:10
14	0:10

5.4 Test Procedure Including Effects of Steaming Milk:
Specification: The test procedure may be performed with the inclusion of simulated steaming. If this is desired, then the steam valve shall be opened in Step C of the procedure, after initiating brewing. The steam tip shall be immersed in water and opened for the amount of time determined in Section 4.4.

6. Interpretation of the Results:

6.1 Identification:
Specification: The Manufacturer, model and serial numbers, number of groups, and the date of the test shall be recorded. Specific operating conditions shall be noted, e.g. single espresso, double espresso, one or more groups in operation, with or without steaming, etc. Other pertinent identifying remarks, such as boiler configuration (dual boiler, heat exchanger), or group type should be noted.

6.2 Brew Temperature of a Brew Cycle:
Specification: The brew temperature shall describe the thermal conditions of water immediately upstream of the simulated coffee cake using two terms, the average brew temperature observed during the brewing cycle, and the one-shot stability. Brew Temperature shall be expressed in degrees plus or minus the stability (for example - 201.5 ± 0.8). In the case of manual data collection, the average brew temperature shall be the temperature observed most often during a specific simulated brew cycle, ignoring temperature observations during the first three seconds of the cycle. Ignoring results during the first three seconds negates the effect of thermometer lag on the result. The one-shot stability shall be one half of the difference between the highest and lowest observed temperatures over the brewing period, negating temperature readings in the first three seconds. For automatic data collection, the average brew temperature may alternatively be the average of all temperature readings during the brew cycle except for those occurring in the first three seconds. The one-shot stability may alternatively be two times the standard deviation of the temperature observations, ignoring observations occurring in the first three seconds.

Technical rationale: Assuming normal distribution about an average temperature, a temperature observation will fall within 2 standard deviations of the average temperature 95% of the time. Standard deviation is defined as:

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2}{n-1}}$$

where y(i) is the value of a single temperature observation, y(overbar) is the average brew temperature, and n refers to the total number of observations. The standard deviation may be calculated as follows:

1) Square the difference between each observed temperature and the average temperature. For example, assume that the observed temperature is 202 degrees and that the average is 200 degrees. The difference is 2 degrees and 2 squared equals 4.

2) Add up all of the squared differences.

3) Divide the sum obtained in step 2 by 1 less than the total number of observations. For example, if 10 observations were made, divide the sum by 9.

4) Calculate the standard deviation by taking the square root of the quotient calculated in step 3. Multiply the standard deviation by 2 to obtain the single shot stability.

The standard deviation may also be easily calculated using functions in common spreadsheet programs. The STDEV function in Microsoft Excel is an example of such a function.

6.3 Brew Temperature Reproducibility:
Specification: The brew temperature reproducibility is the ability of an espresso machine to produce the same temperature water over a variety of use conditions. This information may be calculated from manually collected or computer collected data. The brew temperature reproducibility shall be twice the standard deviation of all average brew temperatures obtained in runs 5 through 14 of a test series. Average brew temperature is defined in 6.2.

6.4 Espresso Machine Temperature Stability:
Specification: The temperature stability of an espresso machine shall be the average of all of the one-shot stability values obtained in runs 5 through 14 of a test series. One-shot stability is defined in 6.2.

6.5 Qualitative Comments:
Specification: Qualitative comments, such as general temperature trends during a brew cycle or in comparison with other brew cycles in the test should be noted in the results.

6.6 Validity of the Results:
Calculations of averages and standard deviations are easily accomplished using a variety of computer spreadsheets. The average temperature value and the method of calculating temperature stability use commonly applied methods. However, the result of a single test series is not as valid as results supported by multiple tests. When possible, the test series should be repeated in order to gain confidence in the information that they provide.

References:

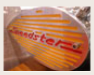
1. *Manual on the Use of Thermocouples in Temperature Measurement*, ASTM Special Publication 470A, Omega Press, Stamford, Connecticut 06907, 1983.

cinergi

#2: Nov 10, 2005, 7:37 pm

Why are just the 1st 3 readings thrown out? I have seen others throw out the 1st 8 - 10 readings like Schomer. This makes the most sense to me because looking at most profiles I see sharp temp increases during the 1st 8-10 seconds then it pretty much levels off. I would guess that this is due in part to thermometer lag, time to full pressurize and saturate the puck. Throwing out just the 1st 3 readings makes for mighty big stability readings.

Doug



malachi

#3: Nov 10, 2005, 7:39 pm

Different tools result in different methodologies.

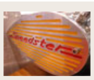
"Taste is the only morality." -- John Ruskin

cinergi

#4: Nov 10, 2005, 8:04 pm

As far as I know, aren't we all using more or less the exact same tools (Scace thermofilter with a Fluke)? And isn't that the whole point so that we can compare results?

Doug



malachi

#5: Nov 10, 2005, 8:28 pm

That's not what Schomer used - it's not what was used to create most if not all of the profiles you're talking about.
The Scace has been around for what... 3 months?

"Taste is the only morality." -- John Ruskin

cinergi

#6: Nov 10, 2005, 8:44 pm

The shape of a profile using the Scace device is very similar to the profiles you get when placing a t/c inside the cake. In other words, you see the same sharp increases in temp during the 1st 8 - 10 sec. resulting in one shot stability readings of +-3 degrees if you just throw out the 1st 3 sec. whereas, throwing out the 1st 8 - 10 sec. results in much lower stability readings of +-.5 degrees.

barry

#7: Nov 11, 2005, 12:14 am

i'm sure greg will elaborate, but in the instructions it clearly states: "Ignoring results during the first three seconds negates the effect of thermometer lag on the result."

the thermocouples he's using have a time constant of 1/2 second, so within three seconds it should be reading brew water temp with considerable confidence. what you are suggesting would chuck out the data you don't want to see just because you don't want to see it.

cinergi

#8: Nov 11, 2005, 12:22 am

I'm just trying to figure out how someone like Schomer and others can say their machines are stable to within .5F – 1F. It seems the only way anyone can make this claim is to ignore the 1st 10 readings. If you only ignore the 1st 3 readings, there is no way to get any lower than 5F – 6F variance within a shot (i.e. max temp – min temp ignoring 1st 3 readings).

Doug

barry

#9: Nov 11, 2005, 12:42 am

> **cinergi wrote:**
> If you only ignore the 1st 3 readings, there is no way to get any lower than 5F – 6F variance within a shot (i.e. max temp – min temp ignoring 1st 3 readings).

not if your machine is up to temp and works well. that's the whole point of the measurement system: to determine which machines perform and which don't. if your machine is running a 5F intrashot variance, and you desire a flat line brew temp, then you need to do something about that variance (and not just ignore the numbers you don't want to see).

cinergi

#10: Nov 11, 2005, 9:17 am

Can anyone give me just one example of any machine that has a intrashot variance (max temp minus lowest temp ignoring readings 1 – 3) of less than 5F (as tested according to WBC testing procedures)?

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