The Correlation between PID Temperature Setting and Water Brewing Temperature

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April 2011

Introduction
The water brewing temperature can become much more consistent in the Rancilio Silvia espresso machine with the PID temperature controller modification. A detailed comparison of a standard Silvia with a PID controlled Silvia can be found on the following web site.
http://www.home-barista.com/forums/rancilio-silvia-performance-with-without-pid-t4691.html#51201
The boiler temperature can be stabilized by a PID temperature controller in less than 10 minutes; however, the water brewing temperature takes more time to stabilize because of how the Silvia boiler and grouphead structures are designed. The PID temperature setting for the boiler should be set higher than the optimal water brewing temperature to compensate for the heat loss of the grouphead. Fig. 1 shows how the grouphead is connected to the boiler in the Rancilio Silvia espresso machine.

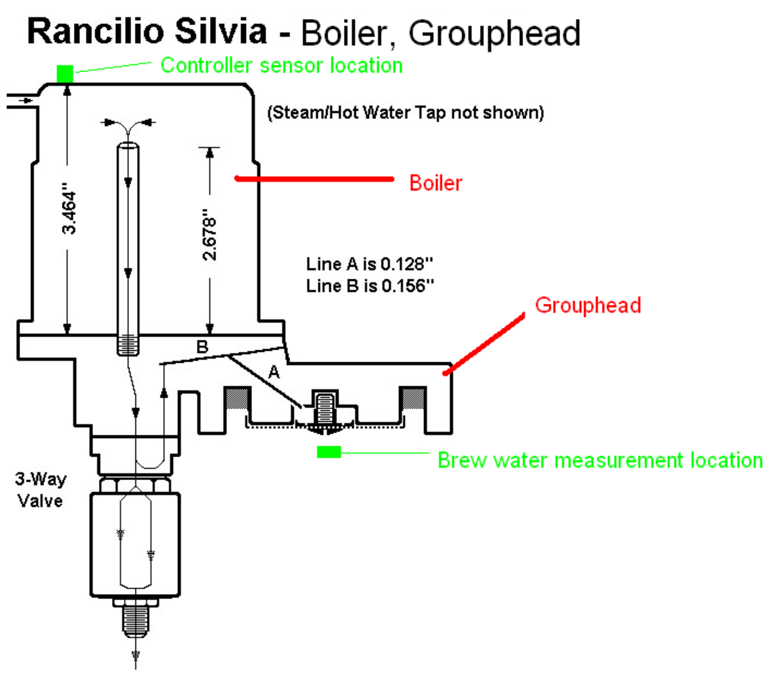


Figure 1.

Equipment and setup

Three Rancilio Silvia espresso machines were used for this study. Machine No. 1 is a 7 year old used machine. Machine No. 2 is brand new machine. It is an old style machine (made before September 2006). Machine No. 3 is a new machine with the new pod-adaptable grouphead.

Table 1 , Rancilio Silvia espresso machines used for this study.

name	Manufacturing date	Serial number
Machine No. 1	May 2000	60008720
Machine No. 2	May 2006	60062127
Machine No. 3	Jan. 2007	60071376

Three kits were used for this study. Here is a list of their configurations.

Table 2. Kits and Thermofilter calibration information.

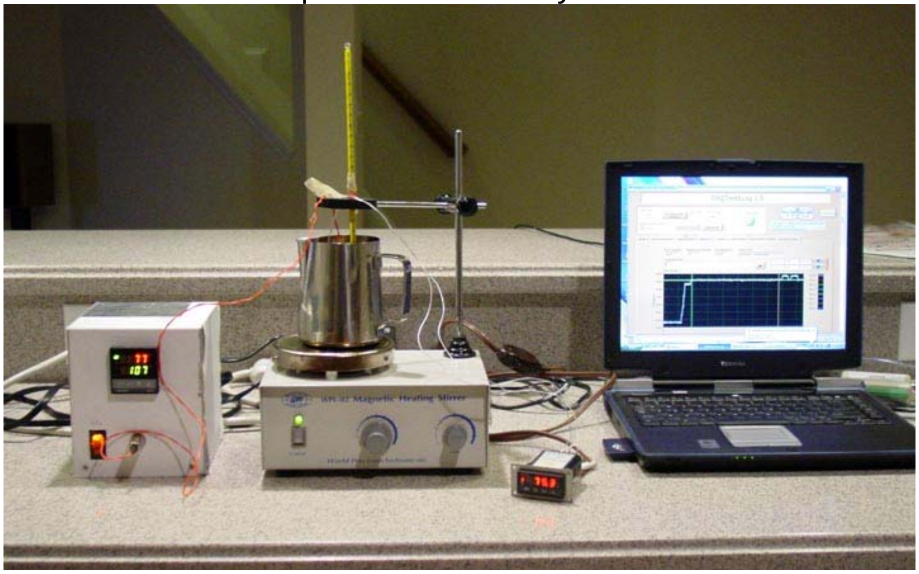
Kit	Sensor	Temperature resolution	Calibration range
No.1	Screw RTD	0.1°C	80-110°C
No. 2	Screw RTD	0.1°C	80-110°C
No. 3	Washer RTD	0.1°C	80-110°C
Thermofilter meter	T type thermocouple	1°C	70-95°C

Kits 1 and 2 were only tested on machines 1 and 2 because the sensor can't be mounted on the machine 3. Kit 3 was tested on all three machines.
Water brewing temperature measurement was done by the Scace Thermofilter. This device is currently used by World Barista Championship (WBC) and United States Barista Competition (USBC) technical standards teams for testing and evaluating the machines used in competitions. The details of the Scace Thermofilter can be found at http://www.home-barista.com/forums/scace-thermofilter-temperature-device-instructions-t515.html

The Thermofilter was connected to a digital thermometer that converts the T type thermocouple signal to a 0-5 VDC analog signal output (Auber instrument, SYL-1712). The thermometer was connected to a 16 bit data acquisition system. The sampling rate was 128 Hz. One limitation of this system is that the output of the thermometer has only 1 degree resolution.
All tests were performed in an air-conditioned rooms maintained at 25 °C (76-77 °F).

Calibration of the meter.
The temperature standard we used is a precision mercury filled glass thermometer. Temperature range is -20 to 150 °C with 1 degree division. This meter is not NIST traceable but was calibrated with the ice water mixture and boiling water technique described at http://www.biggreenegg.com/boilingPoint.htm#pressure. It was also verified by a NIST traceable thermometer at 37.0°C. The maximum error of this thermometer is <0.2 °C over the 0 to 110°C range.
Controller calibration

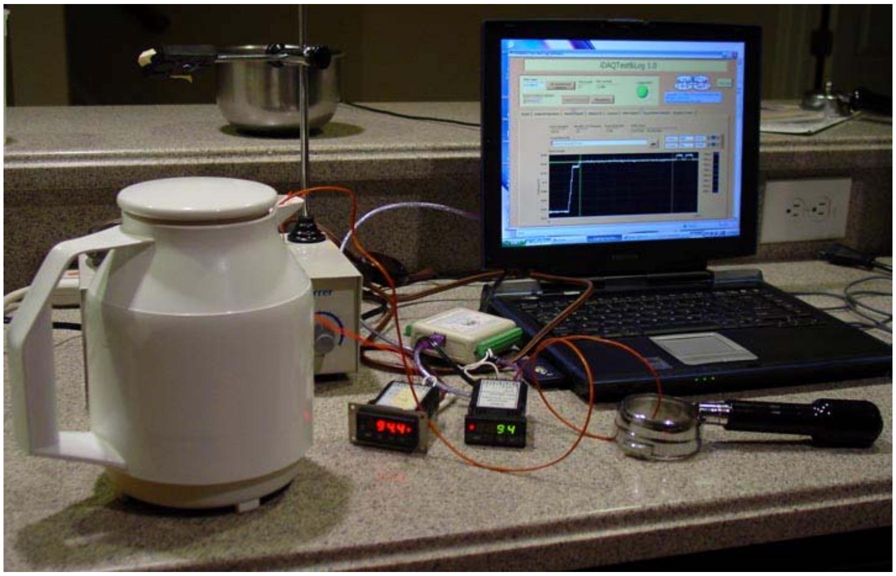
The set up for calibrating the controllers is shown in picture 1. A stainless steel pitcher filled with cooking oil was placed on a hot plate with magnetic stirrer. The hot plate was controlled by a PID temperature control system to make the temperature stable. The mercury thermometer was inserted to the oil bath at its immersion line. The temperature slowly changed from 80°C to 110°C at rate of <0.5°C/min. The controller reading was compared with the mercury thermometer, with the error adjusted by the meter's offset. After calibration, all of the controllers had < 0.2°C errors when compared with mercury thermometer.



Picture 1, Set up for calibrating controllers.

Thermofilter calibration

Since the themofilter was not used for over 100°C and the oil bath might damage the glue used on it, it was calibrated in a Dewar thermos as shown in Picture 2. The thermos was also used because it took a long time to equilibrate the temperature, due to the large thermo mass attached and limit heat circulation (this is not the case when measuring the brew water because the water moves very fast). Boiling water was poured into the Dewar that contained the thermofilter and a calibrated RTD sensor. After 20 minutes of equilibration (cap sealed), the reading was compared with the calibrated thermometer. After calibration, the error of the thermofilter was <0.3°C.



Picture 2. Thermos used for calibrating Themofilter

The entire experiment took 12 days to finish. After the experiment, we re-calibrated all the controllers and the Thermofilter to make sure no instruments drifted over this period of time.

Flow rate of the thermofilter

While the pump for Machine No. 2 was running, we collected water from Thermofilter for 120 seconds. We collected the water in the middle of pumping to eliminate the error due to the dead volume in the Thermofilter. We collected 308 ml water (measured by weight with a 0.1g resolution lab grade scale). That averages to a flow rate of 2.56ml/s. When we ran the pump for 25 seconds only, the shot volume is in the 63 to 68 ml range for all three machines. No adjustment for OPV was made.

Results and discussions

Time required for brew temperature to stabilize.

The following figures plot the water brewing temperature (Tb) change with time measured by the Scace Thermofilter. The time started when the machine was powered up. Each data point represents a 25 second double shot, unless indicated otherwise. All temperature readings were picked at the peak value unless the peak duration was less than 2 seconds. In all tests, the controller reached the set temperature in less than 6 minutes after it was started from room temperature.

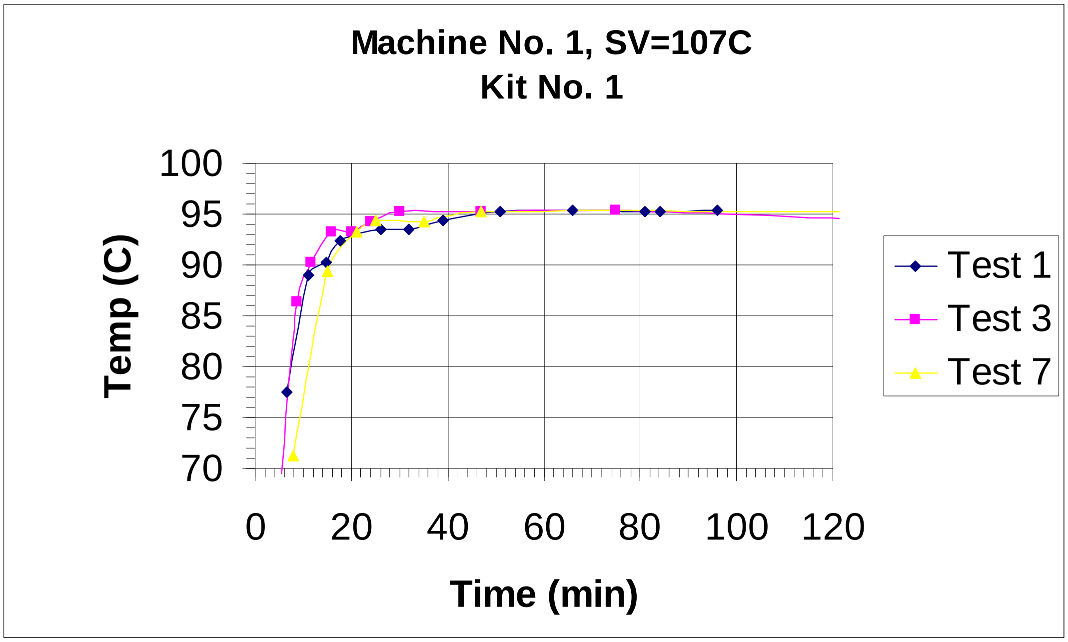


Figure 2

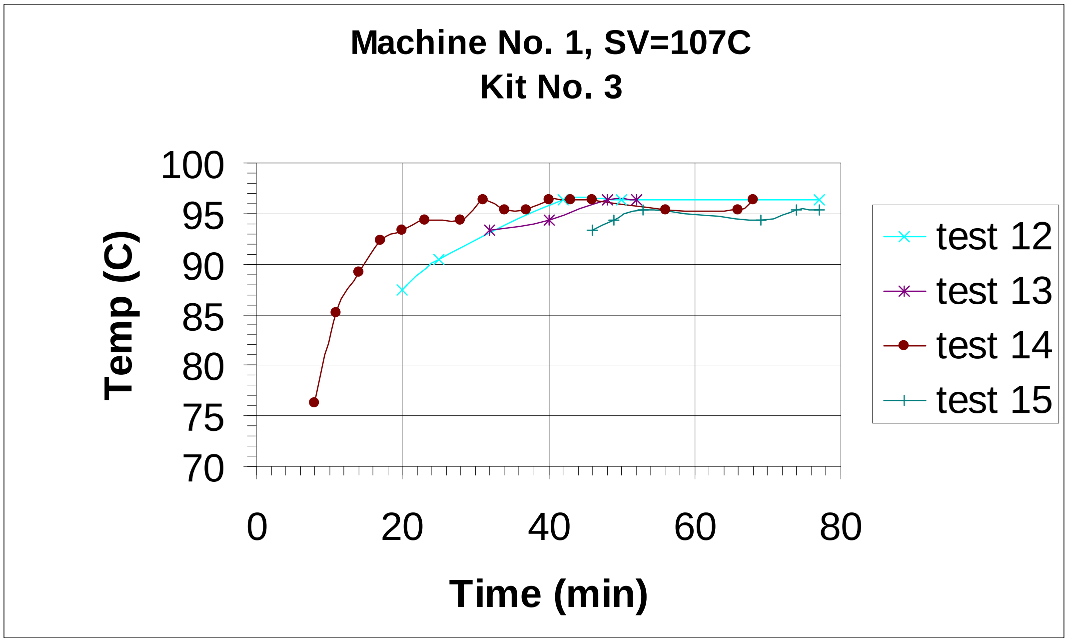


Figure 3

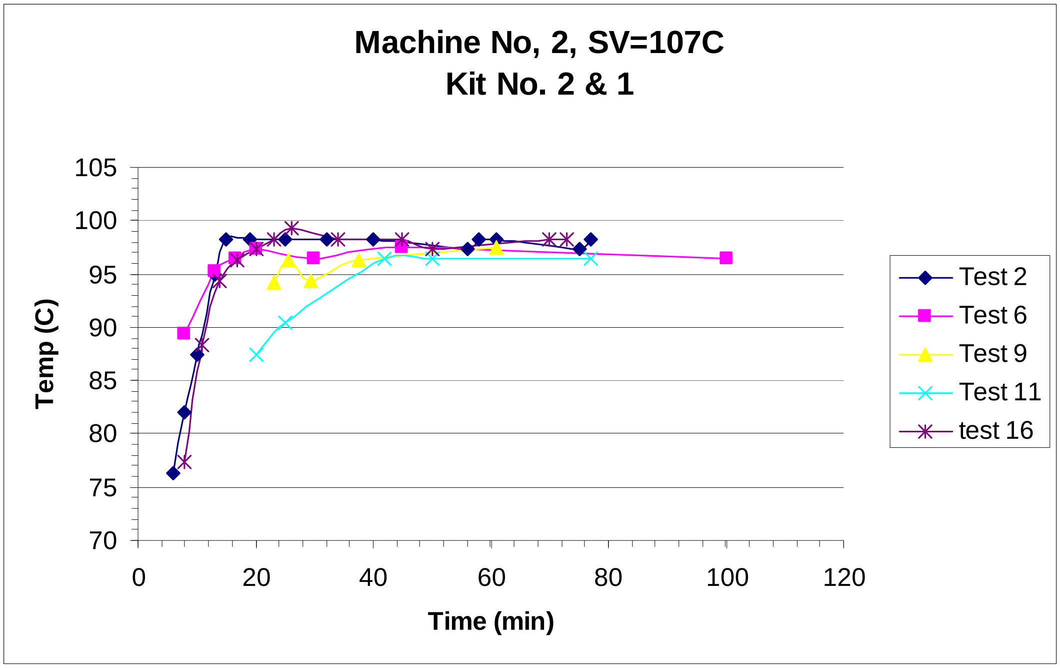


Figure 4. Test 11 and 16 was controlled by Kit No.1. The rest were controlled by Kit No. 2.

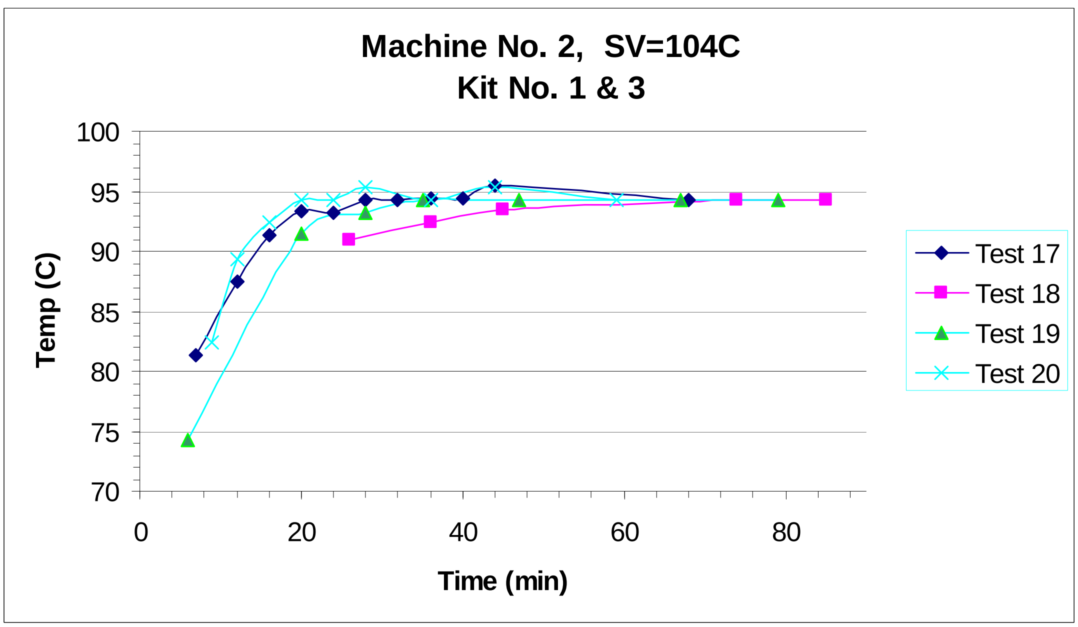


Figure 5. Test 20 was controlled by Kit No. 3. The rest were controlled by Kit No. 1. For test 19, the first point is a 150 ml (5 oz) pump (60 seconds).

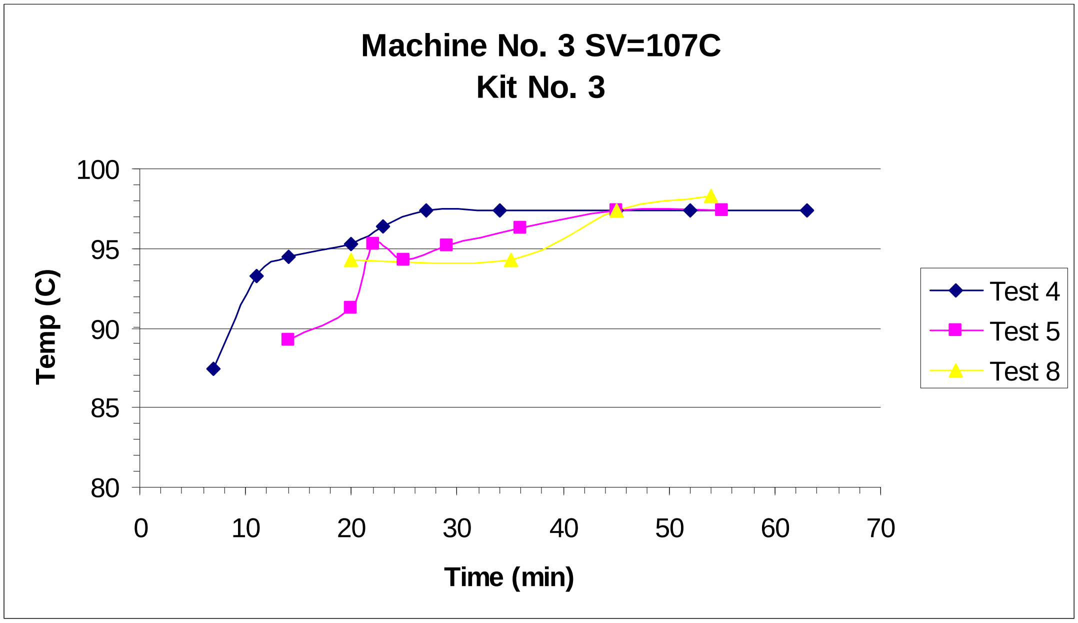


Figure 6.

From these figures we can see that

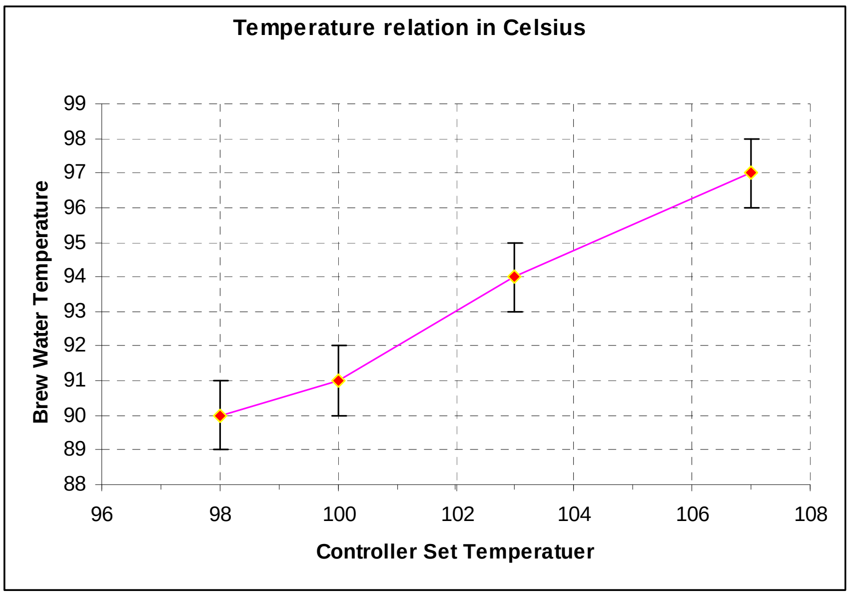
1) When the machine started from cold, the Tb can be 20 °C lower than when it is warmed up, even if the boiler temperature is stabilized. Therefore, it is important to let the machines warm up before brewing starts.
2) When the Tb was stabilized, it was about 8 to 10 °C lower than the controller set temperature (SV). Fig 2, 3, 4 and 6 indicated that for the same SV setting, Tb of Machine No 1 was about 1-2 degree lower than that of Machine No. 2 and No. 3. The differences were independent of the kit used.
3) After the machine was powered up for 45 minutes, the Tb stabilized to +/- 1 degree C in almost all tests.
4) Test 15 in Figure 3 indicated that even after machine was powered up for 45 minutes, the first pull was still two degrees below the stabilized Tb. This indicates that a few blank pulls to flush the cold water in the grouphead are important.
5) From Figure 1-4 we can see that if we pull a blank every 3-4 minutes, the Tb can be stabilized in 20 to 25 minutes.
6) Test 19 in Figure 5 took the least pumping effort to stabilize the Tb in a relatively short time. In this test, 150 ml (5 fl oz) of water was pumped at 6 minutes after power up. Then, another 60 ml (2 fl oz) flush at 20 minutes. The Tb stabilized at 28 minutes.
7) The shot at 28 and 30 minutes in Test 14 of Figure 3 indicates that when two pulls were placed at 2-3 minutes interval, the Tb can be 1°C higher for the second pull even if the temperature on controller does not show an overshot. That is because the heater is working hard between the shots; sometime it can make the water over heat a little bit. In contrast, the shots

at 46 and 56 minutes are about one degree lower than the shot at 36 minutes. That indicates the water temperature will drop a little bit if no shot is pulled for 10 minutes.

8) Tests 2, 6 and 16 in Figure 4 rose much faster than the rest of the tests. We believe the reason might be due to very high SV of the controller and slightly higher room temperature during the test. The Tb at the beginning of the test is near the boiling temperature of water. When we reduced the SV to 104°C (figure 5) the rising phase slowed down.

The relationship between Tb and SV

Following figure shows the relationship between Tb and SV. This is the average of three machines. All data was taken 45 minutes after the SV is changed and after several shots to let system stabilize.



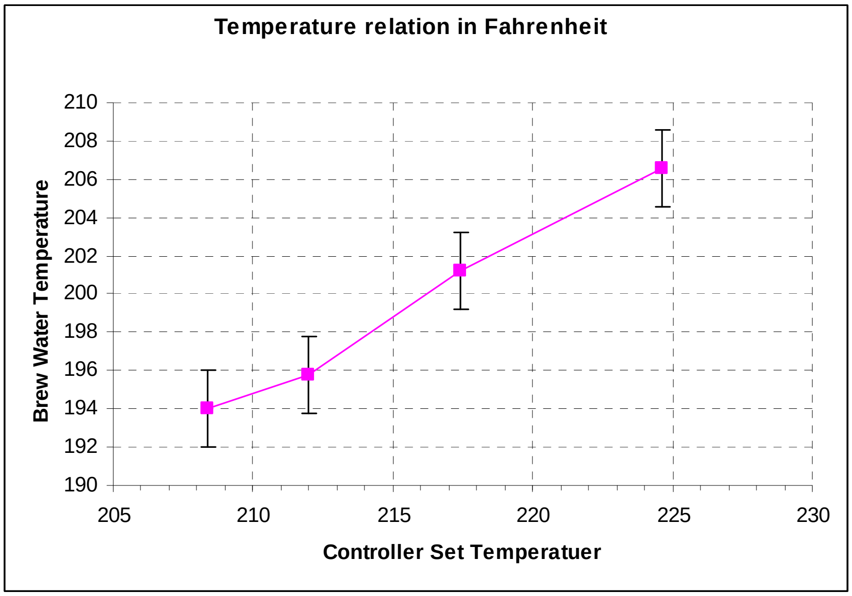


Figure 8. Correlation between the PID temperature controller set temperature and the water brewing temperature detected at the grouphead by Scace Themofilter. Top, display in degrees Celsius. Bottom, Display in degrees Fahrenheit.

In this test, the older machine (No. 1) was consistently in the lower range of the error bar, while as the new machines are consistently in the higher range of the error bar. It is not clear if this indicating the newer machine has better heat transfer to the grouphead than the old machines. More machine tests are needed.

The performance of the Scace Thermofilter.

The recorded temperature waveforms, during the shot, have a rising phase that lasted 2-5 seconds on average. Many factors can affect the waveform of the rising phase including the temperature of the thermofilter before the shot, the dryness of the thermofilter, the response time of the sensor, and the response time of meter. Since the average temperature calculation will include the rising phase of the shot, using average temperatures instead of peak temperatures will make this study more sensitive to the thermofilter condition and how it is used. Fig. 9 shows the difference between a shot made with the Thermofilter containing the warm water from the last shot and a shot made with a dry Thermofilter. This is the main reason that we choose to use peak temperature values instead of the average temperature values for all the plots. We believe the peak value has a closer relation to the water brewing temperature and is less subjective to the method used than the average value. When the Thermofilter is dry, the waveform has a very flat plateau even if the grouphead is still cold. The temperature change during the 25 second period is less than 2°C normally. It should be noted that because the peak value is used, the data we obtained will be higher than some other studies that used the average value.

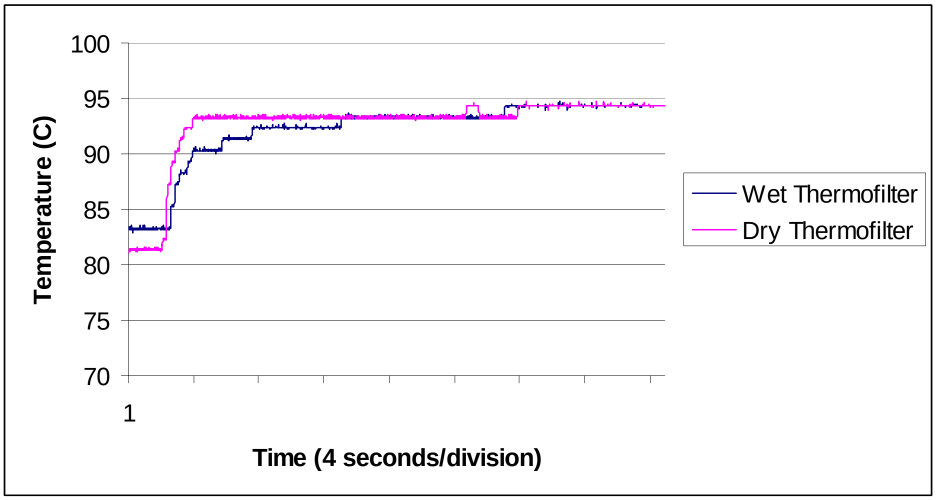


Figure 9. Waveform difference between a dry Thermofilter and a wet Themofilter that contains the water from previous shot. These are the two last data point of "Test 18" in the Fig 5. We would get different values for Fig 5 if we used average temperature instead of the peak temperature.

The waveform of the shot is almost independent of the temperature of the thermofilter before the shot is pulled. We compared a waveform between a 31°C Thermofilter and 80°C Thermofilter, the peak temperature difference is less than 1°C. However, the temperature oscillated sometimes when the Thermofilter is cold (data not shown). It is not clear what caused that.

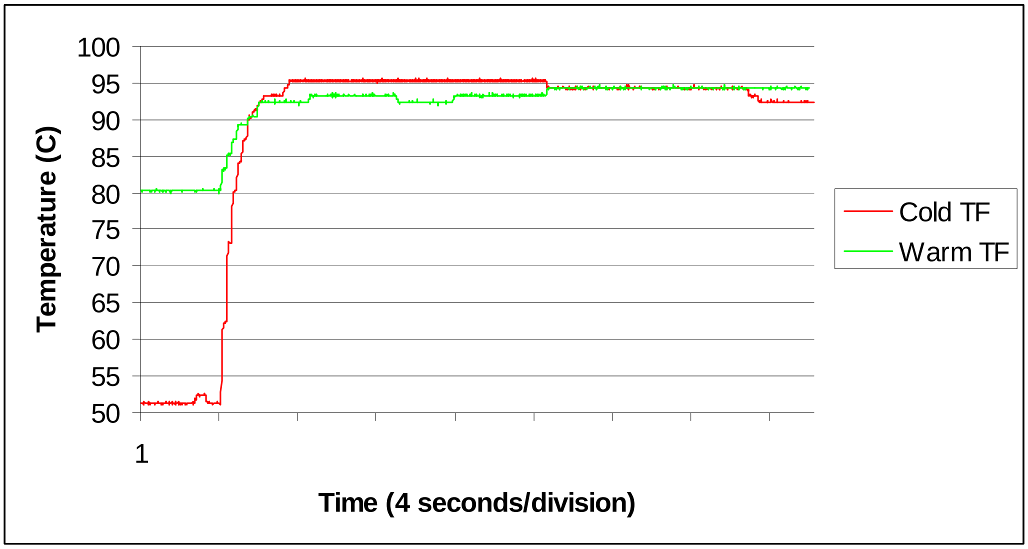


Figure 10. Waveform difference between a cold & dry Thermofilter and a warm & wet Themofilter. The cold Thermofilter was soaked in tap water before being mounted to the grouphead. It was equilibrated to 31°C before mounting to the grouphead. However, the heat at the grouphead quickly warmed the sensor tip in the Thermofilter to 51°C before the shot was pulled (as shown in the figure). As we can see the average temperature will be very different than the peak temperature.

An interesting observation is that when the grouphead is cold, a 60 second shot will show two temperature peaks. The first peak appeared immediately after the pump is started. Then the temperature quickly drops down. It starts to rise again around 30 seconds after the pump started. It is not clear where the cold portion of water came from. This indicates that when the grouphead is cold, a little longer pumping will help to speed up the heating.

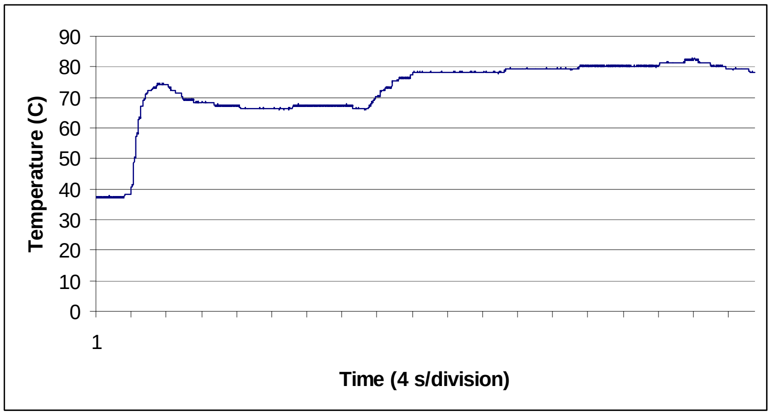


Fig 11, Temperature waveform when the grouphead is cold (6 to 8 minutes after machine is powered up).

Conclusion

There is an 8 to 10 °C (15 to 18 °F) difference between the controller set temperature and water brewing temperature when machine is stabilized. The difference increases as the controller set temperature increases. The difference might vary about 2°C (or 4°F) between different machines. It will take at least 20 minutes, but could be as long as 45 minutes, for the water brewing temperature to be stabilized after the machine is powered up. Flushing the machine shortens the warming up time. When the machine is warmed up, the Rancilio Silvia espresso machine produces a very stable water brewing temperature for a double shot espresso (60 ml water).

Acknowledgement

The author would like to thank Eric Svendson for many helpful suggestions on this study.