



HOSPITALITY INSTITUTE OF TECHNOLOGY AND MANAGEMENT

670 Transfer Road, Suite 21A • Saint Paul, Minnesota 55114 • USA • TEL: (651) 646-7077 • FAX: (651) 646-5984

e-mail: osnyder@hi-tm.com • web site: <http://www.hi-tm.com>

CHOOSING THE RIGHT THERMOMETER TO VERIFY FOOD TEMPERATURE

by O. Peter Snyder, Jr., Ph.D.

Hospitality Institute of Technology and Management

Introduction

One of the most technically demanding but least understood critical items in food safety is the measurement and control of food temperatures. Food is really not cooked and cooled correctly for pleasure, because pleasure is a learned value that starts when we are born and depends on our culture. The main purpose of cooking to a certain temperature and cooling correctly has always been to make food safe to eat. Animal and human fecal pathogen contamination of food has been a problem from the beginning of time. Cooking makes the food safe.

The FDA Food Code (2001) temperatures for cold holding, pasteurization, and hot holding are obsolete and, in most cases, not based on science, but are chosen for regulatory "command and control" by the FDA. The USDA's HACCP rules are the ones that must be used for updated control information. The USDA performs scientific studies to determine the kill of *Salmonella* in meat, poultry, and eggs. Today, the USDA wants a *Salmonella* decimal reduction in beef of 6.5D and in poultry, 7D. The USDA guidelines (2001) allow poultry with 12% fat to be pasteurized over the complete temperature range of 136°F (82 minutes) to 165°F (less than 10 seconds). Actually, most of the time, food must be cooked to a higher level of doneness than this for customer satisfaction. A hamburger cooked to 155°F for 22 seconds (6.5D) is too pink, and chicken cooked to 155°F for 1.3 minutes (7D) is too red, to be accepted by the consumer as safe. While color should never be a basis for safety, it remains the primary one for consumers, who are the final checkpoint for the safety of the food that they eat. The advantage of meeting the USDA temperature requirements is that it is possible to get very high yields of meat and poultry without drying out the food. An example is a central commissary fully cooking an item such as a chicken breast at 140°F for 35 minutes, because it will later be reheated in one of its retail food operations to 165°F for service. Low-temperature pasteurization at the commissary gives a much more pleasing, juicy consumer item.

Cooling is another procedure where considerable savings can occur if the slower, safe cooling rates are used. 9CFR 318.17(a)(2) says that any cooling process can be used so long as there will be no multiplication of toxigenic microorganisms such as *Clostridium botulinum* and no more than 1 log increase of *Clostridium perfringens* within the product during cooling. While regulators will pressure operators to cool as fast as possible, cooling from 130 to 45°F in 15 hours or to 40°F in 22.3 hours is absolutely safe (Juneja et al., 1994).

Measuring temperatures

The key to food processes producing better quality food more consistently, then, is accurate temperature measurement of the slowest heating spot in cooking or the slowest cooling spot in cooling. This is typically the center temperature of a food being cooked or cooled. What is the

size of this spot? The general FDA / USDA assumption is that there are about 1,000 *Salmonella* per gram in the middle of meat or poultry, and this number of *Salmonella* must be reduced to 1 per 100 grams (or milliliters) in the middle of the product. When the uncertainly factors are incorporated, the FDA requires a 5-log reduction in ground meat and fish, and a 6-log reduction in roast meat. The USDA requires a 6.5-log reduction in meat and a 7-log reduction in chicken. The goal of the temperature-measuring device (thermometer), then, is to measure the center temperature in a volume of 1 ml in the food to determine if the coldest point in the food has been subjected to a food time at a cook temperature to achieve the required reduction. To meet these requirements, the temperature-measuring device must have a small tip and be tip sensitive to find and measure this spot.

One thermometer that historically has been used for food temperature measurement is the bimetallic coil thermometer. Actually, it should never be used, because it is incapable of measuring thin foods such as hamburgers or 1-ml volumes in larger food items such as casseroles. It is not capable of finding the coldest spot. Figure 1 is a cutaway of this thermometer.

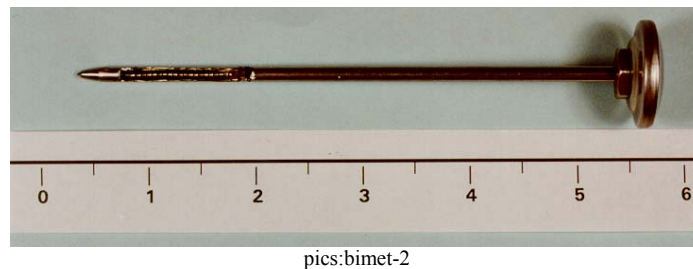


Figure 1. Cutaway of bimetallic coil thermometer

The thermometer is constructed with a coil from the tip up about 2 to 3 inches, depending on the manufacturer. The entire coil must be in the food to measure temperature. The coil expands or contracts to temperature and gives an average reading across the length of the coil. If the tip area is at 200°F, and the top of the coil is at 100°F, as in a pan of food on a steam table, the coil responds as if the temperature is the average, 150°F, and through a wire attached to the dial pointer, shows 150°F.

Why should this thermometer never be used? Every time the unit is used, the coil may be jarred and moved; so, one does not know if it is still calibrated when it is used. Secondly, and more significantly, the sensing device is so long, it is impossible to find the cold 1-ml spot in food pasteurization or, in cooling, to find the center 1-ml temperature in a container of food to determine if the 1-ml volume is meeting time-temperature safety standards for control of pathogens.

The most contaminated food, microbiologically, is usually the food with small geometries, to include a 1/4-inch-thick hamburger, a meatball 1 inch in diameter, a piece of fish 1/2 inch thick, and shrimp 1/2 inch thick at the middle. For these highly contaminated foods, it is essential that bimetallic coil thermometer not be used to determine if the center of food is adequately pasteurized. A tip-sensitive thermometer must be used.

Electronic thermometers such as thermistors and thermocouples, discussed later in this paper, are tip sensitive and do not use the mechanical coil technique of the bimetallic thermometer. Hence, they are able to find the 1-ml cold / hot spot volume temperatures in food.

The measurement of temperature during the cooking / cooling process

Historically, the thermometer, usually the bimetallic coil thermometer, has been used to measure the temperature of food after the food is removed from the cooking device, not during the cooking process, unless it was a turkey or beef roasting for a long time in an oven. However, in food operations, we want to know the temperature of the food as it cooks in order to anticipate when a time-temperature pasteurization value has been reached, and the cooking pasteurization process can be stopped. Overcooking food is costly and ruins quality. Therefore, it is necessary to have a thermometer that will do this, thus signaling when food should be removed from the cooking device. The smaller the tip of the electronic thermometer, the faster the response. The cooking process can then actually be graphed as a food cooks, and end times for a temperature can be predicted very accurately.

When food is cooled, if food temperature measurements are taken during the cooling process, it is possible to predict how long it will take for the cooling to be accomplished, because cooling follows strict mathematical rules. It is not necessary to spend 20 hours to determine the time when the center temperature of food will be cooled to a specified end temperature. It can be calculated by using a couple of cooling values from a specific cooling study.

There are thermometers on the market that use a liquid crystal that changes from a clear to a black color when the liquid crystalline device reaches a specific temperature. If we want to know simply that frozen food did not thaw or that food in a refrigerator stayed below 50°F, and if a 2°F accuracy is adequate, these are useful devices. At the end point, the crystalline material melts and changes from clear to black, and one knows that the temperature has been exceeded. There are thermometers available where the crystalline material is on the tip of a little piece of paper, and the object is to stick this temperature stick into the food. (See Figure 2.)



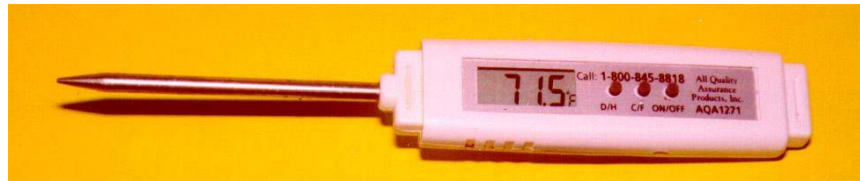
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Figure 2. T-Stick

If it turns black, it means that the temperature is above a critical point. However, this is not appropriate for measuring pasteurization temperatures, because it is impossible to know by how much the food might be overcooked, and below temperature, it does not say what the temperature is and how much more cooking is necessary. They cannot measure cold spots.

Stem diameter and heat travel up or down the stem

Let's now discuss some characteristics of the various electronic thermometers. One of the first problems to be controlled is heat travel up or down the stem of the thermometer. A typical thermistor thermometer has a 1/8-inch stainless steel stem approximately 5 inches long. (See Figure 3.) The temperature-sensing resistor is in the tip of the stem.



pics for broch:th-ster

Figure 3. Thermistor thermometer

The rule for control of heat is that the tip be inserted more than 5 times the diameter of the stem. In the case of a 1/8-inch stem, this means, the tip needs to be inserted 5/8 inch into the food. For some foods such as children's hamburgers that are less than 1/4 inch thick, this is difficult. There are other electronic thermocouple thermometer tips that are only 0.040 inch in diameter; so, the tip needs to be inserted only 0.2 inch. Figure 4 is an example of a thermocouple with a thin-tipped probe on the left and a 32-gauge wire air temperature probe on the right.



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Figure 4. Thermocouple with thin-tipped, 0.040 probe

There are also thin-tipped probes that can be purchased from thermocouple manufacturing companies that are as narrow as 0.01 inch, which is about the diameter of a human hair. These probes can easily measure the temperature of a pea on top of a pan of peas on a steam table or a slice of beef on the top of slices of beef. For food holding temperature measurement, it is necessary to have very thin-tipped measuring devices in order to measure surface temperatures. Surface temperatures are affected by surface water evaporation of hot food, as in a steam table. The thin thermocouple wires will allow for accurate measurement of surface temperatures.

Uncovered hot food on a steam table with a center temperature of 140°F will have a top surface temperature of about 115°F in a cafeteria-style room at 70°F and air relative humidity of 60%. This is due to evaporative cooling from the surface of the food.

Calibration

All thermometers, especially the bimetallic coil thermometer, need to be checked for accuracy on a periodic basis. The basis for this is different for every thermometer, because it depends on to what degree they vary from calibration to calibration. For example, if the thermometer is being

checked every three months, and it has drifted more than 2°F from a specified check temperature, and the desired accuracy is to be more accurate than $\pm 2^\circ\text{F}$, the calibration frequency needs to be increased to, say, one month. This way, the thermometer will be recalibrated before it exceeds its accuracy requirements. On the other hand, if at three months and then, at six months, the calibration is within the stated accuracy of less than $\pm 2^\circ\text{F}$ variation from the set point, calibration can be extended to once every six months or longer. This is a common calibration time for most electronic thermometers.

When beginning a calibration procedure, it is important to realize that what is of the most interest is to what degree the thermometer varies from the set point when it is checked in the standard temperature device. If the desired accuracy is better than $\pm 2^\circ\text{F}$, and the thermometer is off by 3°F, this indicates that all temperature measurements since the last calibration were incorrect, and all of the food manufactured, for example, in a USDA processing facility and checked by this thermometer since the last calibration period, technically, has to be recalled.

So, in establishing a critical limit for a process, one must consider the thermometer being used. If the thermometer being used has an accuracy of 1°F, and the critical limit is 155°F, if the operator assures that the food reaches 156°F, it can be assured that the food has reached 155°F pasteurization exposure. If the thermometer is only accurate to $\pm 5^\circ\text{F}$, then, food must be cooked to 160°F to compensate for the possible inaccuracies of the thermometer.

How to calibrate a thermometer

The first question when calibrating a thermometer is, "What will be used as a calibration standard?" The simplest answer is slush ice. It makes no practical difference, according to the National Institutes of Standards and Technology, whether distilled or plain tap water is used to make the ice and the water for food thermometer calibration. Nothing should be added to the water. For instance, adding salt would depress the freezing point, change the melting temperature of ice, and invalidate calibration. The ice must be crushed in a machine (e.g., food blender) added to a container of reasonable volume such as a cup holding 1 pint of liquid, then, enough water added to just come to the underneath the top of the ice. Then, a thermometer to be calibrated is immersed into the ice far enough to assure that the sensing device is in the middle of the slush ice. It is allowed to sit for 30 seconds or longer, until the thermometer comes to equilibrium. The thermometer calibration can then be checked or adjusted. The ice point, 32°F, is easy to achieve, is reasonably reproducible, and is accurate to within a few hundredths of a degree of 32°F.

Because mechanical thermometers are not truly linear in their response to temperature change, they need to be calibrated, at least, at a second point. Depending on the span of the thermometer and accuracy desired, this could be three to five points. Electronic thermometers have stored calibration curves; so, if they are accurate $\pm 2^\circ\text{F}$ at 32°F, they will be accurate at 150°F.

The second question, then, is, "What other temperature standards can be used?" What about using the boiling point of water to calibrate thermometers? The problem with the boiling point of water is that water boils at different temperatures, depending on altitude and barometric pressure. At sea level, the boiling point is 212°F, but at 1,000 feet, water points at 210.2°F. In Denver, at approximately 5,000 feet, it boils at 203.0°F. If there is a storm coming, and the barometer temperature goes down about an inch of mercury, the boiling point is 210°F. At 5,000 feet, it goes down, and the boiling point is 201°F. This is an 11°F error. If the condition is 1

inch of mercury over temperature, the boiling point goes up about 1.5°F. This means that, at 5,000, boiling point would not be 203°F, but would be 204.4°F. Since thermometers have their own inherent inaccuracies of $\pm 2^\circ\text{F}$, compounding this with an inaccurate temperature standard, such as using boiling water and assuming it to be 212°F, means that the thermometer is not calibrated correctly. Therefore, boiling water alone is an unreliable temperature measuring point.

How can one make boiling point accurate? Figure 5 shows a quality glass thermometer containing a safe liquid (not mercury) for indication that will read to 0.2°F. The glass thermometer costs about \$100.



pics:fdSafpaper:glass-therm

Figure 5. Glass thermometer for calibration in boiling water

One can put the thermometer in a canister with water on the stove, bring the water to a gentle simmer, read the water temperature, on the accurate glass thermometer, and then, calibrate the food thermometers in the hot water bath.

In this way, the boiling point of water can be used as a calibration point, because one would not have to take into consideration altitude or barometric pressure. The thermometer simply corrects for all variables.

There are some problems with glass thermometers, however. First of all, they break. Secondly, they are difficult to read, because the lines are very close, and a magnifying lens is normally used.

Figure 6 shows a simple water bath using an Omega HH1 high-accuracy thermistor thermometer (Figure 7). This unit used in conjunction with the water bath allows one to measure the temperature of the water bath to a few hundredths of a degree F.



Dennys:therm-test-pics 07

Figure 6. Water bath



pics:FdSafePaper:omegaHH1










Figure 7. Omega HH1 thermistor thermometer

Standard laboratory water baths, which cost \$800 to \$1,000, are very stable in temperature and provide a very easy check for thermometer calibration, especially in a food manufacturing plant. Because the HH1 is portable, it can be taken to refrigerated rooms and other areas of the plant, and temperatures of operating equipment and operating rooms can be measured with high accuracy.

Putting it all together

Recently, I was asked by a company to evaluate a number of pocket thermistor thermometers to find out the differences in calibration and speed of response. Table 1 shows the results of the thermometers and the results of this study. Calibration of the thermometers were checked at three points: 1) ice point, 32°F; 2) room temperature, 70°F; and 3) 163°F, in the circulating water bath with the HH1 thermometer as a standard. Most thermometers performed within their expected specification of $\pm 2^\circ\text{F}$.

Table 1. Comparison of pocket digital thermistor thermometers

Item	Accuracy, °F: Δ temperature difference			Time from 70 to 160°F
	32°F	Rm. temp., 70°F	163°F	
 Taylor 9840	Δ -2.0	Δ -0.6	Δ +0.1	16 seconds
 Taylor 9841	Δ -0.7	Δ -0.1	Δ +0.7	11 seconds
 Taylor 9847	Δ +0.3	Δ +0.1	Δ +0.1	10 seconds
 Cooper DPS300	Δ +1.0	Δ +1.2	Δ -3.4	21 seconds
 Cooper DT300	Δ -1.3	Δ -0.1	Δ +1.0	15 seconds
 Cooper DPP400W	Δ -0.2	Δ -0.1	Δ +0.5	10 seconds
 Cooper DFP450W	Δ +0.5	Δ +0.6	Δ +0.7	5 seconds
 Comark 550B	Δ +0.1	Δ +0.5	Δ +0.6	6 seconds
 Chauncey Group International Focus 50001	Δ +0.7	Δ -0.1	Δ -1.5	7 seconds

Another very important parameter is the time it takes for thermometers to come to temperature. I tested this, as shown in Figure 6, by using a simple electronic timer and timing from 70 to 160°F

in the 163°F bath. This would be the maximum rate of change, because, in food, there would not be the same response. The data show that most of the digital pocket thermometers took 10 to 15 seconds to come within 3°F of the absolute temperature. A couple of them came within 3°F of the set point within 5 to 7 seconds.

Summary

There are many thermometers on the market, and they all perform a bit differently, even though they may be similar in appearance. One must know what one wants to do with the thermometer and then, test the thermometer in order to assure that the thermometer is sufficiently accurate and durable and will respond fast enough to the temperature of the food when used in temperature measurement. Manufacturer information is too general.

Some pocket digital thermometers priced from \$11 to \$15 are remarkably accurate, if one chooses the correct one. If they are handled with reasonable care, they can last many years. The batteries on most will last a couple of years before they need to be changed. The thermocouple thermometer has the advantage of a small tip and fast temperature response.

The bimetallic coil thermometer is not a reliable thermometer to measure temperatures of thin foods. If a child gets sick because of an undercooked hamburger, and a bimetallic coil thermometer was used to measure the temperature, it does not provide a defense of due diligence.

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