Test Procedure for

THERMOMETER CALIBRATION USING CONTROLLED TEMPERATURE BATHS

Texas Department of Transportation

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1. SCOPE

1.1 Calibrate thermometers by comparison with standard thermometers while immersed in stirred water or oil baths. Alternately, calibrate specific points by placing in a reference temperature bath such as a mixture of crushed ice and water. Make comparisons at various temperatures and record the errors. Then use correction factors when reading the thermometer.

Note 1—Few thermometers are absolutely accurate. The value of errors may vary over the range of the thermometer.

Note 2—This procedure may use hot liquids and equipment that will cause burns if improperly handled. Hot oils also emit harmful vapors, so only use with proper ventilation. Most liquid-in-glass thermometers contain mercury. Mercury fumes may be hazardous if the thermometer is broken. This procedure does not address the safety problems of working with these materials. It is the responsibility of all persons performing these tests to use appropriate procedures and safety equipment.

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. DEFINITIONS

2.1 *Bulb*—A bulb is the reservoir of fluid at the lower end of a liquid-in-glass thermometer.

2.2 *Calibration*—Calibration is the determination of errors or differences from the true value.

2.3 *Electronic Thermometer*—An electronic thermometer is an electrical device that measures the change in some property of a sensor to determine the temperature. Three common sensors are Resistance Temperature Detector (RTD), Thermistor, and Thermocouple.

2.3.1 *Resistance Temperature Detector (RTD)*—A resistance temperature detector is the electrical resistance of a metallic sensor varies with its temperature. The sensor is usually nickel or platinum. This resistance change is predictable and is stable with time and use.

2.3.2 *Thermistor*—Thermistor is the electrical resistance of the sensor varies with its temperature. The sensor is usually a composite material containing metallic oxides. The resistance change is not generally as stable with time as the RTD sensors.

2.3.3 *Thermocouple*—Thermocouple is made by twisting or welding two wires of different metals together. When used correctly, a voltage is generated that varies with the temperature. The voltage change is not linear with temperature but is predictable and stable. There are many different "standard" types of thermocouples.

2.4 *Ice Point*—Ice point is the temperature where the solid and liquid phases of water can co-exist.

2.5 *Liquid-in-Glass Thermometer*—Liquid-in-glass thermometer is a thermometer that indicates temperature by how far a liquid contained in a glass bulb has expanded and traveled into a connecting capillary tube. Mercury or colored alcohols are usually used. The capillary tube above the liquid column usually contains a gas such as dry nitrogen. There are three common designs: Complete Immersion, Partial Immersion, and Total Immersion thermometers.

2.5.1 *Complete Immersion Thermometer*—A Complete Immersion thermometer is designed to read correctly when the entire thermometer is exposed to the same temperature. Thermometers inside ovens are being used as complete immersion thermometers.

2.5.2 *Partial Immersion Thermometer*—Partial Immersion thermometers are designed to indicate correctly when immersed to a specified depth. These are marked with a line to show the immersion depth. They may have errors dependent upon the cooling of the glass stem above this mark.

2.5.3 *Total Immersion Thermometer*—Total Immersion thermometers indicate correctly when immersed so that only 6 to 12 mm (0.24 to 0.48 in.) of the liquid column is not immersed.

2.6 *Standard Thermometer*—A standard thermometer is a thermometer whose errors are known. The calibration must be documented and traceable to National Institute of Standards and Technology standards.

2.7 *Stem*—A stem is the part of a liquid-in-glass thermometer containing the capillary tube, various expansion chambers, and markings.

2.8 *Verification*—Verification is to confirm, by either testing or comparison with a recognized standard, that specific requirements are being met.

3. REFERENCES

3.1 ASTM E 77.

3.2 ASTM E 563.

3.3 ASTM E 1.

4. APPARATUS

4.1 *Magnifying lens*, of at least two-power.

4.2 *Standard thermometers.*

5. CHOOSING CALIBRATION POINTS

5.1 Calibrate ASTM specification thermometers at the temperatures given in ASTM E 1, Table 3. Calibrate wide range thermometers, such as electronic or general-purpose liquid-in-glass thermometers, at no less than five points within their range. Use at least one reference temperature bath point to verify any temperatures covered by a thermometer.

EXAMPLE: One useful reference temperature is the ice point of water—0°C or 32°F.

5.2 Calibrate specialized thermometers at the operating temperature and any specified reference temperatures.

6. PROCEDURE

6.1 Determine the accuracy required, the identification number, the immersion depth, and the calibration points to be used. For liquid-in-glass thermometers, verify the condition of the liquid column (See Section 9).

6.2 Calibration should be by comparison with standard thermometers in stirred, controlled-temperature baths (See Section 10).

6.3 Use a reference-temperature bath such as an ice-point bath for direct calibration at specific temperatures (See Section 11).

6.4 Suspend liquid-in-glass thermometers to the proper depth in the bath by the stem above the liquid column. Support electronic sensors by the sheath or wire leads. Immerse sheathed sensors to just short of the leads. Locate each so that they do not touch each other or the bath walls.

6.5 Start with the calibration bath at the lowest temperature to be used. Allow the temperature to stabilize. Consider the temperature stable when two or more consecutive readings of the standard thermometer are equal. Take the readings at least 30 seconds apart.

6.6 Once reaching the correct temperature, reset each thermometer or sensor to the correct immersion depth and again allow stabilization.

6.7 Read the liquid-in-glass thermometers using a magnifying lens with the lens and the user's eye at the level of the liquid column.

6.8 Read the standard thermometer, each thermometer being checked, and the standard again. If the two readings of the standard do not agree within the required accuracy, the bath is not stable. Repeat until the readings match, and then record the temperature of each thermometer.

6.9 To determine the true temperature, apply the correction factor for each point of the standard to its indicated reading. Record the true temperatures.

6.10 Find the error at each point by subtracting true temperature from the indicated temperature. Record the errors.

6.11 Record the correction factor for each calibration temperature. The correction factor has the same numerical value as the error but with the opposite sign.

6.11.1 *EXAMPLE:* If the true temperature is 100.0° and the indicated temperature is 100.8º, the thermometer reads high and the error is + 0.8°. The correction factor to apply at that point is 0.8°.

6.12 Set the bath to the next calibration temperature and repeat the above steps.

Note 3—When using reference-temperature baths, follow the procedure in Section 11.

7. MERCURY-IN-GLASS THERMOMETERS, ICE POINT CORRECTIONS

7.1 The bulb of mercury-in-glass thermometers may slightly change dimensions during use. By comparison, the stem will remain stable. Bulb dimensional changes affect all temperature readings equally. For those thermometers with an ice-point marking, perform periodic verification in an ice-point reference-temperature bath at intervals to determine such changes.

7.2 *Procedure:*

7.2.1 Prepare and use an ice-point bath as instructed in Section 11.

7.2.2 Record the indicated temperature.

7.2.3 The thermometer error is equal to the indicated temperature minus the reference-temperature bath temperature (0°C or 32°F).

7.2.4 A correction factor is equal to the value of the error but with reversed sign. Add the change in this factor to all previously determined correction factors. Observe all plus (+) and minus (-) signs.

EXAMPLE: A thermometer’s correction factor is + 0.15° at 0°. That is, the thermometer reads low and 0.15° must be added to all readings near 0° as a correction factor. Assume that the thermometer had an old correction factor of + 0.20°. The change is minus 0.05°. Apply this change to all the old corrections factors. That is, if the last correction factor at 100° was -0.06°, it is now -0.11°.

Note 4—Verify restricted range and high temperature calibrated liquid-in-glass thermometers periodically. Use an ice-point reference-temperature bath if marked on the stem. Verify electronic thermometers throughout their calibration range.

8. CALIBRATION DOCUMENTATION

8.1 Prepare a certification document that contains:

- make, type or model, and serial number of the thermometer
- sensor type for electronic thermometers
- temperature range calibrated
- correction factor for each true calibration temperature
- standard(s) used
- where the calibration was performed
- date of the calibration
- technician's name
- a copy of the procedure used.

Note 5—In general, it is not practical to apply a label to liquid-in-glass thermometers. If there is no serial number on the thermometer, it may be possible to assign identification and mark the stem with a permanent marker pen or to attach a tag to the thermometer. If this is not possible, the laboratory should develop a written in-house procedure for ensuring identification of the calibrated thermometer and linkage to the certification.

9. VISUAL EXAMINATION OF LIQUID-IN-GLASS THERMOMETERS

9.1 A liquid-in-glass thermometer must have an unbroken liquid column or it will give an incorrect indication.

9.2 Before calibration or use, always examine the column to determine its condition. Use a magnifying lens of at least two-power for this examination.

9.3 Examine the entire length of the capillary tube to verify that there are no gaps in the liquid column or filled chamber.

9.4 Examine all empty chambers to verify that no liquid remains in them.

Note 6—Either improper use or dropping can cause a break in the liquid column or mercury left in a chamber. When using multiple chamber liquid-in-glass thermometers, use in a vertical position.

9.5 There are two common ways to rejoin the liquid column. Perform both carefully to prevent personal injury or breaking the thermometer.

9.5.1 *Preferred Method*—Attempt to force the liquid together by tightly holding the thermometer while slinging it in a circle and jerking it to a stop.

9.5.2 *Second Method*—Heat the bulb slowly in a controlled temperature bath to force the bubble into a chamber and then tap the thermometer to force the liquid to rejoin.

Note 7—Never use an open flame, as the thermometer will almost always break. When heating, the technician must use safety equipment including gloves and face protection.

10. CONTROLLED-TEMPERATURE BATHS

10.1 Make calibrations by comparison in a stirred, controlled-temperature bath. The bath should keep temperature variances within the bath at a minimum. These baths may use water, oil, or specialized heat transfer fluids.

10.2 If a specialized bath is not available, improvise one with a beaker on a hot plate containing a built in magnetic stirrer. The user must be very careful to ensure that the temperature is stable each time reading the thermometers. The thermometers must be close (but not touching each other) in order to read the same. Each thermometer must also be held in the liquid at the correct immersion depth. With practice and patience, it is possible to manually regulate this combination well enough to hold an accuracy of about 0.2°C (0.4°F) for about a minute. This will be sufficient for many purposes.

10.3 Use water baths from the ice point to the boiling point.

10.4 Only use oil baths above the boiling point of water. Determine the flash point of the oil used and always stay well below this point. Special oils for very high temperatures are available but expensive. Always use oil baths in a venting hood to avoid breathing fumes and collecting flammable vapors.

10.5 Use an ice-point bath or distilled water boiling point bath as reference-temperatures. If possible, use a calibrated thermometer to verify that these baths are properly prepared. The temperature of these will change due to the mineral content of the water and the altitude of the workplace.

11. PREPARING AND USING ICE POINT BATHS

11.1 Use a properly prepared ice-point bath for thermometer calibration. Poor preparation and use of the bath will result in errors. With care, one can use common laboratory beakers and stirring equipment to produce an ice-point bath that is within ± 0.01°C (0.02°F) of the true ice point.

11.2 Cool and maintain the water to the ice-point temperature by using slush made of ice shavings or crushed ice particles. Constantly stir the ice and water slush to keep it distributed uniformly. The slush must contain only enough water to wet the ice particles and allow the mixture to be slightly fluid. You must periodically remove water and add ice as the bath is used. For best accuracy, use distilled water and clean, clear ice.

11.3 Do not allow clumps of ice or water pockets to form. When ice particles clump together, the water between them freezes, and the temperature drops. If a pocket of water forms, the temperature in it will rise. A water and ice cube mixture will not cool the water between the cubes sufficiently.

11.4 Do not allow a thermometer or temperature sensor in the ice-point bath to touch any part of the bath or any other thermometer or sensor. At least 25 mm (1 in.) of slush should always be below the lowest point of any thermometer.

11.5 Suspend each thermometer from above and hold at the proper immersion depth. It will be easier to read the liquid column of a glass thermometer if the container is almost full.

11.6 Constantly stir the bath to distribute the ice particles and water uniformly.

11.7 Allow the thermometer or sensor to stabilize at the temperature of the bath.

11.8 Read the thermometer, wait for about a minute, and read again. Record only those readings where the indicated temperature is repeated within the desired accuracy.

Note 8—You may stop stirring momentarily while reading a glass thermometer.

11.9 Record the indicated value.

11.10 Find the error by subtracting the ice point (i.e., 0°C [32°F]) from the indicated value. The correction factor has the same numerical value as the error but with opposite sign.

EXAMPLE: The true temperature is 0° and the indicated temperature is -0.40°; the thermometer reads low with an error of -0.40°, so the correction factor to apply at that point is + 0.40°.