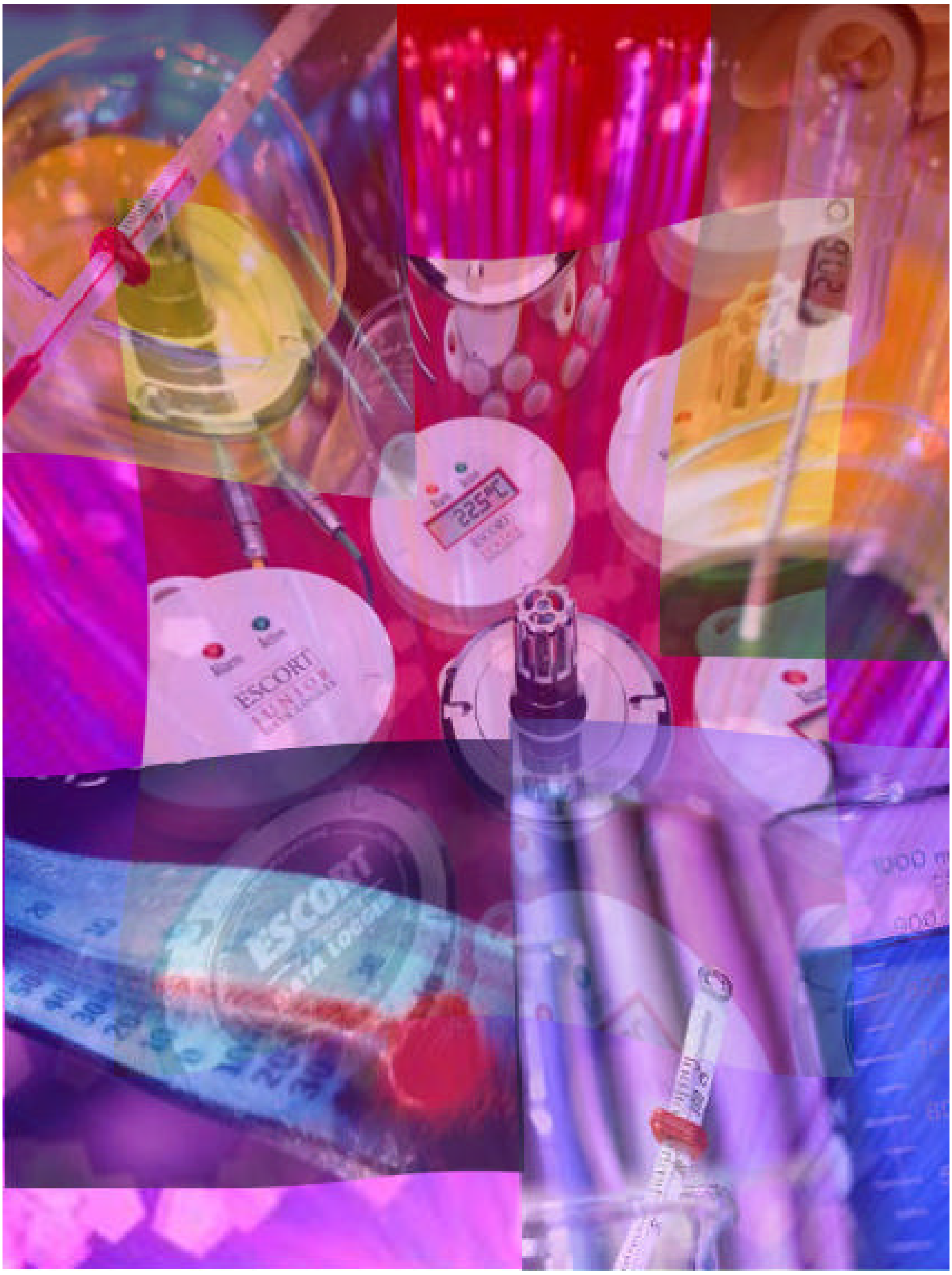

Temperature and Response time Fundamentals

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I. INTRODUCTION

This guide outlines temperature calibration and response time fundamentals that apply to daily use conditions in the laboratory and industry. Most technical guides are written to an advanced level in a specialised field, and primarily benefit the few who are actively working in and are most familiar with that field. In contrast this guide is written to restore the general understanding and background knowledge of the fundamentals, that while understood by the experienced professionals, are not generally understood by the many people who have a "need to know".

The task of insuring accuracy in temperature measurement is of critical importance. Safety and/or health can be compromised, equipment damaged, or product wasted, all can be caused in many processes if the temperature was incorrectly maintained. No matter how precise the measurement or careful the operator, if the device is not calibrated correctly, the end measurement will result in error.

II. TERMS

Lets start with the understanding of a few basic concepts with regards to temperature that are crucial if calibration is to be performed accurately.

Precision:
In temperature measurement has to do with detecting very small changes, also with the ability to repeat measurements again and again with similar results. So a device can be precise if it has the ability to consistently measure the same incorrect value for a particular temperature.

Resolution:
Is the usually the smallest amount of difference (step) that can be accurately detected, but can be the average or maximum of all steps across a given range if the resolution changes. Thus the smaller the resolution the better the end measurement will be resolved, not to be confused with low resolution which means that the steps are large. A device that measures temperature to one decimal place is considered to have a resolution of 0.1%.

Calibration:
Is the act of measuring with the device under calibration, known values from a reference, and recording the error. A simple offset table can then be produced stating the observed error for each temperature point tested. The device may then be adjusted to reduce or eliminate the error – this additional step is called *adjustment*.

Reference:
A reference temperature is the known "real" temperature. There are two common ways of doing this: One is to use another calibrated temperature measuring device that is more accurate than the one being calibrated (usually by a factor of 10 or 100). The second is by using physical constants that produce a known temperature, eg: an ice point.

Accuracy:
Is the ability of a measured temperature to match the actual "real" value of the temperature being measured. Thus if a temperature measuring device has sufficient resolution and is precise at making measurements, as well as being accurate, it will measure the same value at two different locations at the same "real" temperature.

Response time:
Indicates the time taken for an object when moved from one environment to another, to change to a temperature that is near the temperature of the new environment. "Near" will be defined later when we deal with temperature response times.

Specific heat:
Is the quantity of heat required to raise the temperature of one gram of a substance by 1° Kelvin without causing phase change. The greater the specific heat the more energy is required to changed the current temperature of the substance. The approx. specific heat of mercury is 140J/kg°K, aluminium is 900 J/kg°K, water is 4186J/kg°K, and ammonia is 4710J/kg°K.

III. RESPONSE TIME FUNDAMENTALS

All objects react to temperature changes in an environment over a period of time, the time taken is generally[1] constant for a given object and environment. Given this, temperature response times can be calculated for an object in a given environment which allows the end user to judge whether or not the object will respond to temperature variances quick enough to record their existence.

It may also be noted that a quick response time is not always desirable. For instance an operator measuring a temperature may become frustrated when the display of a measuring device fluctuates on every minute temperate change.

Temperature response times are usually defined as a T_{66} or T_{90} value. This is the time (usually measured in seconds) that is required for the object to reach 66.66% or 90% of the change in temperature. If the object's temperature is plotted against time, an exponential graph will result, initially changing quickly then flattening out in the final stages.

An example:

> If an object at 25°C is placed into an environment at 85°C then the temperature change is 60°C (85°C -25°C).
> 66% of 60°C is 40°C so the T_{66} value will be the time taken for the object to go from 25°C to 65°C (25°C+40°C).
> The T_{90} value will be the time taken for the object to go from 25°C to 79°C (25°C+54°C). 54°C being 90% of 60°C.

There are some important concepts that must be understood when comparing or calculating T_{66} or T_{90} values. Most importantly the value is only accurate for the environment that it was calculated from. This is sometimes obvious but often over looked. If the value was calculated from an environment of forced air moving at 2m/s then it will be different from an environment of still air or forced air moving at 4m/s. Likewise if the value was calculated from an environment of stirred water it will be different from an environment of still water or a liquid with a different specific heat like an oil.

The initial temperature of the object and the final temperature of the environment must be constant. Errors occur when the object is placed into the environment and the environment itself is either warmed or cooled depending on the initial temperature of the object. Thus the environment must be large enough or controlled enough to minimise this effect. Also the initial temperature of the object must be stable.

The good thing about temperature response times is that it does not matter how much the temperature change is, the T_{66} or T_{90} values will generally[1] be the same for a given environment. So if an object at 25°C is placed into an environment at 85°C and takes 5 seconds to change from 25°C to 65°C (T_{66} in the above example), the same object initially at 25°C will take 5 seconds to change from 25°C to 85°C when placed into the same environment at 115°C.

To calculate this:

> Temperature change is 90°C (115°C-25°C).
> 66.66% of 90°C is 60°C.
> Therefore the temperature in T_{66} seconds (5) will be 85°C (25°C+60°C).

Notes

1. *Generally* means provided the major mechanism for heat transfer in the given environment is conduction and/or convection.

IV. CALIBRATION FUNDAMENTALS

Temperature calibration is the act of using the device under calibration to measure known values from a reference and recording the error. So what is difficult about comparing two temperatures? Actually quite a lot! And this is where most problems and errors occur.

It all comes down to temperature stability of the environment and knowing the exact temperature of that environment. A common belief is that if an oven control dial is set at 150°C then everything within that oven is at 150°C or if water is boiling it must be at 100°C and/or the steam is also at 100°C. All of these statements can be true but not always and this is the source of most of the confusion and resulting errors.

Temperature Stabilisation:

Entropy is the tendency for all matter and energy in the universe to evolve towards a state of inert uniformity. In the test conditions this is exactly what we want, but instead of the entire universe, we only require the test chamber to become uniformed in temperature and this is where the errors occur. Once we heat the test chamber up it wants to naturally cool down again due to entropy. This cycling introduces temperature errors into the environment, thus parts of the environment are increasing in temperature while other parts are cooling down.

Because the environment cycles over time, the temperature response times of the objects also becomes an important influence. For example take a typical situation where one of the objects in the environment is a reference thermometer with a fast response time, and another is a temperature measurement device under calibration with a slower response time. If the device is calibrated as soon as the reference thermometer stabilises without waiting the extra time required for the temperature measurement device to stabilise, errors will occur.

The key is to create a temperature stabilised environment and use objects that have the same response times or at least take them into account.

Reference Temperature:

The reference temperature is the known “real” temperature and can be sourced in two ways: either by using a more accurate temperature measuring device or through creating an environment by using physical constants. It should also be noted that the calibration points should coincide with the actual temperature ranges that the device is being used in, eg: there is little point in calibrating a thermocouple that measures 750°C in an application by using an ice point method (0°C).

Reference by Temperature Measuring Device:

A mercury/glass thermometer or a precision platinum resistance probe can be used. It should have been calibrated to an accuracy of better or equal to 10 times the required accuracy of the device being calibrated.

Reference by physical constants:

The most easily perform physical constant environment is an ice point. An accuracy of better than ±0.01°C can be achieved if performed properly.

V. CONCLUSION

So we know why temperature calibration is important and the fundamental concepts that cause errors. How temperature stability is of key importance and how a temperature stable environment can become unstable just by placing a new object into it. Now that these issues have been reviewed steps can be taken to reduced the actual influence and therefore reduce the overall error. Happy calibrating.