# The Use of a Hand Held Digital Thermometer in an Analytical Laboratory

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**Abstract**

Digital thermometers are frequently used to check the temperatures of various items of equipment used in analytical laboratories. Such measurements are generally made to verify that equipment is maintaining temperatures between regular calibrations. These measurements can be used as part of preventative maintenance measures and may also be used to justify increasing the period between regular calibrations of the equipment, thereby reducing maintenance and calibration costs. While these measurements are generally easy to make, there are certain considerations that must be made whilst making such measurements. This paper endeavors to highlight some of these considerations, in order to assist laboratory staff to make measurements that are relevant, valid and useful.

## 1. Introduction

Using a thermometer to measure temperatures of equipment in a laboratory seems easy enough, on the surface, but there are some underlying issues that need to be considered to ensure that the measurements are valid. Months worth of data can be collected, only to be discarded when it is discovered that incorrect measurements were made.

Taking a look at some of these considerations in detail, it is hoped it will assist laboratory staff to make measurements that are not only valid but are also useful to the daily operations of the laboratory.

**Important notice:**
As the use of liquid-in-glass thermometers for the purpose of validations is generally decreasing, this paper focuses on the use of digital hand-held thermometers. Users of liquid-in-glass thermometers may still benefit from the topics covered, but there are other considerations pertaining to the use of liquid in glass thermometers that are not covered in this paper. For the purposes of this paper therefore, the term "thermometer" will refer to a digital device and not to a liquid-in-glass thermometer.

## 2. Using and handling the thermometer

There is an old adage that says "when all else fails, read the manual" and another that says "You learn more in two days of fiddling around, than you would in half an hour reading the manual". While these may be true, and are usually what happens in practice, I'm afraid that if you want to start making accurate measurements with your shiny new thermometer, the best place to leave it is in the box, until you have read the manual. The better manufacturers spend enormous amount of money to provide you with a guide to make sure that you get the most out of the thermometer that you purchased. And of course you paid for the manual, so you may as well use it.

However, it's possible that the user manual has been hi-jacked so I'll briefly list some basic precautions common to most hand-held digital thermometers.

Table 1 – Typical precautions during use of hand-held digital thermometer

- **Before using the thermometer, inspect the case. Do not use the thermometer if it appears damaged. Look for cracks or missing plastic.**
- **Pay particular attention to the insulation around the connectors.**
- **Disconnect probes from the thermometer before opening the case.**
- **Replace the batteries as soon as the low battery indicator appears. The possibility of false readings can lead to personal injury.**
- **Do not use the thermometer if it operates abnormally. Protection may be impaired. When in doubt, have the thermometer serviced.**
- **Do not operate the thermometer around explosive gas, vapor, or dust.**
- **Do not apply more than the rated voltage, as marked on the thermometer, between the probe(s), or between any probe and earth ground.**
- **Dual probe thermometers: Measurement errors may occur if voltages on the measurement surfaces result in potentials greater than 1 V between the two probes. When potential differences are anticipated between the probes, use electrically insulated probes.**
- **When servicing the thermometer, use only specified replacement parts.**
- **Do not use the thermometer with any part of the case or cover removed.**
- **Use the proper probes, function, and range for your thermometer and test.**
- **To prevent explosion, do not dispose of batteries in fire.**
- **Follow local laws or regulations when disposing of batteries.**
- **Match the polarities of the batteries with the battery case markings.**

Once you have read and taken note of the contents of Table 1 you can use your thermometer to start taking measurements. But first let us take a look at some user related checks.

To begin with, familiarize yourself with the controls and make sure that the unit is set-up to display measurements based on your type of probe. We will be doing initial calibration checks later, but if the probe type is wrong then our measurements will be incorrect before we even start. It's also a good idea to know how to change from °C to °F and also to change from 1 °C to 0.1 °C resolution. Incidentally, if you press the on/off button and nothing happens… check the battery.

Next, check to make sure that the probe has been connected the right way round. To do this, check the displayed temperature and then hold the end of the probe tightly in your hand. If the temperature reading goes down, then the probe connection is wrong. If the temperature goes up, then we're ready to go.

An important safety tip here with regards to handling the probe. If the probe has recently been exposed to high temperature, it may remain hot for sometime afterwards. This is not limited to just the tip as the shaft of the probe may also be hot. As a guide, take a look at the thermometer display before handling the business end of the probe. The temperature displayed is the temperature of the probe and if it's anywhere above ambient, injury is possible.

## 2. Initial calibration checks

The general use of a thermometer in a laboratory is to verify temperatures of calibrated equipment between the regular calibration cycles. However, the thermometer should also be calibrated regularly and must itself undergo regular verification.

An easy method of verifying almost any thermometer is to use it to measure a known temperature. In order to know a temperature accurately it must be measured and in a laboratory with only one thermometer, the unknown temperature cannot be measured with the thermometer that is being verified. So we need another method of producing a known temperature and the easiest to produce are the freezing and boiling points of water.

Technically speaking we are actually going to use the *melting* point of ice, which for our purposes is 0.0 °C and to achieve it we will need an ice bath. Take a flask and fill it with crushed or shaved ice, then add a little water to make slush. Stir the slush and wait a few minutes. By definition, if ice and water are present, then the ice must be melting and we will have 0.0 °C until all the ice has melted. However, to ensure accuracy, it is best to use distilled water for the ice and water, and to not contaminate the slush with dirty fingers and probes.

Insert your thermometer probe into the ice bath and wait for the reading to settle. The displayed value will show you the error of your thermometer at 0.0 °C.

An additional temperature point that may be used is that of boiling water. Simply boil a suitable amount of water in a kettle and measure the temperature. Your thermometer should read 100.0 °C IF, and you'll notice that this is a big IF, and only IF you are at sea level. Actually, more specifically if the ambient air pressure is at 1013 mBar.

So using the boiling point of water as a known temperature is a little more difficult as the temperature value may change at sea level by up to 3 °C. At higher altitudes such as Johannesburg or Pretoria, the boiling point of water is only 95 ° but it is generally stable to within 0.5 °C so it is more useful.

As with any verification checks, it is important to record your values so that any errors can be accounted for during actual measurements. Records also keep auditors happy, as regular validation should be a part of your quality system and, as many auditors will tell you. "If you didn't document it, you didn't do it".

## 3. Taking measurements

Generally speaking, taking temperature measurements simply requires placing the probe tip into the heat source, allowing it to stabilise and then recording the readings. However there are a number of precautions that must be taken to ensure the validity of the measurements.

### 3.1 Temperature gradients

Any process that has a temperature source is going to produce temperature gradients. This is simply because the temperature source, such as a heating element or cooling coil, will be at the extreme temperature value, and all temperatures further away from the source will tend towards the ambient temperature. This is why we sit near the fire on a cold evening, rather than further away.

This problem can be alleviated by using stirrers of some kind. An oven or incubator may be fitted with a fan that circulates the hot air and a water bath may be fitted with a circulator that pumps the water around the bath. However the effectiveness of these stirrers will depend on their position and design, and gradients may still occur. In fact it would be foolhardy to assume that there are no temperature gradients in a stirred system as the stirring itself can cause vortices which result in cold-spots. Also, the position of the product in the bath or oven may disturb the air or water flow.

So where to measure? Well, ideally measurements should be made in several locations throughout the volume. However, initial qualification of the equipments, as well as the regular calibration of the equipment by an external calibration facility should include some form of temperature mapping. Looking at these results will give you an idea of any hot or cold spots, so you can concentrate on the most important areas, which are those where you place your product.

Take a look at the temperature map on the certificate and see where the probes were placed during the measurements. Since the aim of your verification is to make sure that there is no change between regular calibrations, it is a good idea to take your verification measurements at one or more of these same locations.

An example of a graph is shown in Figure 1 and the associated probes positions are shown in Figure 2.

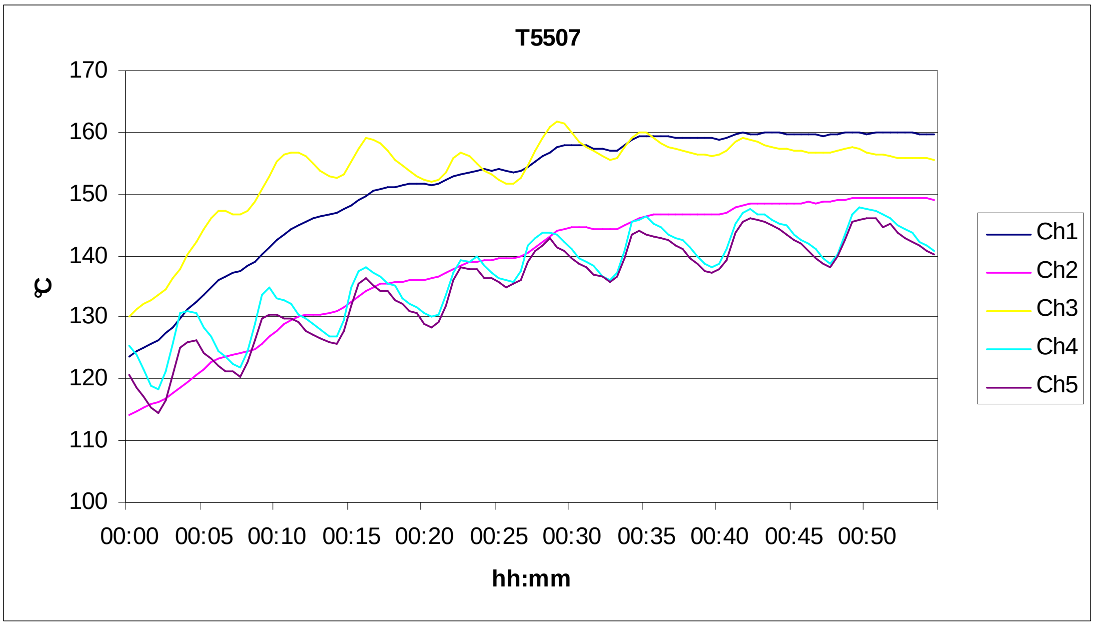


Figure 1: Graph showing measured temperatures at various locations

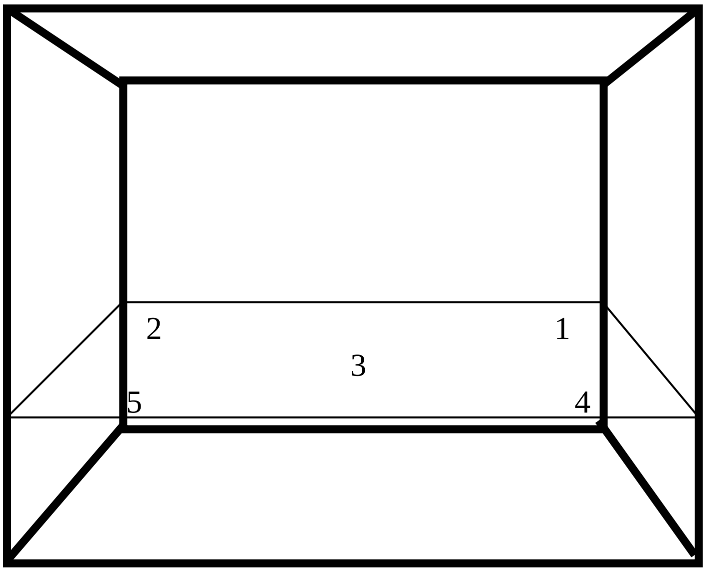


Figure2: Probes locations for the graph in Figure 1

In any case all verification measurements should be made at the same points each time, so either mark them or make a detailed diagram for future measurements.

## 3.2 Temperature fluctuations.

Another factor that may influence verification measurements is temperature fluctuations of the temperature source. For example an oven might be set to 150 °C but the actual temperature may cycle between 140 and 150 °C, as shown on traces 4 & 5 in Figure 1. Taking a single measurement at a single point in time will result in a measurement of any temperature in that range. Taking such measurements daily will initially show apparent random temperature variations, but graphing these results over a long period will indicate the temperature cycle.

Again, regular temperature mapping by a calibration facility will show the temperature cycle and the range of temperatures that can be expected at each location (again, see the graph in Figure 1). Single daily measurements at these locations should therefore fall within this range. For more detailed verifications, it may be necessary to manually record the minimum and maximum values measured over a period of time and check if they agree with the calibration certificate.

### 3.3 Thermal recovery

In many cases, laboratory ovens have a port in the top into which a probe can be inserted to take temperature measurements. However older designs do not have such a port and measurements must be taken through the door. Opening the door to position the measurement probe and then closing it again presents several measurement problems. Probably the biggest of these is that of "thermal recovery".

The problem is that measurements are being made to determine the temperature of the oven, but opening the door releases hot air and allows cool air to enter. Once the door is closed, the oven will eventually return to stability and temperatures can be measured. How long this recovery takes will depend on several factors including the design of the oven and how long the door was open.

The best method for quick measurements is to have a probe semi-permanently installed so that the thermometer can be connected to it without disturbing the oven, but this may not be practical and since the probe would also require regular calibration, this would add to the annual calibration bill.

There is no simple method to calculate when an oven has recovered sufficiently. Educated guesses can be made by monitoring the temperature controller display, or other indications, but the general rule would be to allow as much time as possible before taking a measurement.

The time can be shortened by placing the probe as quickly as possible inside the oven, thereby limiting the time that the door is open. This means that the operator must know before opening the door where the probe is to be placed and to have a quick method of attaching the probe, such as a clip.

Something else to consider is that thermal recovery is not limited to those ovens that require the door to be opened to place the measurement probe. In a busy laboratory another person may have recently opened and closed the door of any oven, incubator or fridge and disturbed the stability. The person taking verification results through a suitable port would not be aware of this and the results taken may be invalid.

### 3.4 Other precautions

Something to remember when taking measurements is that a thermometer indicates only the temperature of its sensor. The key to taking accurate measurements is to make sure that the sensor is at the same temperature as the item that you are trying to measure. (The correct term here, for those readers that like long words is "thermal equilibrium" and if you really want to impress people you can use terms like "the Zero-eth Law").

Those things that prevent the probe from reaching thermal equilibrium relate to "thermal conductivity", "thermal mass" and "thermal momentum".

"Thermal conductivity" is used to describe the ability to transfer heat from one place to another. Insulating material such as that found in the roof of houses and inside the walls of oven and fridges, have a very low thermal conductivity, so the heat stays where we want it. Water on the other hand, has a relatively high thermal conductivity, especially when it is flowing because it carries the heat with it. So if you immerse your thermometer probe in a water bath with good water flow, the probe will reach the temperature of the water reasonable quickly. Air, however, does not conduct heat very well especially when it is stationary, as it is inside a fridge or freezer, and so the probe will take a long time to reach thermal equilibrium with the air inside the fridge or freezer.

Another problem with freezers is that of the formation of snow. Moisture in the air inside the freezer condenses and freezes, forming snow. Now even though snow is cold, it is actually a good insulator, as can be testified by Eskimos that live in igloos built of compacted snow. The problem then is if snow is allowed to form around the probe, then the probe will not reach the same temperature of the air inside the freezer and your measurements will give incorrect values. Precautions that can be taken include making sure that the probe is not resting on or in snow; that the probe is dry when placed into the freezer; and checking for snow when removing the probe.

I mentioned "thermal mass" and "thermal momentum" at the beginning of this section. These relate to how quickly a probe can change temperature and again reach equilibrium with the surrounding medium. These factors are influenced by the size of the probe as well at the material of which it is made. A thinner probe will react faster than a thick probe, and a plastic probe will react faster than a probe in a steel sheath.

The actual reaction time of the probe can only be found by experiment, so it is best to monitor the readings and wait for stability before attempting to make accurate measurements.

### 3.5 Care of the thermometer and probe

As was mentioned before, it may be necessary to place the probe inside an oven and to close the door. If this is the case EXTREME care must be taken to prevent damage to the probe. Some doors of lower temperature ovens are fitted with rubber seals which will protect the probe but be aware that the probe cable will compromise the seal and allow for the movement of air past the door. Other doors are not fitted with rubber seals, and the metal-on-metal door seal may crush the probe cable. You may get away with this a few times, but eventually the probe will need to be replaced. And replacing the probe is not just an expense, it means that you lose all calibration and verification histories for the thermometer.

If the entire probe must be placed into the oven, make sure that the probe handle and cable are rated for the expected temperature of the oven.

Care must also be taken not to damage the thermometer during use. Leaving it on top of a hot oven while waiting for the oven to recover may melt the case and damage the electronics. Dropping it into a water bath will not be good for it either.

# 4 Corrections and uncertainties

The expression "Do not judge a book by its cover" applies just as much to the measurement world as it does to literary works. No measurements can ever be taken at face value and some investigation needs to be done to obtain a value that is closer to the true value.

For our example we'll assume that all the necessary precautions have been taken and that we have recorded the temperature of a water bath at +44.5 °C from the display of our thermometer. Is this the true temperature of the water in the bath? Let's find out.

## 4.1 Corrections.

The first thing that we have to do is to refer to the calibration certificate of the thermometer. Typical results are shown in Table 2

Table 2: Results from a calibration certificate

| Temperature(°C) | UUT value(°C) |
|---|---|
| 0.0 | -0.2 |
| 50.0 | 50.2 |
| 100.0 | 99.8 |

Uncertainty of measurement: ± 1.5 °C

Further inspection of the certificate leads us to discover that "UUT" refers to "Unit Under Test". We can therefore see that when measuring a known temperature of 50.0 °C, our thermometer indicates a value of 50.2 °C and therefore has an error of +0.2 °C. So if we are measuring at +50 °C we must subtract 0.2 °C from the reading. In other words we have a correction of -0.2 °C.

But our measurement is at +44.5 °C, so what is the correction? Well this can be calculated by interpolation between the errors at the listed calibration points of 0.0 and 50.0 °C as follows:

$$Err_{44.5} = 44.5 * \frac{(Err_{50} - Err_{0})}{50 - 0} + Err_{0}$$

$$Err_{44.5} = 44.5 * \frac{(0.5)}{50 - 0} - 0.2$$

$$Err_{44.5} = 0.156$$

Since we only have a resolution on the thermometer of 0.1 °C we'll round this up to an error of 0.2 °C. Therefore our measurement of 44.5 °C becomes 44.3 °C.

At this point it should be noted that the above calculation makes the assumption that the thermometer is linear between these points. A quick check of the calibration results shows that the thermometer does not appear to be linear, so we must go to the specification of the thermometer. This gives a specified accuracy of "±0.05% of reading + 0.3 °C" giving us possible errors at 44.5 °C of 0.32 °C. So while we have calculated the error as 0.2 °C the manufacturer tells us that it could be 0.3 °C.

These calculations exclude the linearity specification of the probe, which is at least ±1.1 °C. But before we get bogged down into even more calculations, let's take a closer look at the calibration certificate:

Below the table we read the statement "Uncertainty of measurement: ± 1.5 °C".

What does this mean and how does it affect our measurements?

### 4.2 Uncertainties of Measurement

While the full calculation of so-called "Uncertainties of Measurement" is beyond the scope of this paper, a general understanding of the principles is required for our measurements.

In any measurement there is a degree of uncertainty as to the accuracy of the measurement. How much uncertainty there is depends on a number of factors but these can be minimized by analysis.

We can see already that our measurement of 44.5 °C had a correction of 0.2 °C that we initially were not aware of. And the same is true of our latest result of 44.3 °C.

Now we are making a simple measurement. What about when the thermometer was calibrated at the calibration laboratory? Were there uncertainties then? Of course, and the calibration laboratory has indicated these on the certificate with the statement:

Uncertainty of measurement: ± 1.5 °C

What this means is that they have calculated that the measurements that they have taken are accurate to within ±1.5 °C. So in fact, although the error at 50 °C is shown as +0.2 °C, in fact the error may be anywhere in the range of 1.5 °C on either side of this value i.e. -1.3 to + 1.7 °C.

So for our own measurements, this is our starting point – "All measurements that we make with this thermometer are only accurate to, at best, ±1.5 °C"

Which brings us back to our own verifications. Before we measured our oven, suppose that we had made an ice bath, measured it with our thermometer and obtained a reading of +0.1 °C. This is 0.3 °C above the value on the calibration certificate.

Does this mean that the thermometer is faulty? That the thermometer results have drifted? That the calibration certificate is invalid?

Simply put, No; as long as the results that you obtain are within at least the uncertainty of measurement on the calibration certificate, your results are valid.

Of course, your own results have their own uncertainty associated with them as well. For example are you 100% sure that the ice bath is not contaminated and therefore not 0.0 °C? If not, then make the ice bath and the measurement again. How about the condition of the probe? Abuse and damage will affect the accuracy of the probe. How sure are you that the probe has not drifted since the calibration? What about the thermometer itself? Could it have drifted?

As you can see, there are many factors affecting the uncertainty of our measurements. Initially, with a new thermometer and a calibration certificate, you can have some confidence in it. As verification results are taken over time and historical data is obtained your confidence in the instrument will increase. Subsequent external calibration results will also increase your confidence in the thermometer, but the bottom line is that none of your measurements is ever more accurate that the associated uncertainty of measurement and in this case that is at least ±1.5 °C.

If you need better accuracy than this in any of your measurement, then a more accurate thermometer should be purchased and it should be calibrated by a laboratory that has the capability to calibrate it with a smaller uncertainty of measurement.

As a rule of thumb, the instrument that you are using, in this case your thermometer, should be calibrated to an uncertainty that is four times more accurate than the specification of the value that you are trying to measure. This is referred to as a Test Uncertainty Ratio (TUR) of 4:1. In our example then, since our thermometer is only calibrated to ±1.5 °C we cannot use it to measure any process that requires an accuracy of better than 1.5 x 4 = 6 °C. Again, this a general rule. In practice, using statistical methods, TURs of 3:1 and 2:1 are possible.

## 5. Conclusion

While valid temperature measurements are not quite as simple as they may initially seem, with a bit of care of your thermometer and some thought about what you are actually trying to measure, you can be confident that the measurements that you make will be valid and useful to your laboratory.

## References


1. Fluke Corp, “51, 52, 53, 54 Series II Thermometer Service Manual”, Fluke part no 1276123 October 1999
2. Fluke Corp, “51 & 52 Series II Thermometer Users Manual”, English, September 1999 Rev.1, 6/01