Non-Contact Temperature Measurement in the Food Industry

Peter Saunders
Measurement Standards Laboratory of New Zealand
Industrial Research Ltd, PO Box 31-310, Lower Hutt

Introduction

The safe storage of all perishable food products is critically dependent on storage temperature. Health regulations govern the temperature range required to avoid the risk of spoilage or disease through bacterial growth. For example, meat products must be stored from 4°C to 7°C, fish products below 4°C, and shellfish from 10°C to 15°C. These regulations have a major impact, for example, in the hundreds of supermarkets throughout the country. Accurate temperature measurement is crucial not only for health reasons but also for profitability through the reduction in wastage that arises from bad measurements.

Conventional contact thermometry using thermocouples or resistance thermometers is often not an appropriate method to measure food temperature for a number of reasons. First, often a large number of items need to be measured in a short period of time. Contact measurements tend to be relatively slow due to the time required for the temperature probe to reach thermal equilibrium with the item. Measurements become prone to error because the operator is under pressure of time. Secondly, it is often not desirable for the probe to come into contact with the product because of the possibility of contamination or damage. Thirdly, direct access to the item may not be possible simply because it may be out of reach.

To overcome these problems it has become common practice, particularly for supermarkets, to use infrared radiation thermometers to measure the temperature of stored food products. While radiation thermometers are capable of rapid non-contact temperature measurement at a distance, a good understanding of their operating principles and good measurement practice are required to obtain accurate and reliable temperature values.

This article discusses these principles and the pitfalls that exist for measurements made near and below room temperature.

Infrared Radiation Thermometry

A radiation thermometer exploits the principle that all objects emit infrared radiation (radiant heat) at a rate directly related to the temperature of the object[†]. The rate of emission increases very rapidly as the temperature increases. At room temperature every object emits energy at a rate of about 470 watts per square metre, while a hot stove element at 500°C emits about 20,000 watts per square metre. Optical components inside a radiation thermometer (similar to those found in an everyday camera) are used to focus the infrared radiation onto a solid-state detector where it is converted into an electrical signal. This signal is then manipulated electronically and finally read out as a temperature on a digital display.

[†] More information on radiation thermometry can be found in the June 1991 and March 1998 issues of *Automation & Control* where we presented articles describing general aspects of radiation thermometry and an application to high-temperature thermometry, respectively.

Radiation thermometers overcome the problems associated with contact thermometers discussed above. There is no need to wait for a temperature probe to come to thermal equilibrium with the target because the target itself is the sensor — its radiant emissions are directly related to its temperature. The only delay in the temperature reading is due to the response time of the detector. This varies from a few milliseconds to about 2 seconds depending on the type of radiation detector used in the thermometer.

The radiation thermometer can be used at virtually any distance from the product, overcoming both the possible contamination and the accessibility problems. Temperature measurements can also be made on moving products. The main limitation is that product must completely fill the field of view of the thermometer. As the measurement distance increases so too does the ‘spot size’ on the target.

Emissivity

As anyone walking on a black-sand beach on a sunny day will know, black objects are very good absorbers of radiation. They are also very good emitters. Of fundamental importance to radiation thermometry is the concept of a blackbody. A blackbody is an ideal object that at a given temperature emits more radiant energy than any other object. A blackbody is characterised by having an emissivity equal to 1. On the other hand, all real objects have an emissivity less than 1, indicating that they emit (and absorb) less radiation than a blackbody. The emissivity of an object is defined as the ratio of the radiant energy emitted by the object to that emitted by a blackbody at the same temperature.

A good practical approximation to a blackbody can be constructed by forming a small aperture at one end of a large cavity. Radiation thermometers are calibrated with the aid of these practical blackbodies, and thus are designed to read the temperature of blackbodies. For measurements on real objects, the detected signal must be amplified to compensate for the lower emissivity. The lower the emissivity the higher the required amplification. A dial or digital adjustment on the radiation thermometer called the ‘instrumental emissivity’ allows the user to enter the value of the object’s emissivity. Emissivity values for many materials are published in tables and are often supplied by manufacturers of radiation thermometers. Care must be taken in using emissivity tables as emissivity is highly dependent on surface quality and can vary significantly for a given material. Emissivity is also a function of wavelength, and to a lesser extent temperature.

In the food industry many products are packaged in plastic or cardboard. In the infrared both of these materials are quite black and have an emissivity in the vicinity of 0.95. For this reason some radiation thermometers are manufactured with a fixed value for the instrumental emissivity of 0.95, and the user cannot adjust this value. It will be shown below that this feature is a severe limitation to obtaining accurate temperature measurements for most practical situations.

Reflectivity

Reflections are potentially the major source of error in radiation thermometry measurements near room temperature. Like emissivity, the reflectivity of an object varies between 0 and 1, but does so such that for opaque objects the sum of the emissivity and reflectivity is equal to 1. Thus, plastics and cardboard with an emissivity of 0.95 have a reflectivity of 0.05 (plastics are opaque in the infrared). This means that 5% of the radiant energy falling on the target that originates from the surroundings is reflected. Thus infrared radiation from the walls and ceiling will be reflected off the target and also detected by the radiation thermometer, adding to the emitted component of the signal. The radiation thermometer cannot distinguish between the emitted and reflected components, so the reading is anomalously high.

Reflection errors are a problem for all radiation thermometry measurements, regardless of the temperature range, but are an acute problem for food temperature measurements. This is because the surroundings are often at a similar temperature to the product and so a significant contribution to the displayed reading comes from the surroundings.

If the surroundings are at the same temperature as the target then the reflected radiation exactly compensates for the fact that the emissivity is less than 1, and the target appears to be a blackbody. This explains why a cavity with a small opening makes a good blackbody. Using an instrumental emissivity of 1 in this case results in an accurate temperature reading. When the temperature of the surroundings is relatively close, but not equal, to that of the target the compensation is not exact. This results in a small error in the reading when an instrumental emissivity of 1 is used.

On the other hand, the reflection problem is compounded for radiation thermometers that use an instrumental emissivity setting less than 1. In this case the emitted component of the signal is compensated by electronic amplification through the instrumental emissivity setting. However, at the same time the reflected component is also amplified and added to the already compensated signal leading to a large error in the reading.

Temperature Measurements

The graphs in Figures 1 and 2 show the errors in the displayed reading for two different scenarios and two different values for the instrumental emissivity. The error is plotted as a function of the true temperature of the target item. A positive error means that the reading is higher than the true temperature. For both of these figures the actual emissivity of the target is equal to 0.95.

In Figure 1 the item being measured is mostly surrounded by a background at room temperature (20°C), and corresponds to an item on a shelf or inside an open refrigerator. With the instrumental emissivity set to 1 the error decreases from a modest value of about 0.7°C for items at 0°C down to zero error for items at room temperature. For these latter items the reflected radiant energy from the surroundings exactly compensates for the reduced emission due to the target having an emissivity less than 1, making it appear that the target is itself a blackbody. This is the ideal measurement situation and should strived for whenever possible.

One way to simulate blackbody conditions when the target temperature is considerably lower than that of the surroundings is to aim the radiation thermometer at a small gap between similar items. This gap forms a cavity whose properties simulate those of a blackbody cavity. Blackbodies do not reflect any of the radiation originating from the surroundings, and so the temperature of the surroundings has no effect on the measurement. Care must be taken that the size of the cavity is at least as large as the measurement spot size.

The upper curve in Figure 1, corresponding to an instrumental emissivity setting of 0.95, shows significantly larger reading error. In this situation the signal corresponding to the emitted radiation is electronically amplified to simulate a blackbody signal, but at the same time the reflection error is also amplified and added to this equivalent-blackbody signal resulting in a significant error. Even by simulating blackbody conditions through sighting on a cavity between items it is not possible to eliminate the error, because the blackbody signal from the cavity would be amplified. The size of the error in this situation (almost 4°C) is larger than the acceptable temperature range for products such as meat, for example. Clearly this could result in acceptable product being discarded or product being stored at too low a temperature. Neither situation is desirable.

Figure 2 shows the scenario corresponding to measurements inside a large walk-in freezer where the temperature of the surroundings is –20°C. In this case the items being measured are all above the temperature of the surroundings. Again, with an instrumental emissivity setting of 1 the radiation thermometer displays a relatively small error, this time slightly negative. The cavity technique described above can again be used to approximate blackbody conditions and reduce the error when the target temperature is higher than the surroundings.

With the instrumental emissivity set to 0.95 the error in the reading is similar to that described above for the higher background temperature, and the same conclusions can be drawn.

Discussion

It is apparent that in the food industry the advantages that non-contact infrared radiation thermometers over other types of thermometry can be exploited only if considerable care is taken in the measurements. In most situations it is possible to correct analytically any error in a radiation thermometer’s reading by taking a series of auxiliary measurements of the surroundings and using knowledge of the emissivity of the target. However, we have shown that those thermometers whose instrumental emissivity is permanently set to 0.95 are not well suited to measurements near or below room temperature where the temperature of the surroundings is comparable to the target temperature. Almost all of the major manufacturers of radiation thermometers have a model of this kind in their range. In most cases these should be avoided.

Of much greater utility are those models with an adjustable instrumental emissivity setting. Although adjustable it is recommended that these models be almost always operated with a setting of 1. It is only for products whose temperature is significantly higher than the background temperature that the instrumental emissivity should be set to the value of the emissivity of the target.

In choosing a particular model of radiation thermometer for a given application factors other than instrumental emissivity (and of course price) that should be considered are the target temperature range, the ambient operating temperature range, and the spot size.

Since radiant energy increases very rapidly with temperature, a wide temperature range requires detection linearity over many orders of magnitude. This may compromise resolution and/or accuracy, and so a radiation thermometer model should be chosen that covers the smallest available range enclosing the target temperature range of interest. The target temperature range also determines the operating wavelength and spectral bandwidth of the thermometer. For applications in the food industry there is little choice in this regard, as most instruments need to operate over a wide bandwidth to achieve sufficient detectable signal, and are restricted to the 7 to 18 µm range where most of the energy is radiated at room temperature.

For measurements made inside a walk-in freezer care must be taken in choosing a thermometer model with an operating ambient temperature range that extends below 0°C. Often a manufacturer will quote a storage ambient temperature range extending below 0°C but the operating ambient temperature range will be restricted to above 0°C. If used below 0°C condensation of water vapour can form on the optics reducing the measured signal. Note that target temperatures below 0°C can be measured provided that the ambient temperature of the thermometer is above 0°C.

The spot size is the area on the target from which the radiant energy is detected. This varies from model to model. As the distance between the target and the thermometer increases so too does the spot size. To obtain accurate readings the target must completely fill the spot size. In using the cavity technique to simulate blackbody conditions it is necessary to be close enough to the target to ensure that the spot size is completely covered by the cavity.

In conclusion, the tight tolerances on food storage temperature place a considerable onus on users of radiation thermometry to ensure that they obtain reliable measurements. We have seen that careful measurement practice and choice of the appropriate instrument can avoid the health risks and wastage associated with bad measurements.

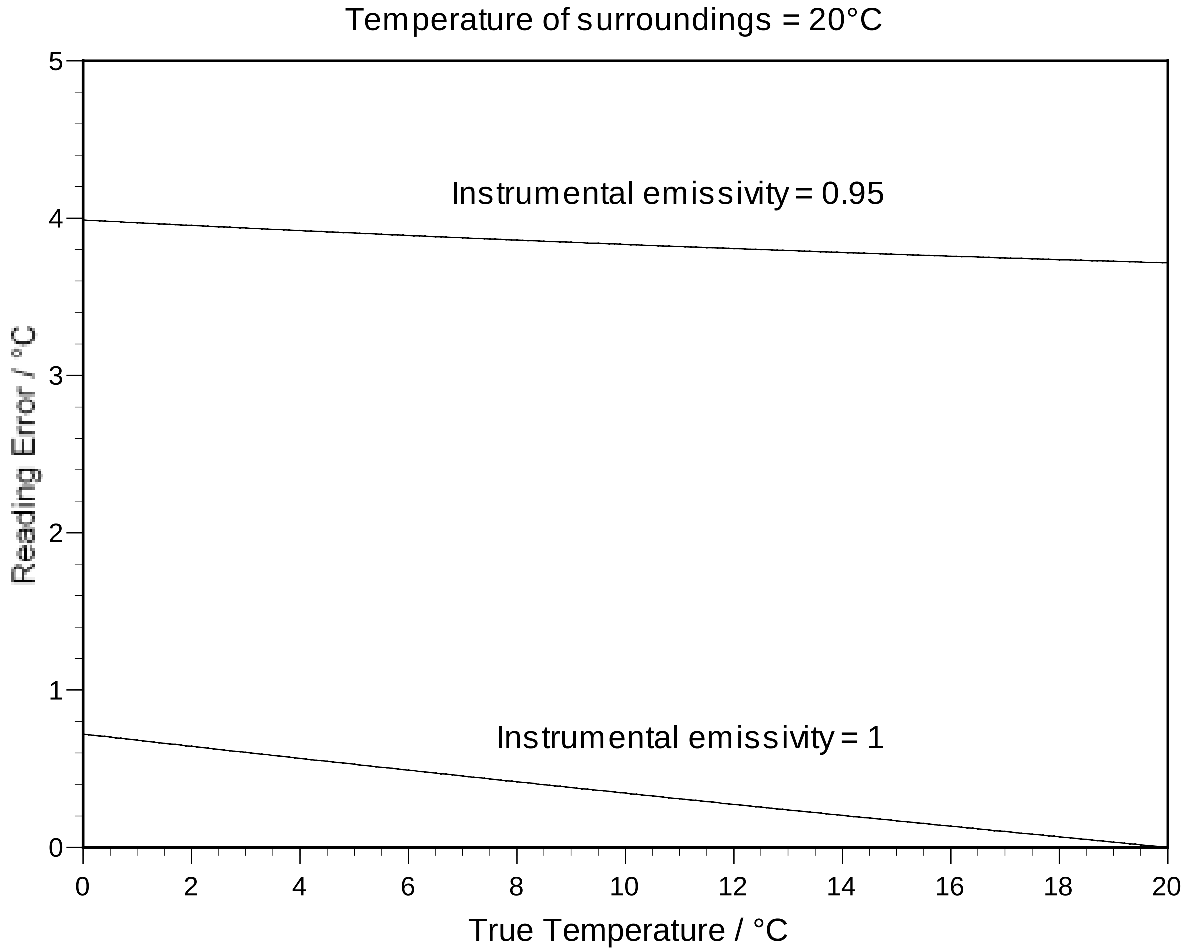
Temperature of surroundings = 20°C
Instrumental emissivity = 0.95
Instrumental emissivity = 1
Reading Error / °C
True Temperature / °C
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
20

Figure 1

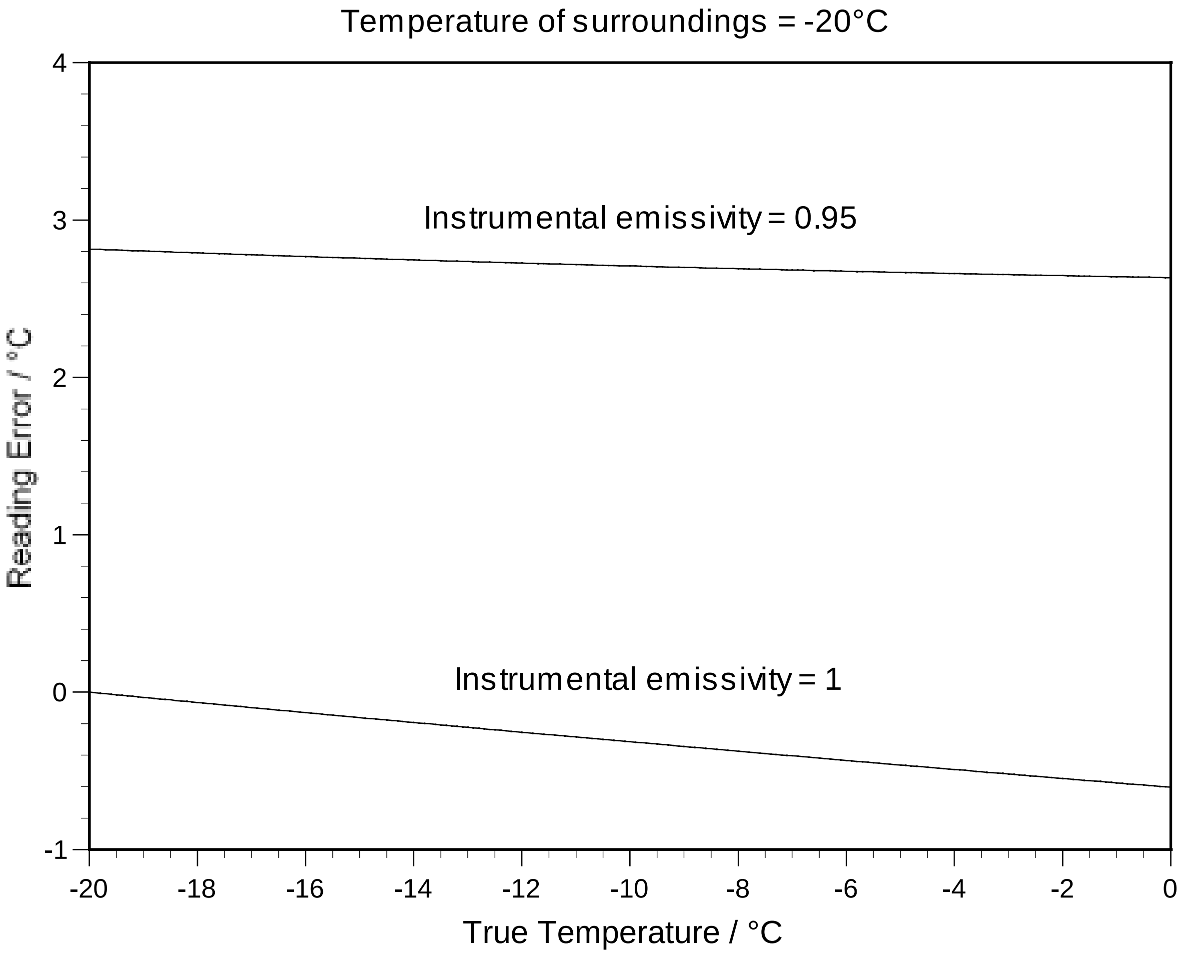
Temperature of surroundings = -20°C
Instrumental emissivity = 0.95
Instrumental emissivity = 1
Reading Error / °C
4
3
2
1
0
-1
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
True Temperature / °C

Figure 2