Background for emissivity calculations: (see slides no. 12, 19, 35)

The Stefan-Boltzmann Law states:

$L_{emi} = \varepsilon \, \sigma \, T_{surf}^4$; ε is the emissivity, $\sigma = 5.67 * 10^{-8}$ [W m^{-2} K^{-4}], T_{surf} is the surface temperature in [K].

No natural material is a perfect black body, although some have an emissivity close to unity, e.g., ice/water mixture or soot (black carbon). Generally, $0 < \varepsilon < 1$. Therefore, there is always a reflected fraction $(1 - \varepsilon)$, which is also measured by an IR sensor or camera in together with the radiation emitted from an object or target surface (depending on the specific material emissivity). The reflected part, $L_{ref} = (1 - \varepsilon) * L_{inc}$, where L_{inc} (incoming) is the IR radiation emitted and reflected from matter (objects, fluids, gas) in a hemisphere around the target surface of interest (see figure on slide 12 and recall experiment 1-a-3).
Slide 19 shows tables with typical emissivities of selected materials.

An IR radiometer (sensor, camera) measures the (thermal) IR radiation reaching the sensor in the spectral range it is sensitive, e.g., 4-15 µm, both emitted and reflected components combined.

For an ideal black body, the emitted IR radiation (L_{emi}) is given as

$$L_{emi} = \varepsilon \, \sigma \, T_{surf}^4, \text{ where } \varepsilon = 1. \qquad (1)$$

For a natural (real) object, the reflected contribtion has to be considered as well (cf. slide 12):

$$L_{meas} = L_{emi} + L_{ref} = \varepsilon_{surf} \, \sigma \, T_{surf}^4 + (1 - \varepsilon) \, L_{inc} \text{ , where } L_{inc} = \varepsilon_{amb} \, \sigma \, T_{amb}^4 \qquad (2)$$

"meas" = measured, "inc" = incoming, "amb" = ambient, "emi" = emitted, "ref" = reflected.

The IR radiant temperature output of a sensor or camera follows from solving Eq.(1) for T_{surf} :

For a theoretical blackbody, it would simply be

$$T_{surf} = (L_{emi}/(\varepsilon\sigma))^{1/4} \quad \text{with } \varepsilon = 1 \qquad (3)$$

For a natural, "gray" object, also the reflected fraction must be considered.
However, the sensor/camera does not know which material it measures and a corresponding emissivity (ε) has to be specified (by the sensor manufacturer or by the user). This is what I call here the "intrinsic" (or preset) emissivity value of the target object used in the sensor for tr radiation → temperature conversion.

To account for the reflected IR radiation (L_{ref}), the incoming IR radiation (L_{inc}) needs to be known or estimated.

In our experiment, we use the room temperature (T_{amb}) and a typical, representative emissivity of the surrounding materials of the lab (glass, concrete, plastic, etc.), here: 23°C and $\varepsilon = 0.95$.

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With the ice bath experiment, we try to quantify the (unknown) pre-set emissivity values used in the IRC (matt, semi-matt, semi-glossy, and glossy) and IRS, using Equation (2), also given on slide 12.
An ice-water mix is used as its state and properties are known, i.e., the surface temperature (melting ice) is equal to 0°C and the emissivity of the ice/water mix is known to be equal to 0.98.
With these values, L_{emi} can be calculated.

Now we have all elements for computing the emissivity value used in the sensor by solving the equation on slide 12 for ε_{cam} or ε_{sen} .

Step 1: compute the true emitted and reflected IR radiation from the ice bath surface:

$$B_{true} = \varepsilon_{ice} \; \sigma \, T_{0°C}^4 \quad + \quad (1 - \varepsilon_{ice}) \; \varepsilon_{amb} \, \sigma \, T_{amb}^4 \qquad (4)$$

Step 2: use B_{true} on the left-hand-side of Equation (4) and the measured temperature (T_{meas}) on the right-hand side to determine ε_{cam} the (intrinsic or pre-set) emissivity of the camera/sensor (by solving for ε_{cam}).

$$B_{true} = \varepsilon_{cam} \, \sigma \, T_{meas}^4 \quad + \quad (1 - \varepsilon_{cam}) \, \varepsilon_{amb} \, \sigma \, T_{amb}^4 \qquad (5)$$

T_{amb} is the ambient (room/lab) temperature assumed to be 23°C, and ε_{amb} is the emissivity of the surroundings, here the lab, assumed to be 0.95.

Last but not least please note that the temperature range of the camera is
-20°C < T < 120°C (-60°C for the newer models).
Any temperature value theoretically lower than -20°C (or -60°C) will be capped and constrained to -20°C (or -60°C), so pay attention when you get this value as it might not be the true expected temperature reading.

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If the sensor/camera would use an emissivity value identical to the true emissivity of the target material (in our case 0.98), and if the assumptions on the temperature and emissivity of the surroundings were correct, the sensor/camera would give the true temperature of the target surface (within the range of the instrument accuracy and potential errors introduced by the user or operator).

If a thermal camera or IR sensor measures a surface of known temperature and known emissivity (e.g., ice/water mixture, 0°C, 0.98) but uses a different (wrong) pre-set emissivity value for the calculation of the surface temperature, the result will be biased since the sum of the true emission plus the reflected component remains the same regardless of the emissivity value used internally in the camera/sensor for computing the temperature.
The camera/sensor however, calculates the target temperature using a pre-set emissivity value and a correction based on the assumptions that (a) the reflected apparent temperature (in most cases the ambient temperature) is 22°C (this is at least the case for the FLIR camera, for the IRS, this info is not available), and (b) a pre-defined value for the emissivity of the ambient environment, e.g., 0.95 which in reality may be different.

If the pre-set emissivity differs from the true emissivity of the target, solving Eq.(2) for T_{meas} will lead to an incorrect temperature value. The larger the difference between true and pre-set (user specified) emissivity, the larger the difference between the sensor output temperature and the true target temperature.

2025-03-28 / HH