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Leave an air gap between instrument box and hot wall

By Professor Dan Loyd

QUESTION: The flue gases from one of our test facilities are transported in an insulated duct with an inner cross-section area of 600 x 600 mm^2. The normal temperature of the flue gases is 250 °C. The channel wall contains various types of insulating material and the outermost layer consists of 1 mm thick metal plating. A box containing temperature instruments is mounted on the vertical duct wall. The temperature of the metal plating is 45 °C when the temperature inside the workshop is 18 °C. On one occasion the ventilation inside the workshop stopped working and the ambient temperature then became 32 °C for a lengthy period of time. What was then the temperature of the metal plating?

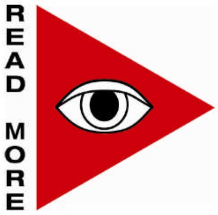
Staffan L

ANSWER: The heat transfer from the flue gases to the inner duct wall occurs mainly by forced convection. Heat is transferred through the insulated duct wall by thermal conduction. Heat transfer from the metal plating to the surroundings normally occurs by natural convection and radiation. The “driving force” behind the heat transfer is the temperature difference between the flue gases and the surroundings: 250 – 18 = 232 °C.

When the temperature inside the workshop increases from 18 °C to 32 °C, the heat transfer decreases and the external surface temperature of the duct increases. If we begin by assuming that all thermal coefficients are constant, the surface temperature will increase from 45 °C to
57 °C. If the calculation takes into account the fact that both radiation and convection are temperature dependent, the temperature of the duct wall will be 56 °C. The reason why the duct wall temperature increases by 11 °C when the ambient temperature increases by 14 °C is because the thermal resistance in the duct wall is considerably greater than that between the duct’s surface and its surroundings. This calculation is based on a number of assumptions, so the result should be used with caution.

If possible, it is advisable to avoid installing instrument boxes directly onto hot surfaces. The thermal conduction from the wall combined with the power dissipation from the instrument’s electronics can cause unnecessarily high temperatures inside the box, which can in turn jeopardise the functioning of the electronics. In the case of temperature measurement instrumentation, its prior calibrations can become worthless. (Read more on page 4.) By mounting the box such that a ventilated gap is created between the box and the duct wall, you reduce the heat flow from the wall to the box (see Figure 1). Instead of thermal conduction you will then have radiation and natural convection. The mounting brackets between the box and the wall should have as small a cross-section area as possible and their thermal conductivity should be low. Stainless steel is a suitable material. Shiny surfaces on the wall and box reduce the heat flow but the surfaces easily get dirty and therefore require maintenance.

If you want to further reduce the heat flow you can install a radiation shield (a metal plate) in the air gap (see Figure 2). In this case too, the surfaces should be shiny to reduce the effect of the radiation. Figure 2 also shows another situation in which you should use a radiation shield. If the insulation becomes damaged, the radiation shield can reduce the risk of the terminal head containing the transmitter becoming overheated.



Extended article: *Continuation with calculations*

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Estimate of the duct wall temperature given an altered workshop temperature
The heat flow per unit area, q W/m^2, from the flue gases with a temperature of 250 ^{o}C to the external surface of the duct wall with a temperature of T ^{o}C can from a one-dimensional stationary analysis be determined from the

$$q = U\,(250 - T) = h_{tot}\,(T - T_{workshop}) \qquad (1)$$

where $T_{workshop}$ is the workshop temperature in ^{o}C, U W/(m^{2}K) is a “reduced” overall heat transfer coefficient and h_{tot} W/(m^{2}K) a total coefficient that includes both convection and radiation.

When the workshop temperature $T_{workshop}$ is 18 ^{o}C the duct wall’s external surface temperature is 4 5 ^{o}C. The heat flow per unit area is then q_{18} W/(m^{2}K)

$$q_{18} = U\,(250 - 45) = h_{tot}\,(45 - 18) \qquad (2)$$

$$U\,(250 - 45) = h_{tot}\,(45 - 18) \qquad (3)$$

$$U\,205 = h_{tot}\,27 \qquad (4)$$

When the workshop temperature increases to 32 ^{o}C the temperature T ^{o}C also increases on the wall’s external surface and the heat flow decreases to q_{32}.

$$q_{32} = U\,(250 - T) = h_{tot}\,(T - 32) \qquad (5)$$

The heat transfer coefficient U includes forced convection inside the channel and thermal conduction in the insulating material and other materials in the wall etc. In this case the coefficient is insignificantly altered when the temperature inside the workshop changes. In contrast, the total heat transfer coefficient h_{tot} will change because it is more temperature dependent. If we begin by assuming that the total heat transfer coefficient h_{tot} is constant we can easily calculate the duct wall temperature T from (4) and (5). We find that T = 57 ^{o}C.

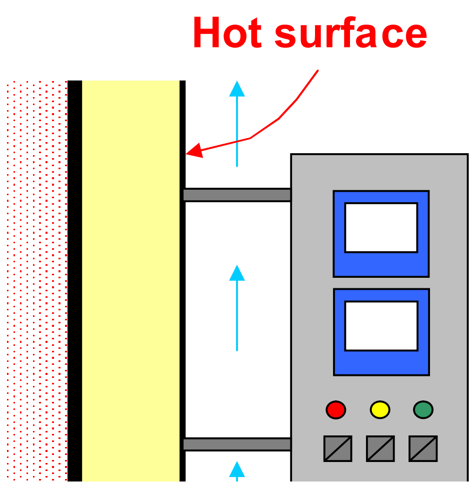

Figure 1. An instrument box is attached to a hot metal surface with extended brackets that leave an air gap. The gap reduces the heating of the instruments.

For the total heat transfer coefficient $h_{tot} = h_{conv} + V_{rad}$ both the convective heat transfer coefficient h_{conv} and the radiation surface heat transfer coefficient h_{rad} depend on the temperature. If we calculate the radiation heat transfer coefficient for the duct wall temperatures of 45 ^{o}C and 57 ^{o}C and the corresponding workshop temperatures of 18 ^{o}C and 32 ^{o}C we get 6.1 W/(m^{2}K) and 6.9 W/(m^{2}K) respectively. In this calculation the duct wall is assumed to have the emission coefficient of 0.95. If we do the corresponding calculation for natural convection and a vertical wall with a height of 0.6 m the convective heat transfer coefficient becomes 3.6 W/(m^{2}K) and 3.5 W/(m^{2}K) respectively. This means that the total heat transfer coefficient h_{tot} changes from 9.7 ^{o}C to 10.4 ^{o}C, a 7% increase. Using (4) and (5) we now find that T = 56 ^{o}C.

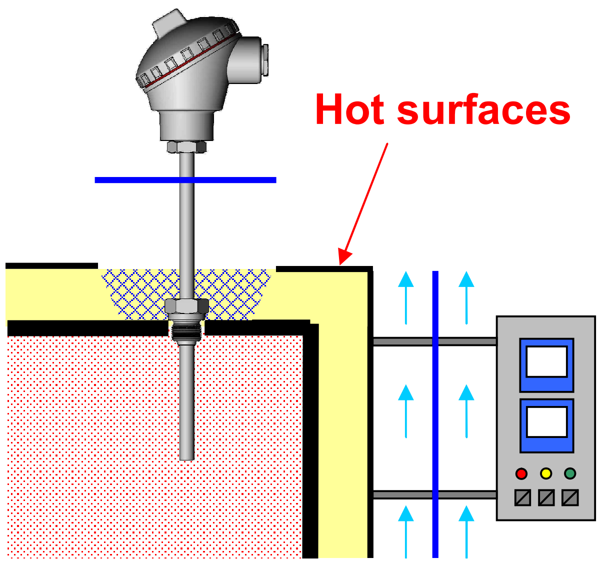

Figure 2. The same as Figure 1 but a metal shield (blue) in the air gap further reduces the radiant heat from the hot surface to the box. The insulation (yellow) can sometimes be inadequate (chequered pattern) after the temperature sensor is tightened into place. In the same way a shield (blue) can limit the heat flow to the sensor's terminal head, which normally contains a transmitter.

An additional calculation with the new duct wall temperature is not necessary because the temperature change is small and the calculations are based on a number of uncertain assumptions. Other assumptions will give different results. For example, if the duct's external surface is more shiny, the emission coefficient is reduced and thereby the radiation. The heat flow to the workshop is reduced and the duct wall temperature increases.