What does the temperature sensor in a waste incinerator measure?

by Professor Dan Loyd

QUESTION: To measure the temperature inside our waste incinerator, one device we use is a type N sheathed thermocouple mounted in a protection tube. Its temperature readings are one of the parameters we use to control the incinerator. Which temperature is the thermocouple actually measuring?

Jan L

ANSWER: The combustion temperature inside waste incinerators is normally about 1000 °C. If we measure the temperature inside the incinerator using a sheathed thermocouple inside a protection tube that lacks a radiation shield, we are measuring a temperature that is being influenced by many factors, such as: the temperature of the fuel bed, the temperature of the gas inside the incinerator, the temperature of the flames, and the temperature of the incinerator's cooled walls.

The thermocouple

Heat is transferred to the protection tube enclosing the thermocouple via convection and radiation from the gas and the burning fuel. From the protection tube, heat is transferred via radiation to, among other things, the cooled walls of the incinerator. In addition, inside the protection tube and thermocouple there is an axial heat flow via thermal conduction to the measuring equipment's attachment to the incinerator wall. It is therefore impossible to measure only the gas temperature by using this type of measuring equipment. The thermocouple only measures its own temperature, which in this case consists of a mean temperature, of which the gas temperature is one of the components. The measuring equipment's often robust construction also causes a relatively long response time.

IR pyrometer

If you want to continually measure only the gas temperature inside an incinerator, you can use an IR pyrometer, which is mounted outside the incinerator in question. Temperature readings are taken via a sight glass and within a narrow wavelength range so as to reduce the influence of various types of disturbance. Sophisticated filter technology and data processing of the readings are then used to increase the accuracy of this method. The pyrometer must also be fitted with some kind of equipment to purge it with e.g. bursts of compressed air in order to avoid the optical system becoming dirty.

Suction pyrometer

For inspection purposes and temporary readings we can use a suction pyrometer to determine the flue gas temperature, see Figure 1. A suction pyrometer is a long, water-cooled instrument, which we can insert via the existing inspection hatches in the incinerator wall in order to reach the relevant areas of the incinerator to measure the flue gas temperature. The gas is sucked at a very high velocity past a sheathed thermocouple, which is surrounded by a radiation shield to minimise the effect of the radiation. Suction pyrometers are not designed for continuous measurement of flue gas temperatures.

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Extended text:

More about suction pyrometers

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A suction pyrometer is not an operational instrument but rather primarily an inspection instrument that is used to measure the flue gas temperature on specific occasions. A suction pyrometer is shaped like a steel tube, which can be four to six metres long so that it can reach and measure inside various parts of the incinerator. This length means that high demands are placed on the instrument's ease of handling and stability of construction. The tube's cross-section can be circular or rectangular. The high temperature of about 1000 °C inside the incinerator means that the instrument must be cooled with water to enable it to function in this demanding environment. The flow of cooling water must be great enough to ensure that the water does not turn to steam inside the instrument. The sheathed thermocouple in the front end of the suction pyrometer is surrounded by a radiation shield in the form of a tube in order to reduce the effect of the radiation – see Figure 1. The radiation shield can be made of steel or ceramic. The flue gas is sucked in via the tube at a very high velocity – about 100 m/s is desirable. Compressed air is often used to operate the suction unit.

The thermocouple is affected by the heat flow via convection from the sucked-in flue gas, and via radiation, partly from the incinerator via the entry hole in the radiation shield and partly from the shield itself. There is also an axial heat flow inside the sheathed thermocouple via thermal conduction to the cooled part of the suction pyrometer. The high velocity of the gas means that convection will dominate over radiation, which means that the temperature reading taken is more or less that of the gas temperature. It is not possible to completely eliminate the measurement error due to the effect of the radiation, but in principle, the higher the velocity of the gas, the lower the measurement error.

The heat balance of the radiation shield is influenced by such factors as convection from the flue gas inside and outside the tube, radiation from the flames and fuel, radiation to the incinerator's cooled walls, radiation to the thermocouple, and thermal conduction inside the protection tube to the cooled section of the suction pyrometer. This has the result that the radiation shield develops a temperature that differs from the flue gas temperature, and this in turn affects the thermocouple and the measurement accuracy. The high gas velocity also means that the thermocouple increases somewhat in temperature when the gas is slowed to a standstill. The size of the total measurement error that occurs when measuring the gas temperature depends on each specific measuring situation.

Unfortunately, it is impossible to calibrate a suction pyrometer in a laboratory, because it is extremely difficult to reproduce the situation that is happening inside a specific incinerator or boiler at a specific measurement occasion. The temperature measured by the thermocouple depends on such factors as the temperature of the flue gas and the radiation shield. The latter, in its turn, depends on such factors as the incineration occurring inside the incinerator while the temperature readings are being taken, and the suction pyrometer's position inside the incinerator at the time. However, the sheathed thermocouple that forms part of the suction pyrometer can be calibrated in a laboratory in the usual way. The difficult measuring environment inside incinerators means that such thermocouples must be calibrated regularly. In suction pyrometers, type N thermocouples are often preferable to type K ones.

The gas that is sucked out of the incinerator via the instrument is normally led to equipment that analyses the composition of the flue gas. By moving the suction pyrometer in the incinerator it is possible to map out the combustion that is occurring inside the incinerator. One problem with suction pyrometers is that they easily become dirty, which reduces the gas velocity and increases the measurement error. As mentioned earlier, suction pyrometers are an inspection instrument and not an operational one.

Measuring the gas temperature in an incinerator or boiler is a complicated project and unfortunately we must always expect some measurement error whatever the measurement method used. The forms of disturbance that arise also vary over time, further complicating the measuring process. The measurement error produced by using a suction pyrometer can easily be several percent of the measured temperature even with a very high gas velocity around the thermocouple. The lower the gas velocity, the higher the measurement error.

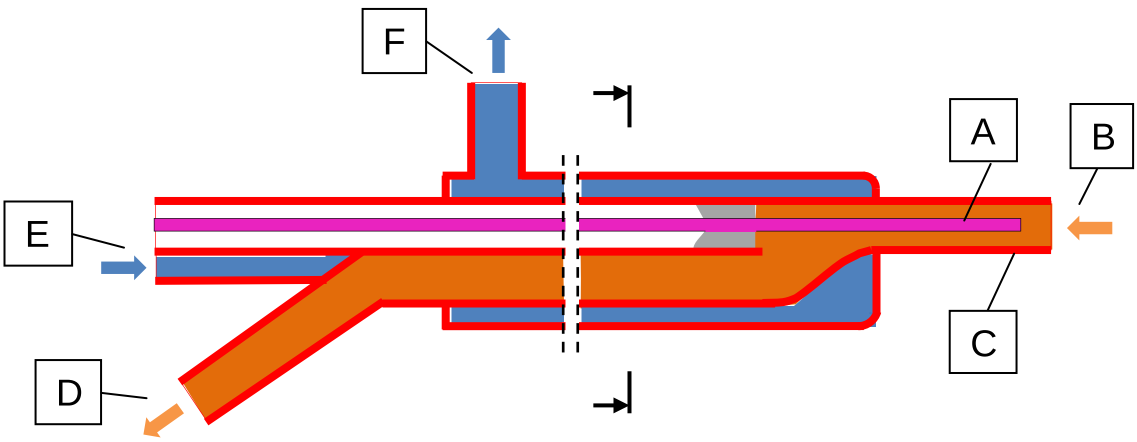

Figure 1.
An example of a suction pyrometer: A) The sheathed thermocouple, B) The entry for the flue gas, C) The radiation shield for the thermocouple probe tip, D) The exit for the flue gas, E) The entry for the cooling water, F) The exit for the cooling water.

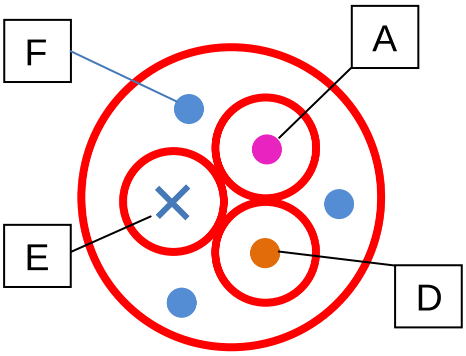

Figure 2.
Cross-section of the suction pyrometer from the cut marked in Figure 1.