Thermal imaging is vital

The importance of reducing harmful emissions and improving combustion efficiency in reheat furnaces

Among the most pressing issues for the iron and steel industry is the need to reduce its environmental footprint. Worldwide air pollution control regulations require producers to measure emissions of control emissions of species, such as carbon monoxide (CO) and oxides of nitrogen (NOx) and particulate matter, from the steelmaking process and downstream operations, such as rolling mills.

In addition, the widespread public awareness of climate change has put pressure on the supply chains of many consumer goods producers to reduce their emissions of greenhouse gases, such as carbon dioxide (CO_2). Fortunately, there are a number of technologies that can be used to improve combustion efficiency and reduce pollution emissions.

Two measurement techniques for improving the efficiency of reheat furnaces that are used to bring a metal billet to the correct temperature for rolling or extrusion processes, are radiometric thermal imaging and oxygen-combustibles measurement. Their benefits include reducing emissions of toxic gases, such as CO and NOx, reducing fuel costs, and reducing the emissions of greenhouse gases, such as CO_2.

These techniques focus on optimising the temperatures within the reheat furnace and on maximising combustion efficiency by balancing the air/fuel ratio within the furnace. Given the amount of fuel used in a reheat furnace, even modest improvements in furnace operation can result in large reductions in both cost and emissions.

Temperature measurements within a reheat furnace have traditionally been made by using thermocouples mounted on the roof and walls of the furnace, or by means of a single-point infrared thermometer. These methods both have limitations. Thermocouples measure the temperature of the furnace walls but not of the billet itself, so models are used to estimate its temperature. These tend to be conservative, so there is a tendency to overheat the billet, which results in significant amounts of wasted fuel.

A single-point infrared thermometer can be used to measure billet temperature directly, saving fuel and improving product quality. An accurate measurement requires a correction for the background temperature. Without this, reflections from the billet surface can result in a significant error in the measured temperature.

Radiometric thermal imaging inside a reheat furnace places specific requirements on a thermal imaging system. The high temperatures within the furnace mean that a short-wavelength imager is preferred, as the intensity of infrared radiation would overwhelm an imager designed for ambient-temperature applications. A short-wavelength sensor also gives more accurate temperature measurements, because it is less dependent on an accurate determination of emissivity. Use of a radiometric thermal imager is important because less-expensive, non-radiometric imagers are available. Although these imagers allow a user to visualise the hotter and cooler portions of a scene, they do not give accurate temperature measurements.

It is impractical to place an imager inside the furnace, but there is a need for a method that allows an imager mounted outside the furnace to view the inside. This can be done using a borescope that allows a wide-angle view of the inside of the furnace even though it requires only a small-diameter penetration through the furnace wall. Because it is an optical device, the borescope must be protected from the harsh environment so it is usually mounted in a water-cooled and air-purged jacket.

A borescope will suffer catastrophic damage if the cooling water fails, so most installations also include an automatic retraction system. This mechanism withdraws the borescope from the furnace if it detects an over-temperature condition at the probe tip or if the purge air fails. A reliable retraction system should include a facility that can withdraw the probe even if the mains power fails; this will typically include a spring-loaded or pneumatic system that does not require electric power to operate. See Figure 1.


Figure 1: An AMETEK Land NIR-Borescope on an automatic retraction mount

Thermal imaging provides a wealth of information that is not readily accessible using traditional temperature measurement techniques, such as thermocouples or single-point infrared thermometers. Most important is the ability to measure the temperature of the entire billet surface. See Figure 2. Image processing software can determine maximum, minimum and average temperatures across the zone of interest. Not only does this minimise fuel wastage, it also allows for increased throughput and improved product quality.

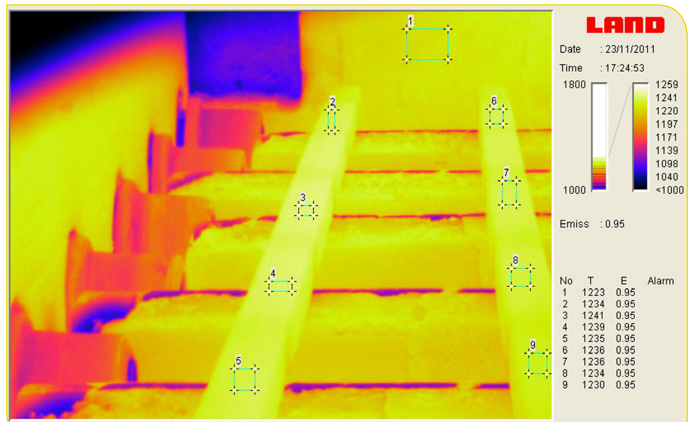


Figure 2: Thermal image of two billets within a reheat furnace

The image processor can also measure the temperature of the furnace walls, so it can compensate for reflected radiation without the need for an additional temperature input.

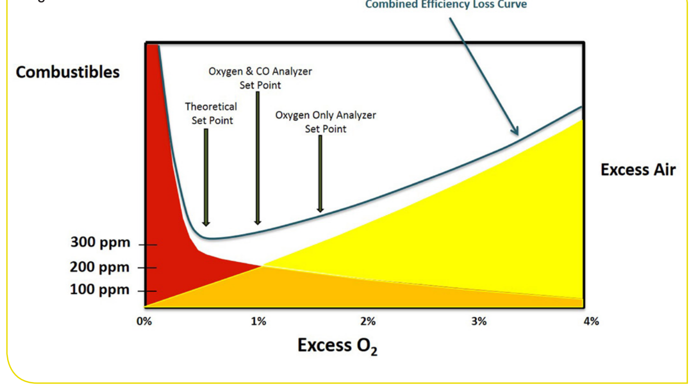
A near-infrared device does not respond to radiation coming from a clean flame, such as that from a natural gas burner, so it is able to view the entire scene within the furnace. Where liquid or solid fuels are used, the radiant flames are visible to the imager. This can be useful, since the flame temperature is key to controlling NOx. Thermal NOx formation occurs rapidly at temperatures above 1600°C through the Zel'dovich mechanism, so maintaining a flame temperature below that point minimises NOx formation. A longer-wavelength sensor operating around 3.9µm can be used, if it is necessary to produce a flame-free image in a furnace with radiant flames.

The amount of fuel burned in a reheat furnace means that efficiency improvements give large benefits. A gas-fired furnace typically consumes 25m³ of fuel per metric ton of steel processed. Improved temperature measurement can reduce fuel consumption by up to 10%, saving money and reducing emissions. For a large furnace, the savings can total in the tens of thousands of dollars per month.

Combustion efficiency can also be improved by optimising the fuel/air ratio within the furnace. For a furnace burning natural gas under ideal conditions, all the fuel and oxygen from the air would be consumed and the only products would be water vapour (H_2O) and carbon dioxide (CO_2). This is known as stoichiometric combustion. Real combustion processes are inevitably more complicated and stoichiometric conditions cannot be achieved in practice.

In addition to the CO_2 and H_2O, carbon monoxide is formed from the incomplete oxidation of the fuel. Fuel-rich conditions, with very little oxygen in the flue gases, are an obvious source of loss because not all of the fuel is burned. Excess air allows the fuel to burn completely, but the additional air carries a lot of heat out of the furnace. The green line shows the total loss. Under ideal operating conditions there is a very small amount of excess air, though the need for flame stability means that it is preferable to operate with an additional safety margin. See Figure 3.

Figure 3: Loss mechanisms



It is clear that the oxygen concentration is an essential parameter for efficient furnace operation, as it allows the selection of the correct fuel/air ratio. Not only does excess air cause a reduction in efficiency, it results in additional NOx formation. That is because the reactions which form NOx depend on the availability of oxygen molecules. Reducing the oxygen concentration also reduces the formation of NOx. However, adjusting the furnace on the basis of oxygen concentration alone usually results in more excess air than would be ideal for the furnace, because the losses caused by operating in a fuel-rich condition are severe.

Adding a measurement of carbon monoxide to the combustion chamber allows more precise control of the fuel/air ratio, resulting in improved efficiency and reduced NOx emissions. The furnace operator can reduce the amount of excess air to a low level and still be confident that all the fuel is being consumed. Some sensors are not specific to carbon monoxide but measure the total amount of material remaining in the furnace gases that can be oxidised, including small amounts of hydrogen or other combustible gases. When these sensors are calibrated using carbon monoxide, the measurement is referred to as 'carbon monoxide equivalent' or COe.

A combined analyser measuring both oxygen and carbon monoxide simplifies installation, calibration and maintenance

A combined analyser measuring both oxygen and carbon monoxide simplifies installation, calibration and maintenance. It isn't generally possible to place sensors within a high-temperature furnace, so an extractive analyser is preferred. The user must choose between fully-extractive and close-coupled extractive analysers, each of which has its advantages and drawbacks.

A close-coupled unit, such as the AMETEK Thermox WDG-VC (See Figure 4), mounts directly to the furnace wall. It uses an eductor to draw a sample of furnace gases into the analyser, then returns it to the furnace. A small portion of the sample is diverted so it passes over a thermal COe sensor and then a zirconia oxygen sensor.

Figure 4: AMETEK Thermox WDG-VC

The advantage of this approach is its fast response time, with a T90 of less than 10 seconds for oxygen and 20 seconds for COe. This allows for a very fast indication of changes in combustion conditions and makes it easier for the operator to correctly adjust the combustion controls. Drawbacks include difficulty of maintenance. The instrument is mounted close to the furnace, so maintenance is only practical when the furnace is not operating, and it is not possible to remove the instrument while the furnace is hot.

A fully-extractive system, such as the AMETEK Land FGA930E (see Figure 5), has a probe that inserts into the furnace. The analyser is located some distance away. This allows it to remain cool, so there is less stress on the electronic components and it is easier to service, even when the process is in operation. A true carbon monoxide measurement is possible using either infrared or electrochemical sensor. The drawback is that it has a slower response time, typically between 45 and 60 seconds, which makes it less convenient to adjust the combustion controls in real-time.

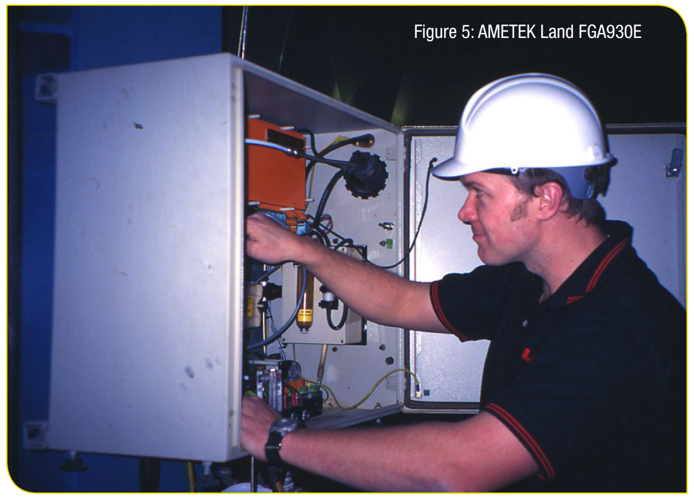


Figure 5: AMETEK Land FGA930E

In conclusion, the use of the latest techniques for measuring process conditions within a reheat furnace, allows the operator to reduce harmful emissions of carbon dioxide and oxides of nitrogen, improve product quality and reduce fuel costs.

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