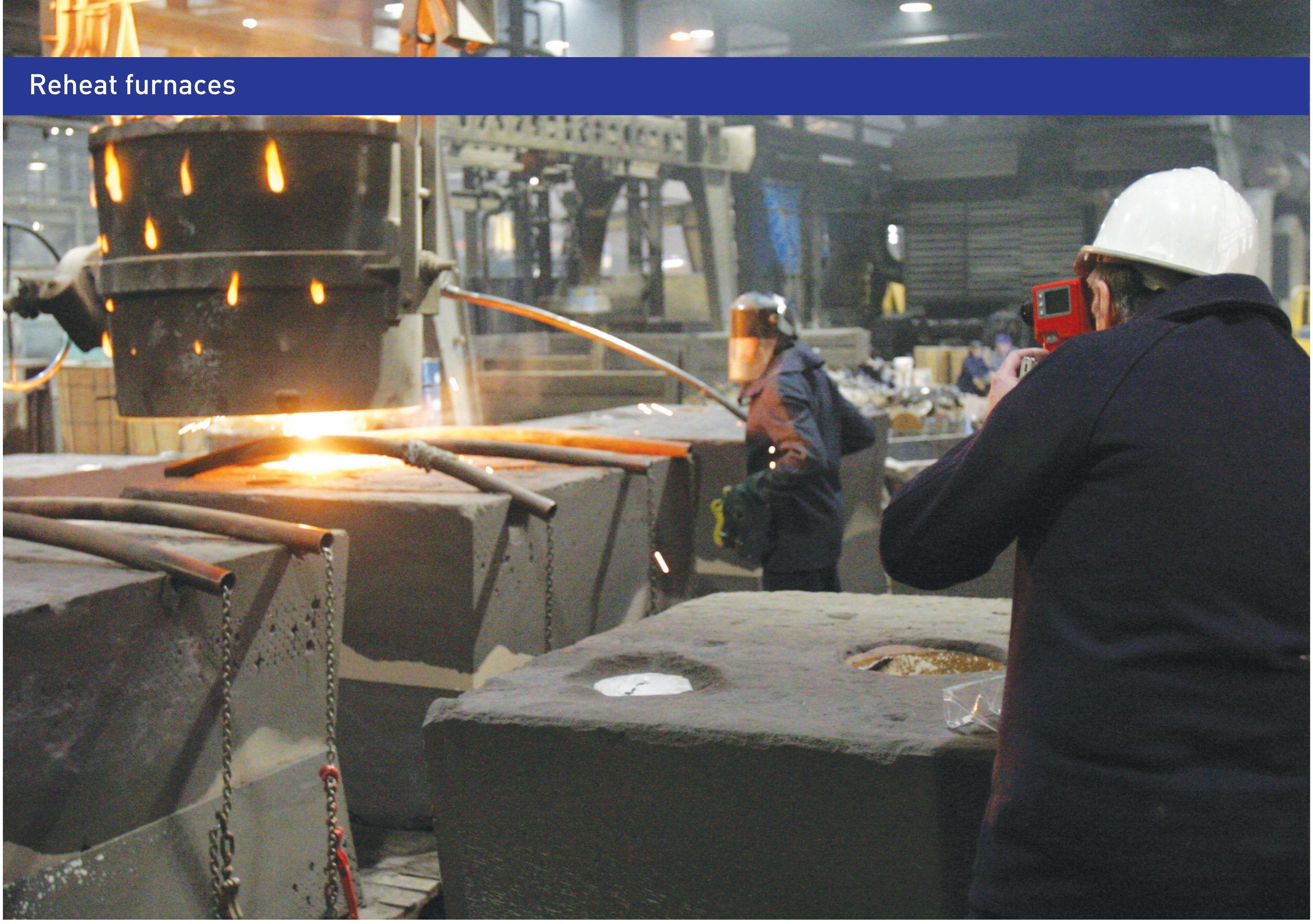
Furnaces INTERNATIONAL

FURNACE TECHNOLOGY FOR THERMAL PROCESSING OF METALS, GLASS & MATERIALS

www.furnaces-international.com
December 2017



Accurate temperature measurement

Richard Gagg* looks at the importance of accurately measuring the temperature of stock as it progresses through steel reheat furnaces.

Most steel plants rely on reheat furnaces to provide stock with a uniform and repeatable temperature to their rolling mills. The aim of the reheat furnace is to create a tightly controlled heating trajectory for the stock as it proceeds from the charge entry to the discharge exit. Ideally for the best fuel efficiency the stock should achieve the desired temperature shortly before discharge.

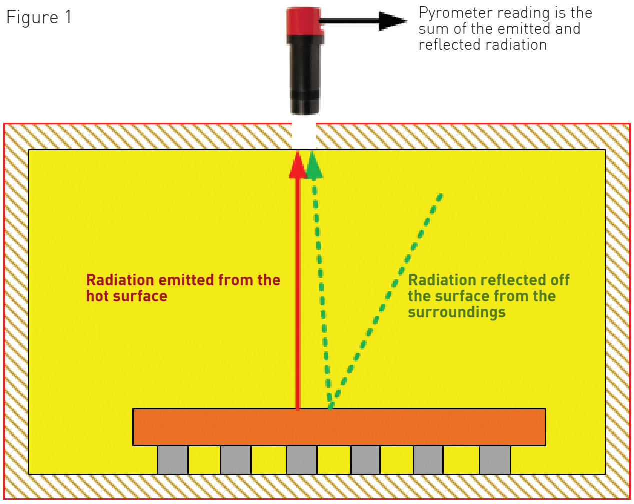
Reheat furnaces have evolved from simple pusher furnaces to walking beam furnaces. The walking beam design produces a much more uniform underside temperature that results in higher-quality finished products. Various fuels are used, usually dependent on local availability and price. With the growing importance of emissions reduction, the industry has seen increased use of oxy-fuelled furnace designs that greatly reduce the formation of nitrogen oxides. These oxy-fuelled systems also are more effective at emitting energy to the furnace load. Regardless of the furnace design or fuels used, it is very important to accurately measure the temperature of the stock as it progresses through the furnace.

Traditional temperature measurements

Thermocouples typically are installed through the furnace roof or walls to measure the furnace temperature in each zone. The furnace temperature is controlled based on those readings. Models based on those thermocouple readings are used to infer the stock temperature as it progresses through the furnace. It is important to understand that the temperature measurements made by the thermocouples are not measurements of the stock, itself, but are measurements of the surroundings.

When thermocouples operate for extended periods at elevated temperatures, their accuracy degrades as their junctions migrate. Thermocouples should be checked on a regular basis and replaced when they become out of specification or broken. As various products are heated in the furnace, care must be taken to understand and accommodate them. Delays or stoppages complicate models.

Figure 1



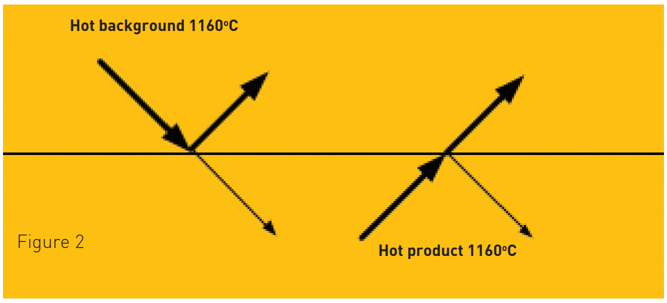


Figure 2

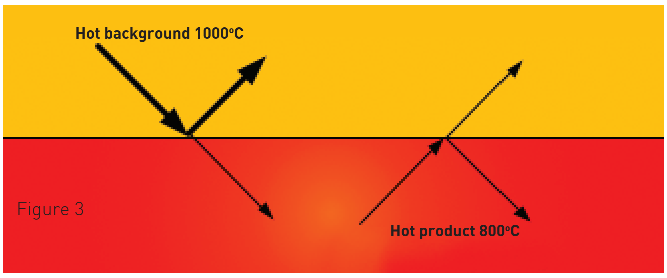
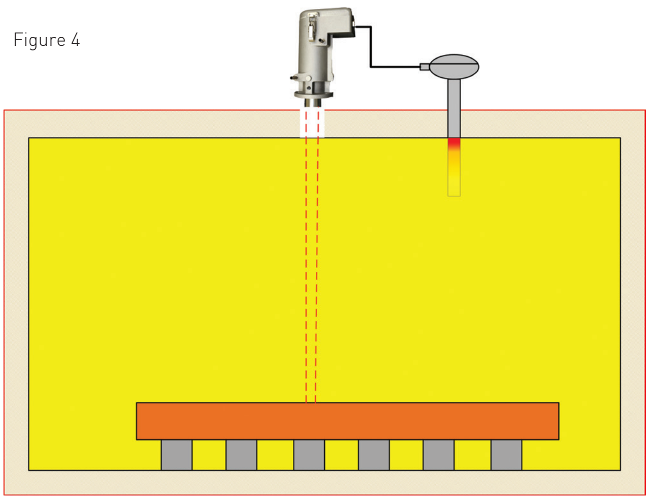


Figure 3

Figure 4



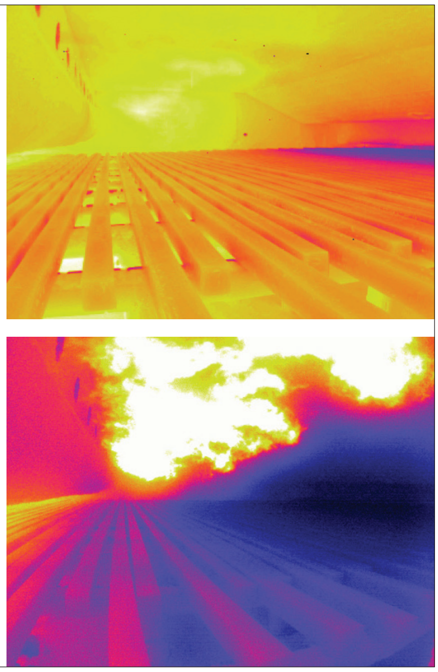


Figure 5
1.0μm image of the gas/oil fired furnace (top) and 3.9μm image, same furnace, transparent flames (bottom)

Some facilities try to compensate for variables by keeping the stock in the soaking zone for a longer period.

Evolving temperature measurements

Non-contact radiation thermometers, also known as infrared pyrometers, have been used for many years to measure actual stock temperatures. A good understanding of the variables involved, as well as the availability of appropriate pyrometer types, is necessary before proceeding to achieve the most accurate temperature measurements. Once the correct pyrometer system is chosen, accurate stock temperature values can be fed to the furnace control model to improve quality and reduce fuel costs. Pyrometer readings are a sum of the emitted and the reflected radiation from the stock. See ***figure 1***.

Soak zone

In the soak zone, the temperature is easy to measure. The surrounding furnace and the stock are at thermal equilibrium, and this environment effectively forms a black body. So, despite the material's emissivity, the emitted component from the stock and reflected component from the furnace combine to produce an environment where everything within it has an emissivity value of 1.0.

If the steel slab has a surface emissivity of 0.80 and the slab surface temperature is 1160 °C, then 80% of the energy of the slab will be emitted. Because Emissivity = 1.0 – Reflectivity (E=1-R) what the slab does not emit it reflects from its surroundings. So, in this example it is reflecting 20% of the energy from the 1160 °C surroundings. The pyrometer measures both the emitted and reflected energy, which when combined is 100% of 1160 °C, see ***figure 2***. So, despite the native emissivity value of the steel the correct emissivity value to use in that black body environment is 1.0. Essentially any type of pyrometer capable of measuring that temperature range can be used and will provide accurate readings. Non-contact pyrometers will provide many years of accurate, drift free measurements.

DEG.C.	0	10	20	30	40	50	60	70	80
700	23.19	27.17	31.75	36.98	42.95	49.74	57.46	66.19	76.06
800	99.69	113.7	129.4	147	166.6	188.3	212.5	239.3	269
900	337.9	377.6	421.3	469.2	521.7	579.1	641.7	710	784.4
1000	953.1	1048	1151	1263	1383	1513	1653	1804	1966
1100	2327	2527	2741	2970	3214	3475	3754	4050	4366
1200	5058	5436	5837	6262	6712	7188	7692	8223	8784

Table 1. (1.0µm raw detector output in mV)

DEG.C.	0	10	20	30	40	50	60	70	80
700	1627	1692	1759	1826	1896	1966	2038	2110	2185
800	2336	2414	2493	2573	2654	2736	2820	2904	2990
900	3165	3254	3344	3435	3527	3620	3714	3809	3905
1000	4100	4199	4299	4400	4502	4604	4708	4812	4918
1100	5131	5239	5347	5457	5567	5678	5790	5903	6016
1200	6246	6361	6478	6595	6713	6831	6951	7071	7191

Table 2. (3.9µm raw detector output in mV)

Pre-heat and heating zones

In the first pre-heat zone, accurate stock temperature measurement is much more challenging. Cold stock is charged into a hot furnace environment, so the reflected component is very high. See ***figure 3***.

Short-wavelength pyrometers

Many end users have learned to use the shortest wavelength pyrometer available because its non-linear response is an advantage if emissivity or other radiated energy variations occur. However, the same factors that make a short wavelength pyrometer the best choice for hot products in cooler surroundings then become an impediment when measuring products in hotter surroundings.

Errors Using Short Wavelength Pyrometers in a Heating Zone

The error can be calculated if raw pyrometer scaleshape data (mV from the detector) is available.

Furnace Wall Temperature (Wt) 1000 °C

Product Temperature (Tt) 800 °C

Product Emissivity (e) 0.8

Product Reflectivity (r) 0.2

The output of the thermometer will be: $V_{out} = e \times T_t + r \times W_t$.

Using values of (e) and (r) and temperature equivalent values from scaleshape table for a 1µm pyrometer.

The output of the thermometer will now be: Vout = 0.8 x 99 + 0.2 x 953. Therefore Vout = 269. Taking the calculated output of 269 and looking up equivalent temperature value from the scaleshape table for a 1µm thermometer will get a temperature value of 880 °C.

The error when using a 1µm under the above conditions is therefore **+ 80 °C**. (see ***Table 1***)

Mid-wavelength pyrometers

With the Same Heating Zone Temperatures but Using a Longer Wavelength 3.9µm pyrometer

The output of the pyrometer is: Vout = 0.8 x 2336 + 0.2 x 4100. Therefore Vout = 2688. The calculated output is 2688 and looking up equivalent temperature values from scaleshape table for a 3.9µm thermometer we will get a temperature value of approximately 840 °C.

The error when using a 3.9µm under the above conditions is therefore **+ 40 °C**. (see ***Table 2***)

The 3.9µm pyrometer with its more linear relationship between energy measured and temperature makes it inherently superior when background temperatures are higher than target temperatures.

In either case, to measure true surface temperatures it is necessary to accurately measure the background temperature and then subtract its effects from the pyrometer's reading. Fortunately, many modern pyrometers can accept a second background temperature measurement input signal from a thermocouple or even another pyrometer and then automatically calculate true surface temperature minus the effects of the reflections. See ***figure 4***.

Furnace atmospheres

If the furnace is fuelled with clean methane/natural gas, both the 1.0µm and 3.9µm pyrometers are unaffected by the products of combustion. However, if dirty fuels are used, they produce significantly more CO_2 and H2O. 1.0µm pyrometers may see interference from those combustion products. A well-documented atmospheric window exists in a narrow waveband around 3.9µm in which the hot CO_2 and H_20 don't emit, so a pyrometer operating at 3.9µm is unaffected.

Thermal imaging

As quality requirements continue to increase, more companies are switching to process thermal imaging systems. These systems provide a high-quality image and are fully radiometric, enabling accurate temperature measurements within the scene. Measurement points, areas of interest and profiles can be placed on the live thermal images.

In ***figure 5*** are two thermal imaging cameras viewing the same reheat furnace, one operating at 1.0µm and the other operating at 3.9µm. This reheat furnace is using a relatively dirty oil/gas fuel. These thermal images show that the 3.9µm imager is unaffected by the flames.

These process thermal imagers also feature secondary inputs, which subtract the reflected component. Process thermal imagers for furnace measurements feature through-the-furnace-wall borescope optics that allow a wide-angle view of the contents while only requiring a small insertion hole. Once installed, these process thermal imagers can operate continuously 24 hours a day.

***Industry Manager – Metals, for AMETEK Land**