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Advantages of 2-Color Pyrometry in Temperature Measurement of the Claus Reaction Furnace

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Pyrometers used to measure Claus furnace temperatures have historically been plagued with operational problems associated with sulfur material being deposited in the mounting nozzle on the vessel or on the viewport window. Both conditions cause an ever-increasing deterioration of accuracy in this critical temperature measurement, often requiring continuous maintenance involving removal of the instrument and cleaning the nozzle and/or viewport to restore accuracy.

While many of these problems have been eliminated by the installation of "Hot-Lens" type instruments that operate hot enough to minimize the buildup of the sulfur deposits in the sight path, certain operating conditions can sometimes allow sight path occlusions to appear. The use of 2 –color ratiometric pyrometer technology can significantly reduce the impact of these occlusions.

By measuring light at multiple wavelengths, it is possible to accurately determine the furnace temperature even if the sight path is partially blocked by debris in the vessel's mounting nozzle or by material build-up on the lens window surface.

Also, by comparing the temperature determined by a single wavelength to the temperature determined by ratiometric dual wavelength measurement, the amount of occlusion can be detected, alerting the operator to schedule maintenance before the temperature measurement accuracy is compromised.

THE PROBLEM OF OCCLUSION

Achieving long term temperature measurement accuracy using Pyrometers in Claus Thermal Reaction Furnaces has proven to be problematic.

Pyrometers determine temperature by measuring the light radiated from the object being measured. Pyrometers used to measure Claus furnace temperatures have historically been plagued with operational problems associated with sulfur deposits building up on the viewport window as shown in Figure 1 or forming in the pyrometer mounting nozzle, as shown in Figure 2. Both conditions cause an ever-increasing deterioration of accuracy in this critical temperature measurement, often requiring continuous maintenance involving removal of the instrument and cleaning the nozzle and/or viewport to restore accuracy.

Figure 1 Sulfur deposits on a pyrometer viewport window

It is well established that most of these problems can be eliminated by the installation of “Hot-Lens” type instruments where the window, valve, and nozzle operate at a high enough temperature to minimize the buildup of the sulfur deposits in the sight path. This practice also eliminates the need for a high-volume nozzle purge. Such purges can cool the nozzle, promoting material deposition further down the sight path and causing corrosion of the nozzle.

Despite the use of “Hot-Lens” technology, certain operating conditions can sometimes still allow sight path occlusions to occur. Process upsets, operator errors (turning off the steam that keeps the lens and nozzle hot), unusual feed gas compositions, certain gas flow patterns within the furnace, etc. can potentially transport occluding material into the sight path.

To understand how these occlusions affect the measurement and to lay the groundwork for understanding how two-color pyrometry can eliminate these effects, let us consider how a typical single-color pyrometer works.

Figure 2 Material collecting in the bottom of a sight port nozzle. Similar occlusions can occur in pyrometer process nozzles.

Advantages of 2-Color Pyrometry in Temperature Measurement of the Claus Reaction Furnace

How a Single-Color Pyrometer Works

Figure 3 shows a typical pyrometer measuring the temperature of a furnace. A broad spectrum of light is emitted by the refractory hot-face of the furnace. This light passes through the reacting gases, which absorb and emit light in various wavelengths in amounts that depend on the gas composition, concentration, and temperature. The light then passes down the nozzle and through a window. An optical filter passes a narrow band of wavelengths to a sensor, whose output is amplified. The non-linear amplified sensor output (Figure 4) is then processed to calculate temperature.
Any occlusion in the nozzle or on the window reduces the sensor voltage by an amount that is proportional to the visible area that is occluded, and resulting in a corresponding reduction in the reported temperature.

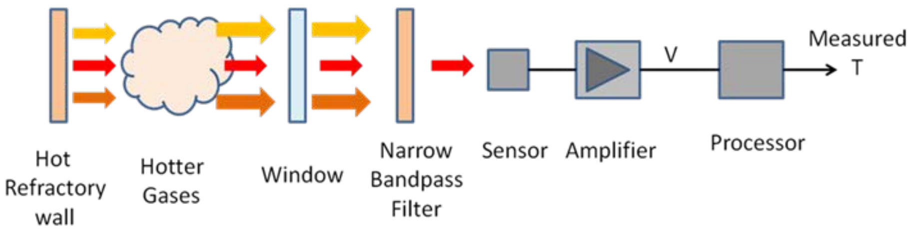

Figure 3 Schematic Representation of a Practical Single-Color Pyrometer

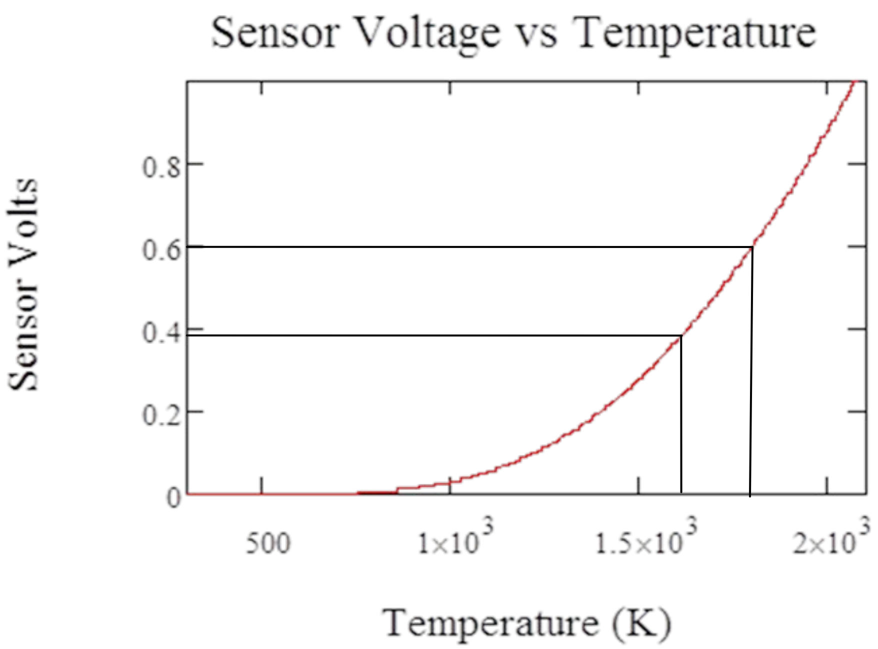

Figure 4 Typical Sensor Output vs. Temperature in a Pyrometer.

HOW A RATIOMETRIC TWO-COLOR PYROMETER WORKS

Figure 5 shows a typical two-color pyrometer. In this case, separate filters select two different wavelengths of light which are measured by two different sensors.
The output from these sensors as a function of temperature is shown in Figure 6. The shapes of the two

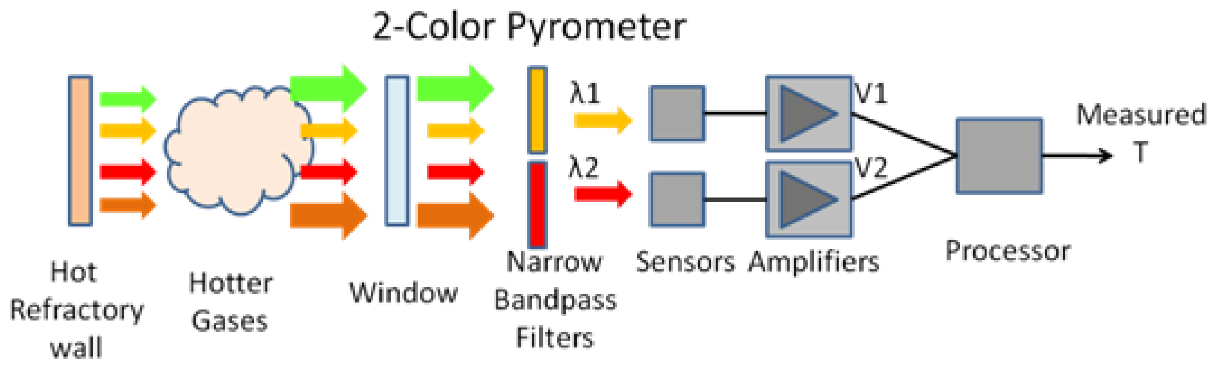

Figure 5 Schematic of a Two-Color Pyrometer

curves are different because of the different wavelengths used. The processor calculates the ratio of the two sensor voltages (Figure 7). The ratio is then used to calculate the temperature.
The reason that the ratio is calculated is that it cancels out any attenuation caused by occlusion as illustrated by Figure 8. The resulting ratio is the same no matter how much the signal is attenuated by material in the sight path, and (assuming that a measureable amount of light is reaching both sensors) can be used to calculate the furnace temperature.

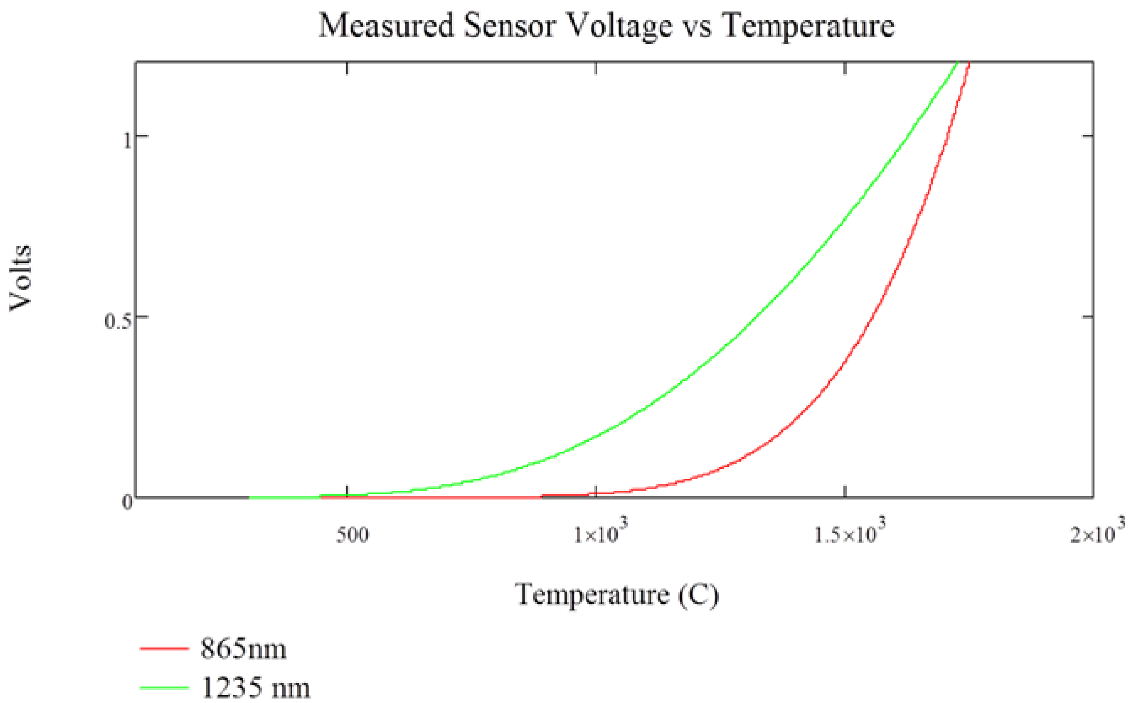

Figure 6 Sensor Output vs. Temperature at Two Different Operating Wavelengths

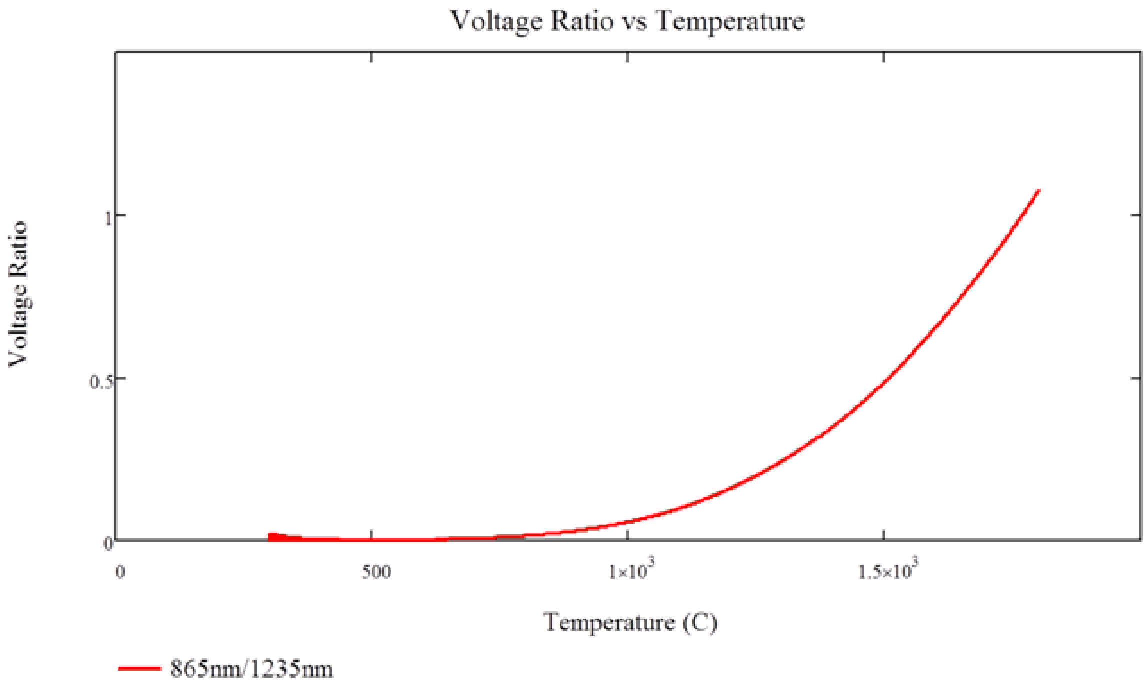

Figure 8 Sensor Output Ratio vs. Temperature

Reduction in V1 caused by occlusion

$$R(T,\lambda_1,\lambda_2) = \frac{Occ \cdot V1(T,\lambda_1)}{Occ \cdot V2(T,\lambda_2)}$$

Reduction in V2 caused by occlusion

Figure 7 Effects of Occlusion Cancelled by Calculating a Ratio

ACCURATE MEASUREMENT IN THE FACE OF OCCLUSION

Thus, two-color pyrometry offers a huge advantage over single-color pyrometry in the Claus Furnace. By measuring light at multiple wavelengths, it is possible to accurately determine the furnace temperature even if the sight path is partially blocked by debris in the vessel's mounting nozzle or by material build-up on the lens window surface. Portable versions (Figure 9) can be used to spot check temperatures even through partially clouded sight ports.

Figure 9. Handheld two-color pyrometer can accurately read refractory temperature through partially clouded sight glass.

OCCLUSION DETECTION – EARLY WARNING OF COMING PROBLEMS

After calculating the temperature using two-colors, one can then calculate what sensor voltage would have been measured if there had been no occlusion. Comparing this theoretical value to the actually measured value allows one to calculate the amount of occlusion that exists in the sight path. This can allow an alarm to be tripped if the occlusion exceeds a certain amount, alerting an operator to the need to investigate the nature of the occlusion and schedule appropriate maintenance. Note that this alarm will be tripped <u>before</u> the occlusion has progressed far enough to compromise measurement accuracy.

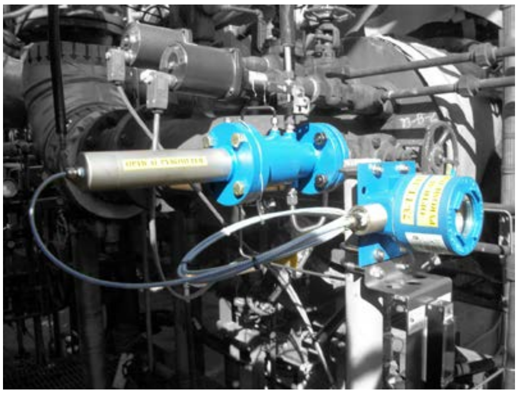

Figure 10 Two-color pyrometer can provide early warning of occlusion <u>before</u> accuracy is compromised.

LIMITATIONS OF RATIOMETRIC 2-COLOR PYROMETRY

The occlusion cancelling effect of making a ratiometric measurement as illustrated in Figure 8 assumes that the attenuation of both wavelengths is the same. In most cases, this is a good assumption - the occluding material is generally thick enough to be opaque at both of the measured wavelengths. In those cases where the occlusion blocks one wavelength more than another, the occlusion-cancelling effect is incomplete and can result in measurement errors. These errors can be either positive or negative, depending on which wavelength is the most attenuated. Examples of what can cause this type of error include sighting through a different type of glass than was used in calibration or translucent coatings of material on the window. Practical experience shows the errors to be far less than single-color errors.

Two different bands of atmospheric transparency are used. The minimum measured temperature is determined by the detection threshold of the shortest wavelength sensor and by the amount of occlusion. The ratiometric measurement can only be made if there is a measureable amount of light at both wavelengths. At lower temperatures, the amount of light at the shorter wavelength may fall below the measurement threshold, even though there is still a measureable amount of light at the longer wavelength. In those cases, the pyrometer typically reverts to a single-color measurement using the longer wavelength.

USING DUAL WAVELENGTHS TO MEASURE REFRACTORY AND FLAME TEMPERATURE

Another use of multiple wavelengths is to improve the accuracy of flame temperature measurement. Hot gases radiate and absorb light in discrete wavelengths, as opposed to the refractory wall, which radiates over a broad range of wavelengths. Refractory temperature is measured by choosing wavelengths where the process gases are highly transparent, thus ignoring the light radiated by the gases. By choosing a wavelength at which process gases radiate, you can create a pyrometer that is sensitive to the gas temperature. However, since the refractory also radiates at these wavelengths, and because the gases are partially transparent, the gas temperature sensor sees some light from the gas and some light from the refractory. A dual wavelength pyrometer can theoretically sort out just the gas temperature by simultaneously measuring the light from the refractory at a wavelength that ignores the gas while simultaneously measuring the light from the gas (which includes some light from the refractory). Then, by entering a factor related to the gas transparency, the pyrometer can remove the effects of refractory temperature from the gas measurement.

For example, Figure 11 shows the transmissivity of a typical mixture of gases[1] near the burner of a Claus furnace. Here the feed gas is largely un-reacted. The atmosphere is mostly transparent over much of the near and mid-infrared wavelengths, except for the region around 2.7 microns, where the atmosphere transmits only about half of the light passing through it. A single color pyrometer operating at 2.7 microns would read about halfway between the gas temperature and the hot-face temperature. By knowing that the transmissivity is around 0.5, and by simultaneously measuring the refractory temperature at a wavelength unaffected by the gas, a two-color pyrometer can remove the effect of the refractory radiation and calculate the actual gas temperature.

LIMITATIONS OF 2-COLOR FLAME TEMPERATURE PYROMETRY

For pyrometers intended to measure gas temperature, the measurement can be affected by changes in the gas composition.

Figure 12 shows the transmissivity of the same gases from the same furnace as Figure 11, but near the tube sheet. The composition has changed considerably during the course of the reaction along with a change in transmissivity. A flame pyrometer with a transmissivity setting of 0.5 would overcompensate for

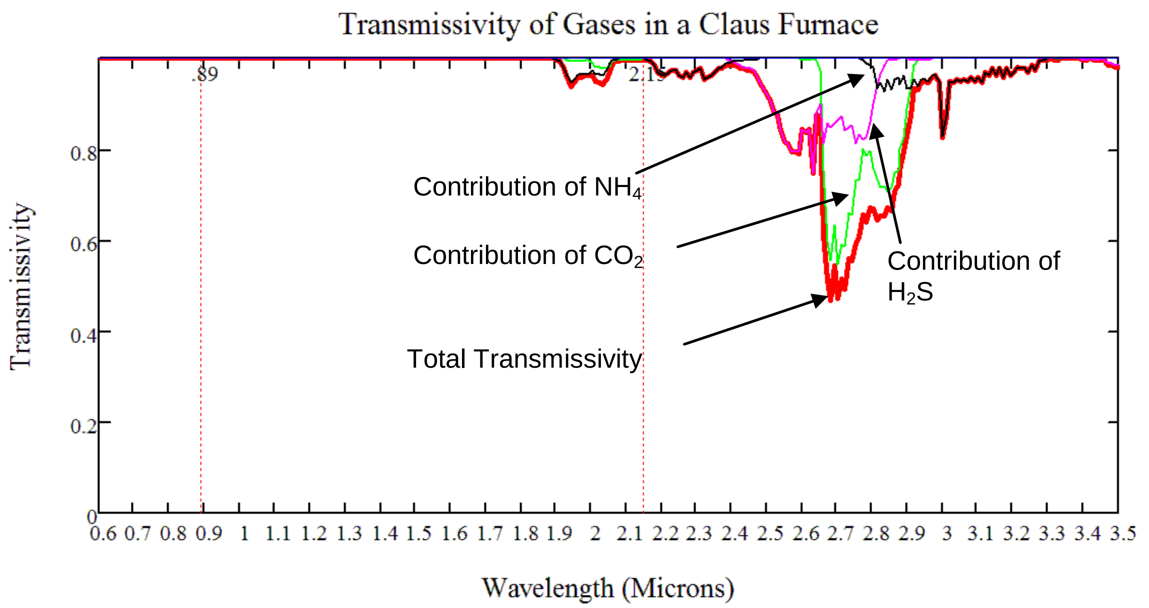

Figure 11 Transmissivity of gases near the burner

[1] Sames, J., Paskall, H., Brown, D., Chen, M., & Sulkowski, D. (2009). Field Measurement of Hydrogen Production in an Oxygen-enriched Claus Furnace. In *Sulphur Recovery* (12th ed., Sulphur Experts. pp. 2.24-2.28).

the gas composition of Figure 12 The two figures shown are for a constant feed gas composition. Changes in feed gas composition and flow rate will further affect the transmissivity at all points along the furnace. Thus while it is possible to compensate for the transmissivity for a given set of operating conditions, the accuracy will suffer as soon as the operating conditions change.

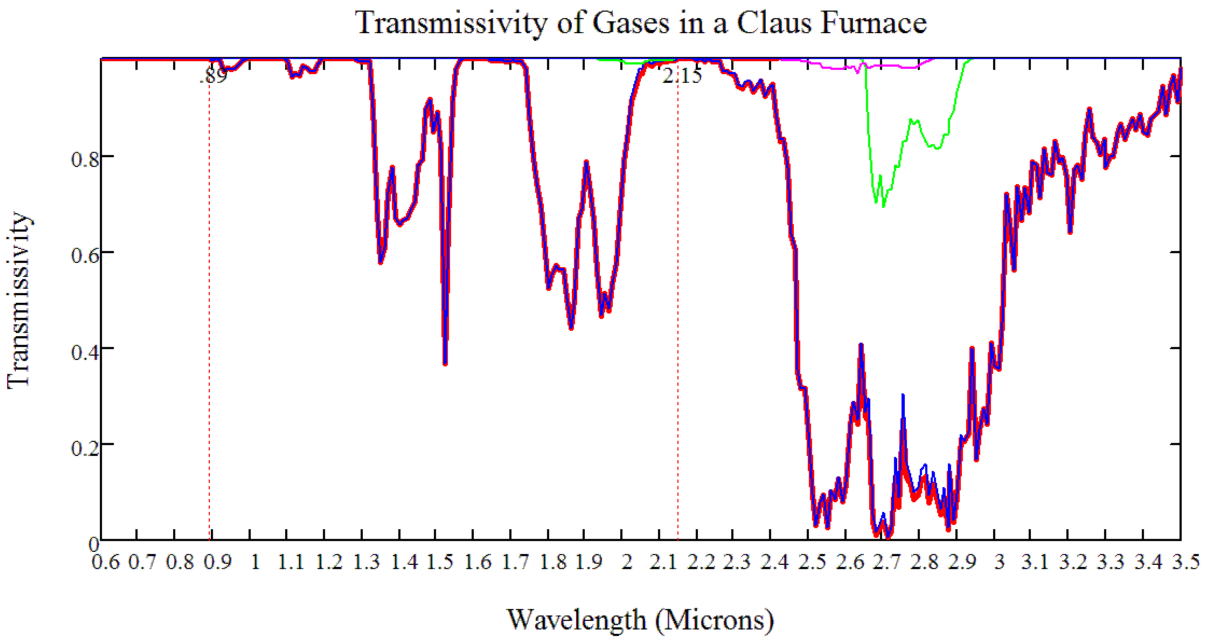

Figure 12 Transmissivity of gases near the tube sheet