White Paper

L.J.STAR INCORPORATED

Process Vessel Lighting: Just Be Cool

Analysis of White LED Light Frequency (Color Temperature) Spectra on Stainless Steel, Absorption and Reflection

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Warm white (relatively red) and cool white (relatively blue) light-emitting diodes (LEDs) were tested to determine their relative efficiency in illuminating a stainless steel tank. A warm white Lumex LED and a cool white Lumex LED were placed at a port on a stainless steel tank, and the luminosity of each LED was measured at a second port using an Extech 401027 Pocket Foot Candle Light Meter. Results showed the cool white LED to be more efficient at illuminating the tank.

Study Purpose

The purpose of this study was to determine which color temperature of white light is best suited for viewing the interior of stainless steel vessels. This technical report discusses the color absorption and reflection of cool and warm white light by stainless steel. Only the two extreme ends of the spectrum of warm and cool white light were tested to demonstrate color frequency of absorption and reflection.

A common configuration for lighting a stainless steel vessel is to use a port for the light inlet and another port for viewing, with both ports located on top of the vessel. Viewing and/or inspection is typically performed with the unaided eye or with a visual camera system that shows the inside of the vessel without altering the data.

Note: When the word *color* is used, it refers to different frequencies in the electromagnetic frequency spectrum. For example, the wavelength range of the color blue is 400–460 nanometers (nm).

The Components of Light

White light is a combination of various visible colors of light. For example, red, green, and blue (RGB) light produce a white light when combined in suitable proportions. When there is more of a specific color in comparison to other colors in the visible light spectrum, the white light is changed. This change in the white light is identified as the color temperature. Color temperature is expressed in units of degrees Kelvin (K). Color temperatures can vary from the most visible violet on the high end of the visible light spectrum to red on the low end of the visible light spectrum or 400-700nm wavelength.

Note: Ultraviolet (UV) and infrared (IR) radiation are also produced by common white light sources, but because they are not visible, they are not addressed in this report because its focus is on the visual aspects of material colors.

Most materials have a specific color. The color of a material represents the varying amount of colors in the light that the material does not absorb. Metallic materials also have specific colors that they absorb on their surface before the light is reflected by them. This color absorption has to do with the material's atomic structure and wavelength band gap. For example, gold has a yellow/reddish color when viewed under white light. This yellow/red color is due to the material absorbing the other colors of light that mixed with yellow/red to make a white color. Therefore, the light that is reflected by the gold contains more yellow and red. The colors that gold absorbs are blue and green. If gold, which is very malleable, is reduced in thickness to a few microns so the point at which light can pass through it, then blue and green light will pass through the material.

Silver, in contrast, absorbs UV light, but all the other colors contained in visible light are reflected. Therefore, silver is known for having the greatest reflectivity, and is therefore used in most mirroring applications.

This explanation of visible color is commonly referred to as *band theory*.

Stainless steel has a band gap of its own. In addition, there's a passive layer of primarily chrome (III) oxide (Cr_2O_3), just nanometers thick, on the metal's surface, which affects the color frequency absorption and reflection. Chrome (III) oxide absorbs color wavelengths in the red and yellow portion of the spectrum, resulting in a blue-green color. This is the primary reason for the blue hue of stainless steel under white light.

When white light is reflected by a material like gold, the colors green and blue are absorbed, i.e., removed from the spectrum, and therefore the light intensity is also reduced. The exact amount of light reduction depends on the amount of the removed color portion of the white light. For example, if a material is visibly red, it absorbs blue (420nm) light. If a blue light of that specific color wavelength (420nm) were shone on the red material, it would absorb 100% of the light. The result is that the absorbed blue light is converted to heat.

Light Sources

Two major sources of light are used in today's industry. The first, which has been used for many years, is the filament-type lamp with halogen gas excitation known as a halogen lamp. Halogen lamps produce warm light based on their concept of operation. A tungsten filament produces white light with its peak on the warm (red) side of the frequency spectrum. Halogen lamps produce a large amount of light; however, they consume a large amount of electrical energy, which is converted to heat.

The second major light source is the LED. This light source is the electroluminescence of a semiconductor metal doped alloy that is electrical current dependent. The color the LED emits is based on the material's band gap. The band gap is modified by doping with various metals in the semiconductor material in the LED manufacturing process. Because LEDs' light production is based on the metal's band gap, LEDs consume relatively small amounts of energy and have a higher luminous efficacy than other current light sources. Luminous efficacy is a measure of electrical energy converted to light vs. heat.

Study Parameters

LEDs were used in this study because their semiconductors can be made to produce warm white light, cool white light, and all color temperatures in between.

For the purposes of this study, it was important to identify that an LED that produces cool white light produces a higher luminous flux (LF) than an LED that produces warm light. Luminous flux is defined as lumens per watt.

For this study, a warm white Lumex model SML-LX4747MWC-TR10 LED and a cool white Lumex model SML-LX4747UWCATR10 LED were used. In order to compensate for the higher luminous flux of the cool white LED, the current driving the cool white LED was reduced so that the LED light outputs matched. An Extech 382275

600 Watt Single Output Laboratory Grade DC Power Supply was used to drive both LED modules. The input voltage and the input current are outlined in **Table 1**. The initial light output was measured a foot away from the light using a one-foot sanitary connection spool piece. This light output is recorded in **Table 1** as "Light Output I (initial)."

The LED lighting unit was placed on the same 1.5-inch top port of a 20 Liter 316L stainless steel vessel. The vessel contains a 3-inch Metaglas® sight glass in the top center of the vessel. Given that both the light and the sight glass are located on the top of the vessel, all of the light that is measured through the sight glass is reflected off the 316L stainless steel interior surface of the vessel. This light output is recorded in **Table 1** as "Light Output R (reflected)."

The light was measured with an Extech 401027 Pocket Foot Candle Light Meter at the 3-inch sight glass for each of the lights. All measurements for both LEDs were performed at the same distance for every test. This allows making a direct correlation between lumens and foot-candles (fc).

Table 1: Study Setup Parameters and Result Values

Lumex LED	Input Voltage (V)	Input Current (A)	Light Output I (foot-candles)	Light Output R (foot-candles)
Warm	12	0.96	900	45
Cool	12	0.71	900	51

Perspective comparison: A well-lit (no sunlight) room or office ranges between 5 and 15 foot-candles.

Conclusion

Cool white light is more effective than warm white light for viewing the interior of stainless steel vessels because more of the light produced is reflected rather than absorbed and converted to heat. The difference in light output from the vessel was nearly 12% or 6 foot-candles, which is a significant value for visibility. The result is that cool white light generated by the use of LEDs allows for greater visibility of a vessel's interior.

L.J. Star offers a broad line of LED sight glass lights, all constructed using cool white LEDs to ensure maximum process visibility. L.J. Star's LED lighting products are widely recognized for their quality and performance. All are designed to help customers reduce their lighting maintenance costs, prevent the transfer of heat to processes, and help customers meet their green processing goals. L.J. Star has received a Vaaler Award from Chemical Processing magazine for its development of the LED Ex Luminaire Series 55-EX with an explosion-proof rating, which is ideal for use in hazardous areas.

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