“Flameless” Oxy-Fuel Combustion for Metals Heating and Melting

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Combustion and its application for metal heating and melting have been around for a long time. Although the field is constantly evolving, game-changing new combustion technologies are few and far between. The introduction of oxy-fuel technology to replace air-fuel combustion is certainly one of them. The most recent of such is arguably what many call “flameless” combustion. Still rather new and not well understood by the end users in the industry, the idea sounds rather academic and seems to challenge the fundamental necessity of a flame to release heat in fossil-fuel combustion.

In fact, flameless combustion does not mean the absence of a flame. It just means the perceived absence of a visible flame by the human eye. This type of combustion can be thought of as “stretched” into a much greater volume than a conventional luminous flame. Consequently there is a lower peak flame temperature and a much more uniform temperature profile in the flame zone. Sometimes flameless combustion is also referred to as “volume combustion,” “spacious combustion,” or “mild combustion.” Such combustion is also characterized by the lack of soot which is often abundant in a conventional flame to give off blackbody luminosity in the visible part of the radiation spectrum. It is therefore understandable that a flameless combustion flame is not visibly distinguishable from a hot furnace background due to the reduced peak temperature difference between the two and the lack of soot in the combustion zone.

People often ask the question, “Will there be a penalty in the radiative heat transfer due to the lower flame temperature of flameless combustion,” as many people understand the strong temperature dependence of radiation. The answer is “no.” It is common to think of a flame in a defined space that is isothermal. However, this is an erroneous over-simplification. Flame temperature is not constant throughout the flame volume, and neither is heat transfer. There simply isn’t just a single radiation heat transfer rate in the furnace. Rather, radiation heat transfer rates are vastly different at different points in the flame, and even at different times due to changes in the furnace environment. The sum of all the virtually infinite number of radiation heat transfer rates is what the load perceives as a collective rate. In fact, an extremely high initial flame temperature is not necessarily good for heat transfer, as it cannot be maintained throughout the flame. The temperature of the flame decreases along its length due to heat loss to the surroundings, and so does the heat transfer. The highest heat transfer rates and the best temperature uniformity are produced by a flame source that has the mildest temperature variation along its length, which is believed to be typical of flameless combustion. It is probably also common to associate flame luminosity with high flame temperature. Luminous flames are usually produced by slow mixing and sharp concentration gradients of fuel and oxidant. The temperature of such a flame will be significantly lower than the adiabatic flame temperature. In fact, the temperatures of most of the flames used for industrial heating and melting are far below the adiabatic flame temperature due to mixing being the rate limiting step and the radiative loss to the environment.
Another factor that works to compensate any effect of the lower flame temperature of flameless combustion is the radiation view factor. The view factor is how well the flame and the load see each other. We see things better when they are 1) closer, 2) larger, and 3) straight-on. The same is true for radiation heat exchange between the load and the flame. Although barely visible to the naked eye, flameless combustion creates a significantly larger flame volume than a conventional luminous flame, leading to better view factors between the flame and the furnace or the load. However, it should be noted that radiation scales with the view factor linearly while to the fourth power of the temperature, so the improvement in the view factor cannot fully compensate the temperature effect. Nevertheless, the highly uniform pattern of heat distribution by flameless combustion further helps with the efficiency. A conventional flame radiating from a much smaller flame volume tends to set up larger temperature gradients in the furnace. This can lead to localized over-heating of the load nearest the flame while leaving other parts cold. Higher temperature set-points or longer process time would therefore be required just to heat up the cold spots, incurring excess energy consumption and the risk of metal loss at the hottest spots.

Another important feature of the flameless combustion technology is the high flame momentum compared to that of a conventional luminous flame. Flameless burners generally operate with multiple fuel injection nozzles at high gas exit velocities, adding a significant convective component to the total heat transfer. The increased flow circulation and penetration further ensure a uniform temperature profile inside the furnace and reduce the heat transfer boundary layer at the metal surfaces. These high momentum jets act like pumps, entraining a large amount of furnace gases and setting up beneficial flow circulation patterns on the furnace scale. Any cold spots or stagnant zones in the furnace are thereby minimized. The power of radiation enhanced with convection delivers the optimal mode of heat transfer, in the same manner that a “convection oven” for home baking is more energy efficient, heats food faster and avoids localized burning.

Another characteristic of flameless combustion is its ability to convert a larger portion of its heat through the re-radiation of the heat from the furnace walls onto the metal in an almost black-body-like fashion. This is possible because of a spectral energy distribution in the IR region which is favorably absorbed by refractory materials. The radiation view factor between the furnace walls and the metal is much larger than that between the flame itself and the metal. The end result is a more uniform heat delivery to the load and a higher thermal efficiency. A furnace with a smaller temperature gradient also adds accuracy to process control and helps avoid large swings in the furnace temperature over time. Flameless combustion can also help achieve controlled burner firing, which is less effective with thermocouples that can only provide local measurements unless the furnace has a relatively flat temperature profile.

How is flameless combustion achieved? Flameless combustion takes place if the fuel and oxidant streams are highly diluted before they mix with each other. This pre-combustion dilution is usually achieved by entrainment of the furnace gases into the fuel with oxidant jets issuing from the burner nozzles, which are often separated from one another. For this to be effective, the furnace temperature must exceed the auto-ignition temperature of the fuel used because of the delayed onset of combustion reaction.

Air Products offers a unique flameless burner for metals melting and heating applications whose installation requires minimum or no modifications to the existing combustion flow control systems. Our new flameless combustion burner can be used for both batch and continuous firing. Most common flameless burners are best suited for continuous firing at a steady-state rate. They do not handle the ramp-ups and ramp-downs usually required for batch furnaces, because of the abrupt change between the flameless and the start-up modes, as the burner turn-down in the flameless mode is usually limited.
Air Products’ flameless combustion burner is designed for a wide turn-down, with seamless and continuous mode transition, ensuring safe burner operation even in cold furnaces. While oxy-fuel combustion can bring up to 50% fuel savings compared to cold air-fired operations, the Air Products flameless combustion burner can deliver up to 10% fuel savings and 10% oxygen savings over and above the benefits achieved by a conventional oxy-fuel burner.

Air Products has an extensive team of combustion technical experts, experienced industry engineers, and knowledgeable equipment engineers dedicated to developing innovative combustion technology. This team leads product development and provides technology support in applications for ferrous and non-ferrous metals, glass, boilers, reformers, and alternative fuels. With several laboratory test furnaces, and state-of-the-art computational modeling capabilities, Air Products combustion R&D team addresses the use of all type of fuels, oxygen enrichment, and full oxy-fuel applications. In addition, Air Products combustion technology is supported by our commercial technology engineers with years of industry experience aligning our R&D efforts to market needs.