
The Flame Game: Controlling Variables for Optimal Performance

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Not all flames are created equal. That's logical, because not all burners are identical. Designing combustion equipment involves more than simple pipe and nozzle sizing. A solid understanding of combustion science helps to harness its power safely and efficiently. Good engineering helps to turn this science into reality. Burner design considerations that maximize the heat transfer efficiency include mixing intensity, flame shape, flame momentum, and fuel or oxidant staging arrangements.

Overall, flames can be categorized according to the fuel and oxidant mixing techniques: either pre-mix or nozzle-mix. Most flames found in industrial heating applications are the nozzle-mix type where the fuel and oxidant flow in separate conduits until they both exit into the ambient. This type of flame is much safer than pre-mix flames where the fuel and oxidant become well mixed in a chamber before entering the combustion zone. Pre-mix flames are subject to flashback when flame propagates back to the mixing chamber, posing serious explosive hazards. Although seen from time to time in very specific processes, pre-mix flames lack the controllability of nozzle-mix flames.

A flame can also be classified as either laminar or turbulent based on the flow speed out of the nozzles. Most industrial flames are turbulent which refers to the flow regime, not necessarily the appearance of the flame, as a turbulent flame can still look straight and well-defined. Some turbulent flames have relatively low momentum to minimize either direct flame impingement wear on the furnace or entrainment of the volatile and particulate process materials. Other turbulent flames have higher flame momentum to help deliver heat in a well-packed furnace. The differences can be achieved by changing nozzle exit velocities, using a pre-combustor to simulate partial pre-mixing, and choosing an oxidant with various oxygen concentrations.

The use of different oxidants is also a method to differentiate flames into one of three categories: (1) *air-fuel* or *oxy-fuel* when the oxidant used is either air or pure oxygen (2) *oxygen-enriched* when the oxidant has an oxygen concentration anywhere in between, and (3) *air-oxy-fuel* when the burner uses both air and pure oxygen.

In addition, the type of fuel – gaseous, liquid, or solid – contributes to vastly different burner designs and combustion characteristics. The choice of fuel depends on availability, cost and certain process requirements. For example, liquid fuel is more readily available in Asia than North American and Europe where the use of natural gas dominates. However, the rising cost of natural gas and fuel oil are forcing many industries to start looking at the option of using solid fuel in their processes, but it's a balancing act between the low fuel cost and the added post treatment requirements.

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The use of air versus oxygen must be weighed carefully as well. For a furnace built for air-fuel combustion, one must evaluate the impact on the furnace refractories and flue gas handling system before switching to oxygen. Pure oxygen raises the flame temperature significantly, drastically improving the heat transfer to the load, but it can also damage a furnace interior not designed for such high temperature operations. The flue gas volume reduces, but the temperature of the flue gas will increase, putting strain on the equipment downstream the furnace.

If used properly, oxy-fuel combustion brings substantial savings to the process by increasing the production, reducing the cycle time, de-bottlenecking a process and saving on fuel usage. Nevertheless, increasing the oxygen concentration in the oxidant is usually accompanied by significant increases in NO_x emissions due to the elevated flame temperature as mentioned before. However, this problem can be combated with proper burner designs by using techniques such as fuel or oxidant staging, and external or internal flue gas re-circulation. Whatever type of combustion is selected for a particular process, the overbearing criterion for a good burner is high heat transfer efficiency, which translates to less money spent on fuel and oxygen.

While oxygen staging may be very effective when applied between the primary flame and a material like molten glass—that's where the heat is needed the most in a glass tank—it may not always be a good idea in other furnaces, such as an aluminum melter. If oxygen gets too close to the aluminum or if the staging delays mixing so much that it lengthens the residence time of free oxygen and oxidizes aluminum, the burner would be a costly mistake. Many aluminum melters run the combustion fuel-rich to avoid oxidizing conditions. However, overall sub-stoichiometry does not guarantee the absence of local oxidizing conditions. The primary objective in managing the combustion process in aluminum melting should be avoiding concentrated oxygen jets around the metal. Oxygen should find fuel before it even gets a chance to contact metal. A properly designed burner should not have to run deeply "sub-stoich" to prevent metal oxidation. Using the right type of oxy-fuel burner with proper installation saves fuel cost and makes the process safer.

While burners are the primary means of aluminum melting, they take on more of an auxiliary role in the ferrous industry. Except for the dedicated uses in reheat furnaces and ladle preheating applications, burners mainly provide supplemental heating or other auxiliary functions in iron and steel production. With natural gas prices skyrocketing, supplemental heating by burners becomes less attractive. However, there remain numerous applications critical to the process that use combustion for other purposes. For example, supersonic oxygen injection is an integral part of Electric Arc Furnace (EAF) steelmaking. Combustion is often used in this technology to provide a flame shroud around the oxygen jet to minimize the jet's momentum loss. Combustion is also needed in solids injection in cupolas or pulverized coal injection for coke replacement in blast furnaces.

In addition to these application-specific needs, facilities constantly work to lower environmental emissions, increase fuel efficiency and improve burner reliability—all of which are universally important regardless of the process. For example, low NO_x emissions from industrial processes are becoming increasingly urgent due to a variety of drivers such as government regulations and corporate responsibility. Oxy-fuel combustion may amplify NO_x generation in a leaky furnace thanks to the much higher flame temperature. Air ingress or purge flows into the furnace are a fact of life, therefore, oxy-fuel burner design has to compensate. Significant R&D efforts are required to curb the burner NO_x sensitivity to air leakage. It is especially true in burners meant to use oxygen-enriched air which is notoriously conducive to high NO_x formation.

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Air Products has a vast amount of technology and field experience in the selection, installation and the operation of metals burner offerings. We offer a distinguished line of combustion equipment in a full range of industrial applications. The Rapidfire® series offerings deliver robust performance in many applications. The OEZ model has proven effective for oxy-fuel aluminum melting and ladle preheating, and the AEZ model for flexible air-oxy-fuel aluminum melting, and OLN and ALN are the low-NOx models of oxy-fuel and air-oxy-fuel metals burners. For aluminum melting, Air Products also offers the Rapidfire LEAM® and RILEE™ processes which aim to reduce unburned hydrocarbon emissions and save fuel cost. For the ferrous industry, the Air Products APCOS™ system can handle oxygen injection, auxiliary heating and solids injection all in one compact burner for cupolas, while our strategic partner, Process Technology International Inc. (PTI), completes our ferrous combustion portfolio in many geographies with the JetBox™ flame-shrouded supersonic oxygen and carbon injection system for EAFs. With our proven industry track record and committed combustion resources, Air Products is ready to take on future challenges in industrial process heating.

Behind every successful burner is a great combustion team. Air Products has an extensive team of combustion technical experts, experienced industry engineers and knowledgeable equipment engineers dedicated to developing innovative combustion technology, helping customers improve their processes and designing safe and reliable combustion equipment. The Air Products combustion R&D center boasts about 20 full-time technologists—half of them with a Ph.D. degree in engineering. This team leads product development and provides technology support in applications for ferrous and non-ferrous metals, glass, boilers, reformers and even materials synthesis. With several active laboratory test furnaces, one high-tech combustion lab and state-of-the-art computational modeling capability, Air Products combustion R&D covers all types of fuel use, oxygen enrichment and full oxy-fuel applications. In addition to the R&D team, our commercial technology engineers with many years of prior experience in glass, aluminum, steel and refractory industries help align the R&D efforts with market needs and provide direct technology support to our customers.

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