

Low-NOx Flat-Flame Burner

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Roof firing of flat flame burners across the furnace width is a common practice for heating steel slabs or billets in reheat-furnace soak zones. This methodology has the potential to provide very uniform temperature distribution across the furnace hearth that directly affects the final quality and downstream processing of the metal being heated. Firing across the furnace roof requires appropriate burner spacing and flame patterns to transform selective combustion-product radiation and convection heat transfer into a continuous radiation band across the entire width of the furnace roof.

To further boost production efficiency and reduce specific fuel consumption, common recuperative heat recovery systems are utilized, resulting in typical preheated combustion air temperatures up to 900°F (482°C) and fuel savings of up to 30%. A major disadvantage of preheated air, however, is the resultant increase in peak flame temperatures that generate significantly higher NOx emissions. Therefore, overall heat transfer, combustion efficiency and reduction of pollutants - formed mainly in the near-burner zones - are critical factors in both the burner

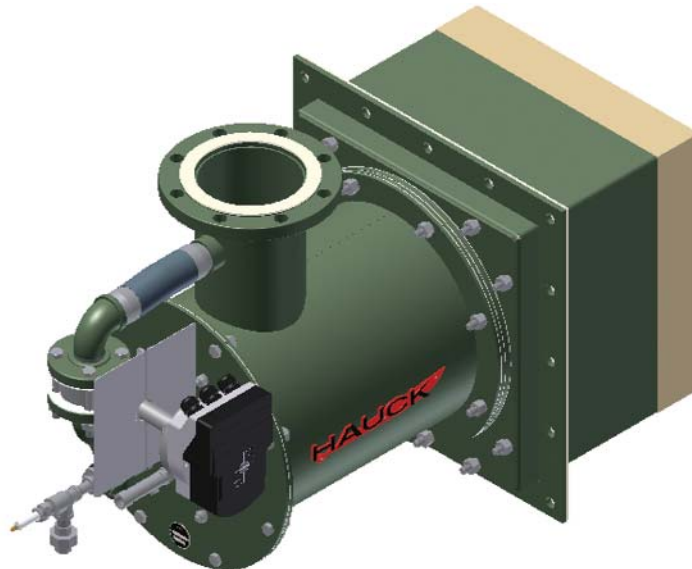


Fig. 1. Wall-hugger Invisiflame® gas burner

and furnace design. The burner design largely dictates the flame structure, efficiency of burning, heat transfer and NOx formation.

Burner Development and Principle of Operation

Based on extensive experimental work and Computational Fluid Dynamic (CFD) modeling using Fluent® CFD software, a novel low-NOx wall-hugger gas burner (Fig.1) was developed to meet the rigorous demands of metal reheating and other high-temperature applications.

The optimized burner design features central fuel injection surrounded by multiple levels of carefully controlled air staging to ensure peak combustion efficiency and flame stability during cold furnace startups while simultaneously minimizing NOx emissions.



The flame hugs the furnace wall - even at high turndown ratios - allowing the burner to be placed close to the load for maximum radiant heat transfer. The burner fires any clean industrial fuel gas with a gross heating value of 500 Btu/ft³ (4,450 Kcal/m³) or greater with ambient or preheated combustion air. The burner operates in two modes dependent on furnace temperature:

- Firing Mode
 - Furnace temperatures < 1600°F (870°C)
- Invisiflame® Mode
 - Furnace temperatures > 1600°F (870°C)

Control of the two modes is done automatically via a furnace-zone thermocouple that drives a motorized butterfly valve to control the level of air staging in the burner. The Firing Mode produces a visible and scannable flat flame appropriate for lower furnace temperatures from cold start conditions up to 1600°F. The flame is anchored to the burner - much like conventional burner designs - resulting in very low carbon monoxide (CO) emissions even in cold furnaces and with only 5% excess combustion air. The air-staged design, however, yields quite low NOx emissions even with preheated air.

At furnace temperatures above 1600°F, the Invisiflame® Mode is preferred, yielding even lower NOx emissions despite higher furnace and preheat temperatures. Under these heavily air-staged firing conditions, the flame is virtually invisible to the naked eye.

The burner was mounted to an experimental test furnace capable

of providing preheated combustion air temperatures up to 900°F (482°C) and was tested over a wide range of operating parameters, including natural-gas flow rates, excess air levels, air preheat temperatures and furnace temperatures. The collected data included flow rates, temperatures and pressures for natural gas and air, furnace draft, furnace-chamber temperatures, furnace exhaust-gas-temperature and flue gas composition.

Burner Performance

The CFD model computed velocity and temperature distributions for flat-flame burner firing at 2.8 MMBtu/hr (820 kW) in the Invisiflame® mode with preheated air of 900°F (482°C) and furnace temperature of 2350°F (1290°C). These are depicted in Figures 2 and 3 respectively.

Fuel and air inlet-port geometries combined with controlled air staging yield the axial-velocity profile shown in Figure 2. The air/fuel mixing and initial heat release cause the flame zone to stretch and entrain large amounts of furnace flue gases at the burner centerline. This is demonstrated by the highly negative axial-velocity zone in the near-burner field. This furnace flue-gas entrainment further suppresses NOx emissions. Even with preheated combustion air, the resultant peak flame temperatures, shown in Figure 3, are significantly lower than conventional flat flame burner combustion techniques. The primary gas/air/flue-gas mixture formed in the burner tile is gradually burned

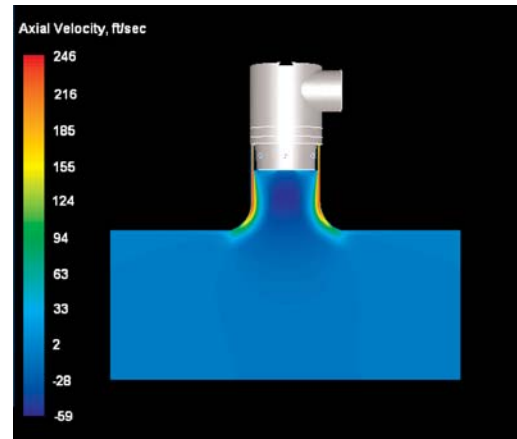


Fig. 2. Axial-velocity contour (ft/s)

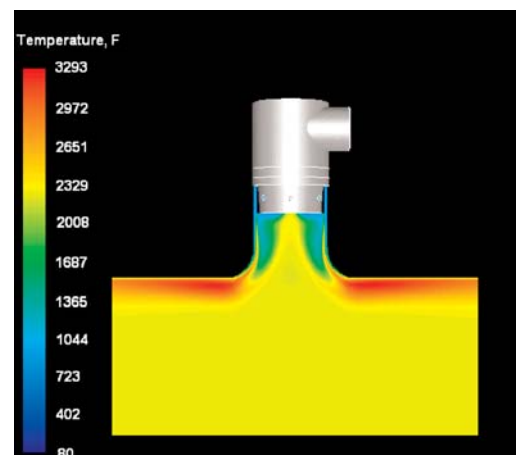


Fig. 3. Temperature contour (Invisiflame® Mode °F)

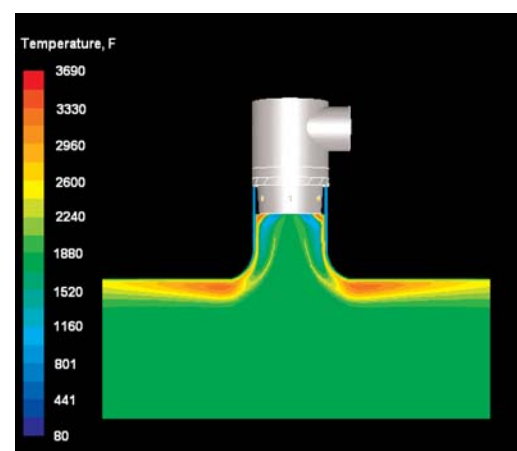


Fig. 4. Temperature contour (Firing Mode °F)

in the furnace at or near the lean flammability limit (as suppressed flame temperatures), thus greatly reducing the formation of NO_x. The temperature profile further demonstrates the extremely flat nature of the flame. Furthermore, the burner turndown ratio exceeds 8:1 with no degradation of the flat-flame profile combustion efficiency.

The CFD model computed temperature distribution for the burner firing at 2.8 MMBtu/hr (820kW) in the Firing Mode with preheated air of 900°F (482°C) and furnace temperature of 1800°F (980°C) is shown in Figure 4. The peak flame temperature of 3690°F (2030°C) in Firing Mode is 400°F higher than Invisiflame® Mode, and subsequent NO_x formation is higher, too. The experimental NO_x data was treated with regression analysis, and the generalized burner NO_x curves are shown in Figure 5.

The burner NO_x formation in Invisiflame® Mode is below 30 ppm (0.036lb/MMBtu or 62 mg/Nm³) for combustion air preheated up to 900°F (480°C) and furnace temperatures of 2300°F (1260°C).

The flat-flame burner fired in the high temperature Invisiflame® Mode provides excellent temperature uniformity to the furnace hearth or load. The computed temperature distribution at two different axial distances from the burner-tile exit is shown in Figure 6. At 23 inches (584 mm) from the burner exit, the temperature variation in front and 40 inches (1,016 mm) to each side of the burner varies less than +/- 1.5 °F (0.8°C).

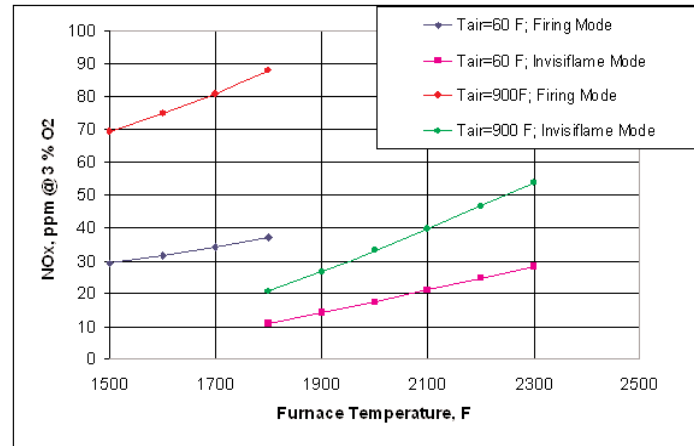


Fig. 5. Burner NO_x emissions

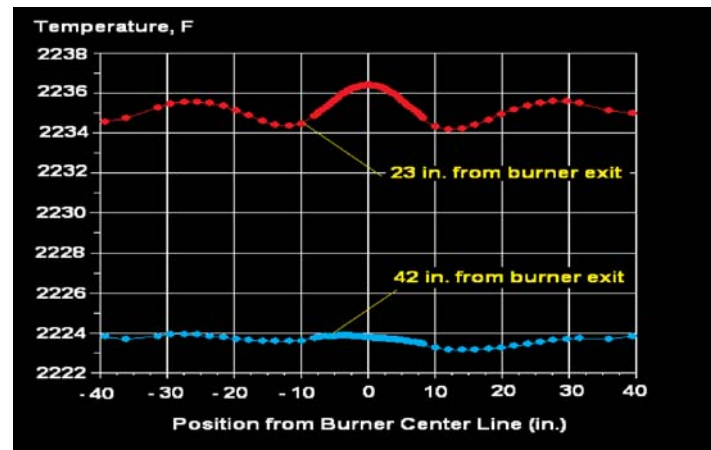


Fig. 6. WHI Invisiflame® temperature profile

Conclusion

The flat-flame burner design incorporating three stages of air injection combines with a very unique fuel nozzle has proven performance benefits, including very low NO_x emissions, high preheat capability for maximum fuel and production efficiency, optimum combustion efficiency with very low to zero CO emissions and excellent temperature uniformity for superior product quality. At high furnace temperatures and preheated air levels typical of reheating and other high-temperature furnaces, NO_x emissions are below 50 ppm corrected to 3% O₂ - less than most conventional burners firing without preheated air.

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