

A Success Story

Pusher Reheat Furnace Collaboration

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Conflicting goals of minimum energy consumption and pollutant discharge challenge steelmakers and their equipment suppliers to use every available technology to design energy efficient, environmentally compliant combustion systems. Armed with a solid understanding of the objectives, advanced modeling and highly efficient burner and control systems, this team designed and built equipment that far exceeds the design requirements. This is their story.



Figure 1 - Nucor Auburn pusher furnace



In today's competitive global marketplace, strict environmental regulations require that steel makers minimize specific fuel consumption while simultaneously reducing pollutants including nitrogen oxides (NOx). With conventional burner designs these two goals were often conflicting. However, using the latest technology burner designs with diffused flame combustion techniques, high levels of efficiency via preheated combustion air with correspondingly low NOx emissions are now being achieved.

One such example is Nucor Steel, Auburn NY mill facility's latest pusher reheat furnace incorporating state of the art TriOx burners from Hauck Manufacturing Company (Hauck).

One example is Nucor Steel's mill facility's latest pusher reheat furnace incorporating state-of-the-art TriOx burners. From the outset, the furnace design had to be capable of energy consumption of less than 1 MMBtu/ton of steel at production rates up to 120 tons/hr, a significant increase from the mill's prior reheat furnace capacity. It also had to comply with ultra-low NOx emissions requirements which are continuously monitored by a dedicated Continuous Emissions Monitoring (CEM) system.

Background

Nucor's furnace, built by Forni Industriali Bendotti S.p.A., is a 60 ft long pusher reheat furnace rated for 120 tons/hr with peel bar discharge. It incorporates a recuperator for preheated combustion air to all burners operated via a mass flow control/PLC system.

The primary mill products include rebar, merchant bar quality; rounds, squares, flats, angles, and channels; as well as special bar quality steels in over 130 sizes of various grades and chemistries and produced from 100% recycled scrap. The reheat furnace replaced an older unit with nominal capacities of 50 tons/hr up to 95 tons/hr with a hot charge and a maximum billet length of only 14 ft.

The new furnace is approximately 42 ft wide and includes a total of 22 TriOx burners divided into four zones of control (Figure 1). There are six burners in the bottom heat zone side-fired and directly opposed to one another and each rated for a nominal capacity of 12.3 MMBtu/hr with hot air. Similarly, there are six burners above the pass line in the top heat zone also directly opposed and rated at a nominal capacity of 9.6 MMBtu/hr each. Finally, the



Figure 2 - TriOx Burner

soak zone is end-fired with a total of ten burners subdivided into two zones of five each with burners rated at a nominal capacity of 2.7 MMBtu/hr each. Further, the furnace height above and below the pass line is 6 ft 6 in with the burners offset away from the pass line to promote combustion burnout and reduce scale formation.

The furnace design includes provisional ports for four additional burners, two in the top heat and two in the bottom heat zones, to increase furnace capacity in the future. For maximum system efficiency and temperature uniformity, the furnace design includes both top and bottom flues. Typical billet size is 6.25 in square by 40 ft long. As with most combustion systems, the entire furnace design including burner placement is critical for overall heat transfer and combustion system efficiency. With the distributed combustion or Invisiflame® TriOx technology, furnace design can directly influence overall NOx production. The burner's port geometry and placement in the furnace wall is very important to ensure maximum flue gas entrainment into the flame root for maximum NOx reduction.

Prior to obtaining the purchase order for this project, Hauck conducted

a detailed Fluent® Computational Fluid Dynamics (CFD) analysis of the furnace heat zones.

Those results were combined with previous individual burner CFD modeling and experimental laboratory data to calculate heat transfer performance, temperature uniformity, flow and velocity fields, as well as expected NOx emissions.

The burner (Figure 2) incorporates three stages of combustion air to minimize NOx formation while maximizing production efficiency with high temperature preheated air. The staged air flow is further controlled by a burner switching valve, also shown, that proportions the correct amount of air to each burner stage, dependent on furnace temperature. For temperatures above about 1,600°F, or Invisiflame® operation, the air flow is heavily staged for minimal NOx production. However, at lower furnace temperatures, which might exist following normal furnace shutdown or maintenance periods, the extreme air staging taking place at high temperatures is inappropriate as large levels of unburned Hydrocarbons (HC) or Carbon Monoxide (CO) could result.

Therefore, via the appropriate thermocouple input, the furnace PLC simply provides an output signal to the burner switching valve control motor to place the valve in the appropriate position for optimal performance and emissions control. The burner is capable of low excess air operation typically 5% with mass flow control, throughout its entire operating range. Fuel efficiency can be maximized over a full range of production rate demands.

The geometry of the burner largely dictates the flame structure, efficiency of burning, heat transfer, and NOx formation. The burner features central fuel injection surrounded by multiple levels of carefully controlled air staging, to ensure carbon monoxide (CO) burnout and flame stability during cold furnace startups while simultaneously minimizing NOx emissions. Optimal fuel and air inlet port geometries combined with controlled air staging and hot air discharge velocities in the 200 ft/s range cause the flame zone to stretch and entrain large amounts of furnace flue gases. As illustrated in Figure 3, peak flame temperatures are significantly lower than in conventional combustion techniques with subsequent ultra low NOx emissions achievable even with preheated combustion air.

Experimental testing of the burner at high fire and with 2,060°F (1127°C) chamber temperatures with pre-heated combustion air of 800°F (427°C) resulted in NOx emissions of approximately 34 ppmvd at 3% O2 (0.037 lbs/MMBtu).

Results

Furnace commissioning took place in April, 2005 with an extended dry-out period followed by immediate production.

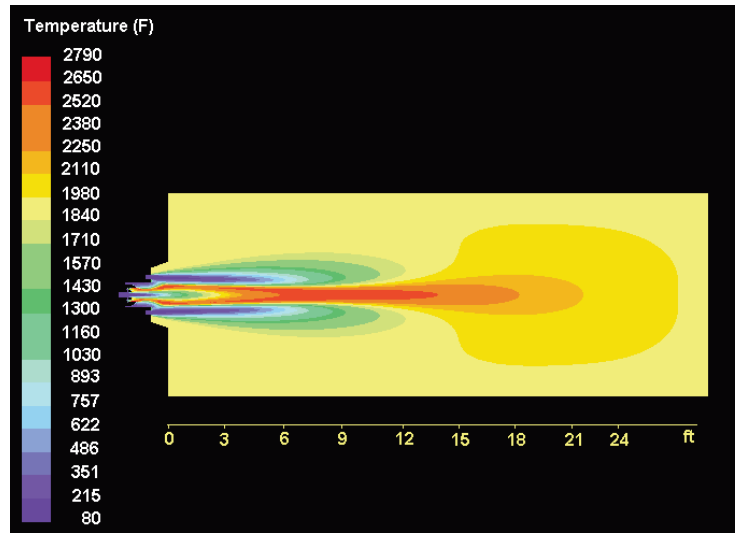


Figure 3 - TriOx burner temperature profile

The following data were collected during normal pusher furnace operations:

- Load type, size, and weight
- Furnace production rate
- Billet surface temperature at furnace discharge
- Furnace zone temperature set points
- Furnace temperatures
- Natural gas and combustion air flow rates by zone
- Emissions of NOx, CO, and O2

Furnace operational data downloaded at maximum production from the PLC are presented in Table 1.

Table 1. Production Data		
Furnace Production Rate	140	Ton/hr
N. Gas Gross Heating Value	1,031	Btu/scf
N. Gas Total Flow Rate	117,960	scfh
Furnace Firing Rate	121.6	MMBtu/hr
Combustion Air Preheat Temperature	827 (442)	°F (°C)
Flue Gas Exhaust Temperature	1444 (785)	°F (°C)
Billet Discharge Temperature	2014 (1100)	°F (°C)
Overall Excess Air	5	%

Furnace outer wall temperatures were also measured for furnace heat losses calculations. Billet surface and centerline temperatures were calculated based on the furnace temperature profile using proprietary heat transfer software and are shown in Figure 4.

The billet heating process occurs smoothly with a mean rate of 17.7 °F/min. in the middle of the heating zones and 4 °F/min. in the soak zones. The overall furnace design including burner positioning, port geometry and spacing provides good furnace temperature uniformity and heat transfer to the metal being heated. Furnace production rates of 140 tons/hr are common despite the original design rating of only 120 tons/hr.

FLUENT® CFD software was utilized to obtain detailed furnace temperature distributions. The temperature distribution in the horizontal sections via the burners is shown in Figure 5. Only one half of the furnace width is shown in Figure 5 for better clarity. The products of combustion (POC's) from the soak zone are included in the model and flow from right to left; only a minor influence of soak zone POC's is seen on the flames with mild distortion in the downstream direction. Simulation results show that high temperature regions are located primarily inside the burner tiles and occupy very small volumes with short residence times leading to very low NOx production. Overall heat or flame distribution patterns in the near burner zones are very similar to single burner modeling results which were validated via laboratory experiment. Temperature uniformity of the POC gases across the furnace width is quite good; the local maximums at the flames result in elevated temperature regions close to the furnace top and bottom walls.

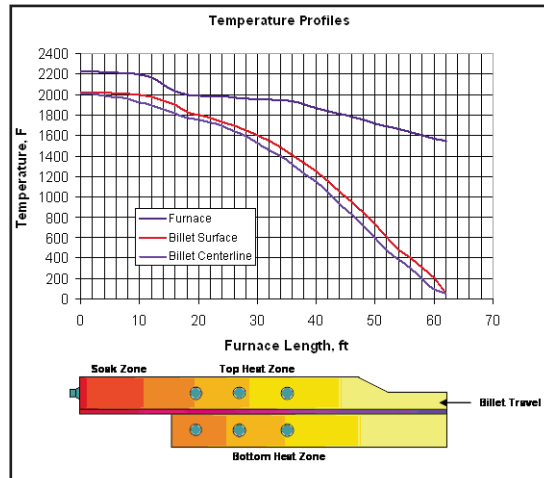


Figure 4 - Temperature profiles

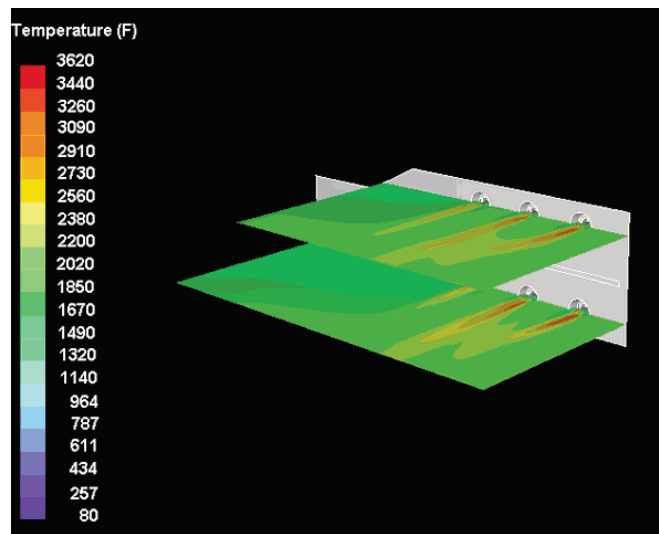


Figure 5 - Temperature profile in horizontal plane via burner centerlines

Billet temperature uniformity and long term successful billet rolling further support Fluent® results.

An overall furnace heat balance was computed (Table 2) based on the data collected.

Table 2 - Pusher furnace heat balance					
Input	MMBtu/hr	%	Output	MMBtu/hr	%
Heat from Fuel	121.6	87.1	Heat of Product	91.2	65.8
Heat of Preheated Air	16.9	12.9	Heat of Flue Gas	40.0	29
			Furnace Walls Heat Loss	1.1	0.7
			Heat of Water Cooling	6.2	4.5
Total	138.5	100	Total	138.5	100



The preheated combustion air of 827°F (442 °C) accounts for about 13% of the total furnace heat input. Furnace wall losses are very low at less than 1% of total heat input. Overall furnace performance is quite good considering the heat absorbed by the steel represents 75% of the heat from fuel input or about 66% of the total heat input if including preheated combustion air. Furthermore, specific fuel consumption of 868,000 Btu/ton is well below the design target of approximately 1 MMBtu/ton.

Emissions, as monitored by the CEM, have remained well below the permitted threshold throughout the furnace operation including production rates from less than 60 tons/hr to 140 tons/hr as well as during cold furnace startups following prolonged mill shutdowns. At the maximum production rate of 140 tons/hr reported here, NOx emissions of less than 0.052 lbs/MMBtu were recorded with air preheats exceeding 800°F (427°C). At lower production rates and slightly lower air preheat levels, NOx emissions less than 0.045 lbs/MMBtu were commonly recorded. Furthermore CO emissions are virtually zero during any operating conditions.

Conclusion

Remaining cost competitive in the face of higher fuel and raw material prices combined with increasing market competition are the challenges faced by every major steel producer. In the case of Nucor Auburn's pusher reheat furnace, the desired method to achieve these goals included a state of the art furnace, control system, and burners utilizing preheated combustion air, but with very stringent environmental regulatory requirements.

Regulatory requirement for ultra low NOx emissions, as well as Nucor's goals of increasing furnace production, reducing specific fuel consumption, and minimizing scale formation, were ultimately achieved and proven in practice with the application of Hauck's Invisiflame® TriOx burner technology. Close collaboration between furnace builder, end customer, and burner supplier combined with state of the art CFD modeling to optimize burner design, placement in the furnace, and burner port geometry have ensured long term success.

To date, rolling operations are running smoothly, production rates have exceeded design targets while simultaneously beating specific fuel consumption targets, and NOx emission are well within regulatory requirements.

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