

Ultra Low NOx Flat Flame Burner Application for Steel Reheat Furnaces

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Steel producers world-wide face the competing challenges of reducing fuel consumption and meeting increasingly stringent emissions regulations when reheating steel. While central heat recuperators are a common means to reduce fuel consumption, conventional burner designs used on steel reheat furnaces yield higher Nitrogen Oxide (NOx) emissions through the higher resultant flame temperatures. As for newer low NOx burners, the choices are often limited by the design requirements of the furnace. Hauck Manufacturing Co. recently supplied a unique application of two different burners as a solution to these two competing challenges through the utilization of both side and roof fired ultra low NOx burners for two advanced technology pusher steel reheat furnaces rated at 120 tons/hr each designed by CMI Thermline in Belgium.



Figure 1. WHI Burner Detail

DISCUSSION

Traditional requirements for steel reheat furnaces include the need to heat the steel uniformly at the required production rate and to do so efficiently. The burners applied are required to be sized and fired in such a way as to meet all the production demands of the furnace including idling. In addition, uniform steel heating requires that particular attention be paid to burner placement. Being able to meet the complete operational demands of the furnace while also providing for uniform heating and the need for ultra low NOx emissions are the drivers for today's advanced burner designs.



The upper soak zones of the reheat furnace are equipped with three rows of four each of 6" WHI flat flame burners while the lower soak zone is equipped with four 12" TriOx side fired burners. The heat zones are equipped with a total of twenty 12" TriOx side fired burners with advanced controls and control algorithm proprietary to CMI Thermline.

The WHI flat flame burner used in the soak zone features triple air staging to minimize NOx and CO emissions even with high temperature preheated air over 550°C. The burner can be equipped for two modes of firing as required; a traditional 'firing' mode with less air staging for cold furnace start-ups and minimal CO formation and an Invisiflame® mode with highly staged air for minimal NOx emissions at high furnace temperatures. The burner features central fuel injection at a compound angle surrounded by multiple levels of carefully controlled air staging to optimize emissions and flame geometry. The burner structure is shown in Figure 1. The first two stages of air provide for a stable flame anchoring point for the low temperature operating mode, while the third stage of air is swirled. The swirl number, defined as(1):

$$S = \frac{G_{\phi}}{G_x \cdot R} \quad (1)$$

where

G_{ϕ} = axial flux of angular momentum

G_x = axial thrust

R = exit radius of the burner nozzle

Further simplification by Chigier and Beer(1) for an axial vane swirler results in:

$$S = \frac{2}{3} \left[\frac{1 - (R_h / R)^3}{1 - (R_h / R)^2} \right] \tan \alpha$$

Where:

R_h = hub or inside radius of the axial vane swirler

α = spin vane angle relative to central axis

was experimentally developed with optimal flame geometry achieved at $S = 0.7$. The high level of swirl combined with the compound fuel injection angle and fluted tile

maintaining the desired flat flame, or Invisiflame®, profile.

A temperature contour of the burner firing in Invisiflame® mode at 820 kW is depicted in Figure 2. Optimal fuel and air inlet port geometries combined with controlled air staging and strong swirl causes the flame zone to stretch and subsequently entrain large amounts of furnace gases in the center axis resulting in lower peak flame temperatures. Note the very low temperatures in the near burner region. The peak flame temperature in this case is

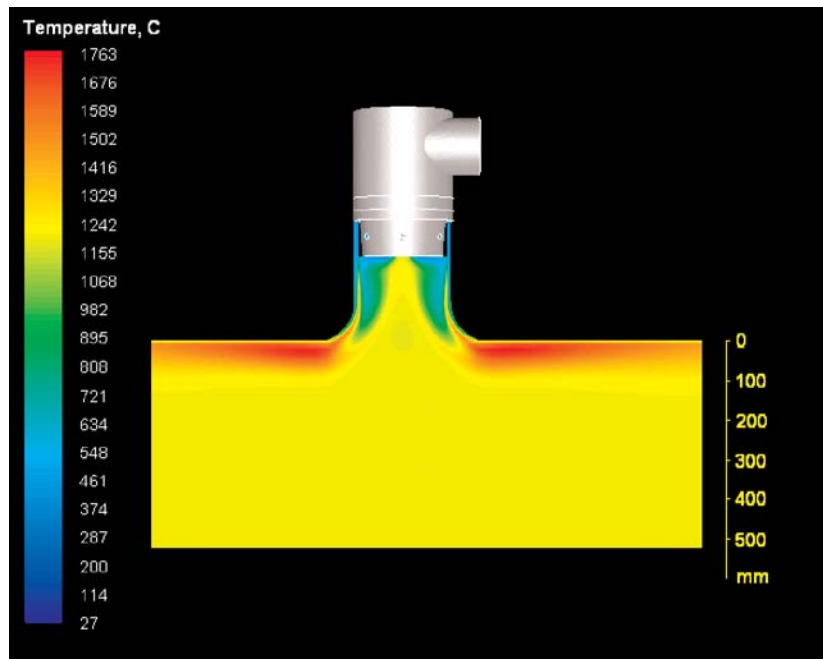


Figure 2. Temperature Contour of WHI burner in Invisiflame® Operating Mode. Firing Rate 820 kW; Air Preheat Temperature 482°C; Furnace Temperature 1,290°C.

geometry produce a flat flame, traditional in visual appearance, with ultra low NOx and CO emissions.

Once auto-ignition temperature of the fuel is exceeded within the firing chamber, the air staging ratio can be changed via the burner's incorporated bypass valve and actuator system to dramatically change the flame anchoring point and further reduce NOx emissions while still

limited to a maximum of 1,760°C despite a furnace temperature of 1,250°C and preheated combustion air of 482°C. The primary natural gas / air-flue gas mixture formed in the core is gradually burned in the furnace, albeit near the furnace roof as desired. The combustion process takes place near the lean limit of flammability, thus the formation of both prompt and thermal NOx are

greatly reduced. Typical NOx emissions are about 117 mg/Nm³ corrected to 3% O₂ (57 ppm) at a furnace temperature of 1250°C and preheated combustion air of 482°C. The overall flame length is limited to less than 100mm. Furthermore, the furnace hearth or steel coverage is excellent as the burner's flat flame shape uniformly 'lays the heat' along the furnace roof, causing the roof to re-radiate to the steel for soaking.

Raising the steel to near soaking temperatures is more commonly performed with side or longitudinally fired burners. As this is the majority of heat demand in the furnace, achieving uniform heating, fuel efficiency, and ultra low emissions is therefore critically dependent on furnace and burner technology employed in the heating zones. For this purpose, Hauck applied a second type of ultra low NOx burner similarly capable of low temperature startup and high efficiency with low emissions at typical heat zone operating temperatures.

The TriOx burner applied in the heat zone also utilizes a triple air staged injection design for maximum production efficiency while minimizing NOx emissions with high temperature preheated air(2). However, unlike the WHI, the third stage air is directed forward resulting in a long flame for desired reach across the furnace width. The burner, depicted in Figure 3, can be equipped with a switching valve to distribute more air to stages 1 and 2 for low temperature start-ups; once auto-ignition of the fuel is reached, the air is more heavily staged or weighted toward the stage 3 slots for optimum emissions reduction as well as reduced peak flame temperatures.

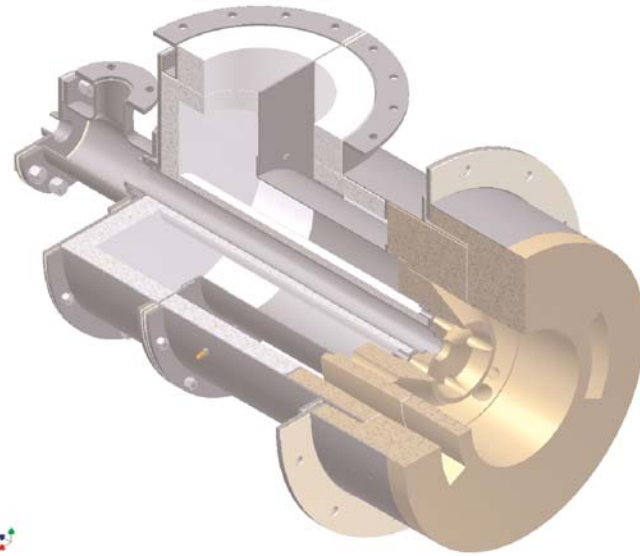


Figure 3. TriOx Burner Detail

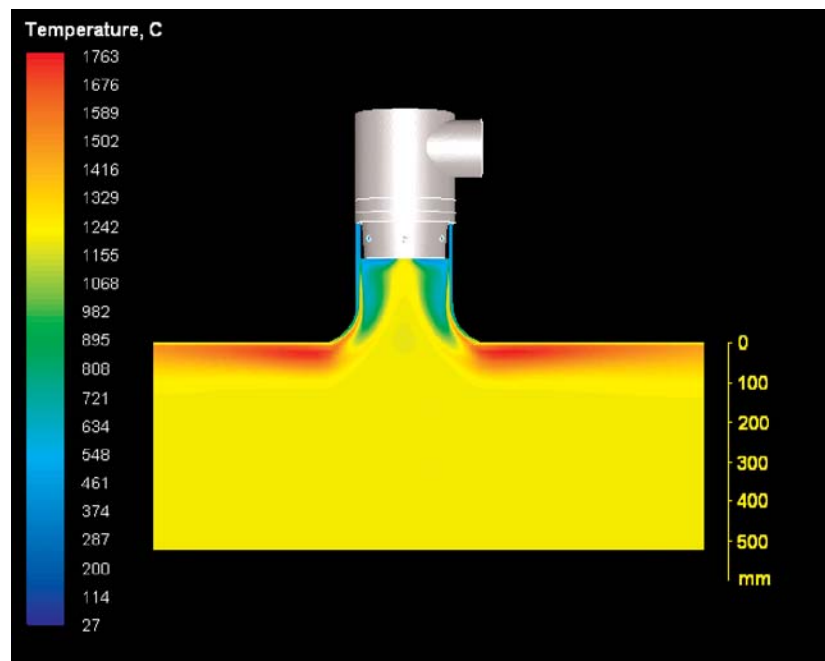


Figure 4. Temperature Contour of TriOx-2012. Firing Rate 2,250 kW; Air Preheat Temperature 482°C; Furnace Temperature 1,176°C.

A typical temperature distribution along the burner axis while firing in the Invisiflame® mode is depicted in Figure 4. Note the lack of traditional flame attachment in the near burner region as the air staging stretches the high temperature zone and allows flue gas entrainment to reduce peak flame temperatures to approximately 1,600°C maximum.

FURNACE MODEL RESULTS

The flow of combustion products was modeled via the numerical solution of the conservation equations for mass, momentum, and energy, and transport equations for turbulent quantities utilizing ANSYS® Fluent® software(3). The Standard k- ϵ model of turbulence and eddy brake-up model for reaction rate term for combustion were used. The discrete ordinates radiation model and the weighted-sum-of-gray-gases were used to model radiation heat transfer(4).

The upper soak zones are equipped with a total of twelve 6" WHI burners capable of firing over 350kW; modeling was conducted at a typical burner firing rate of approximately 150 kW each with 500°C preheated combustion air. The computed temperature distributions along the soak zone width and length are shown in Figures 5 and 6 respectively. Even at a reduced firing rate, the furnace roof coverage is substantially uniform across both length and width of the upper soak zone.

Figure 7 shows a temperature distribution in a horizontal section at 127 mm above the steel surface. The cooler 'edges' are under-predicted by the model due to artificially imposed symmetrical boundary conditions. Even so, the maximum temperature differential slightly above the steel surface is only +/- 4.5°C relative to the mean soak zone temperature setting of 1,255°C. Disregarding the under-predicted outer 'edge' temperatures; the model prediction results in a mean temperature differential of only +/- 2.5°C at the furnace discharge.

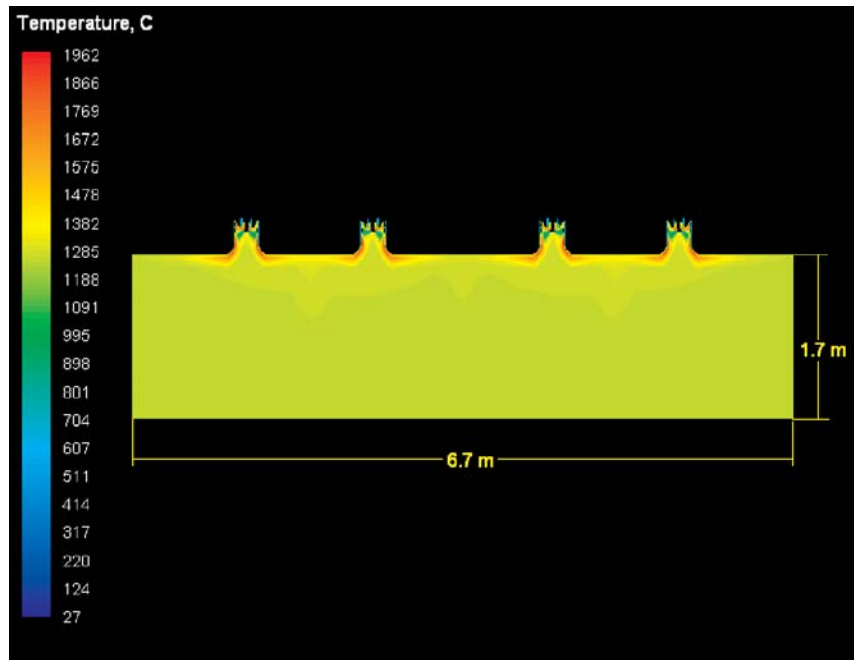


Figure 5. Temperature Contour of the Soak Zone Along the Furnace Width Utilizing WHI Burners

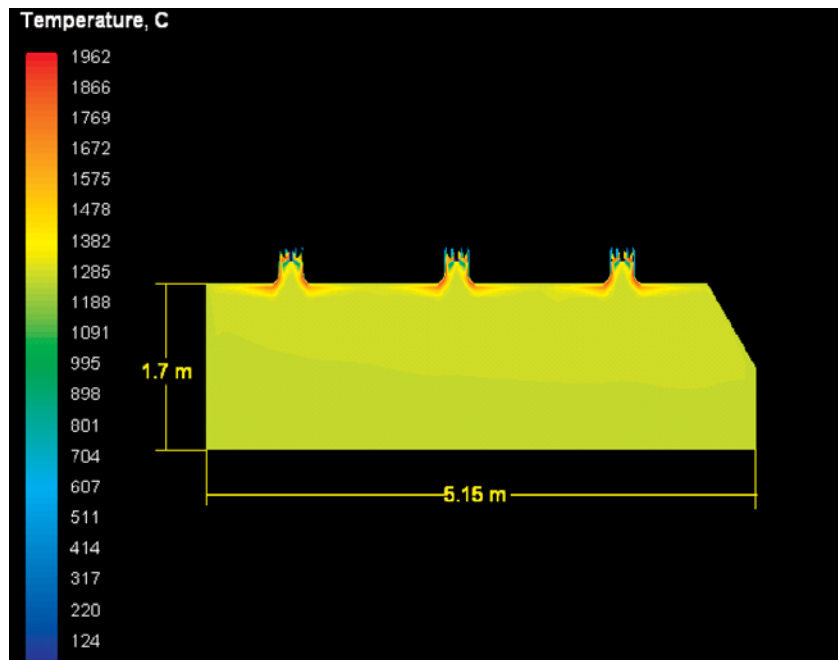


Figure 6. Temperature Contour in the Soak Zone Along the Furnace Length Utilizing WHI Burners

A simplified, steady state, model of the upper heating zone was also conducted. The upper heating zones are equipped with ten TriOx-2012 burners staggered from side to side that are equipped for Invisiflame® firing only. The firing rates were set to 2,050 kW for each burner again with 500°C preheated combustion air. The velocity and temperature distributions are shown in Figures 8 and 9 respectively.

The highly preheated air velocity stretches the flame zone resulting in uniform heat coverage of the steel while simultaneously minimizing peak flame temperatures and the regions or size of these high temperature zones for minimal NOx emissions. As seen in Figure 9, the peak temperature predicted is only 1,650°C. Typical NOx emissions are about 98 mg/Nm³ corrected to 3% O₂ (48 ppm) at a furnace temperature of 1250°C and preheated combustion air of 500°C.

SUMMARY

Through the application of two unique ultra low NOx burners, Hauck provided a solution that allows this particular furnace builder and end steel producer to meet the competing challenges of reducing fuel consumption and meeting increasingly stringent emissions regulations when reheating steel. The use of roof-mounted flat flame WHI burners in the soak zone and side mounted TriOx burners in the heat zone allow the furnace to meet the full range of production demands while also satisfying the economic and environmental challenges faced by the steel industry. Product and temperature uniformity is aided by the sizing, placement and flame geometry of the selected burners.

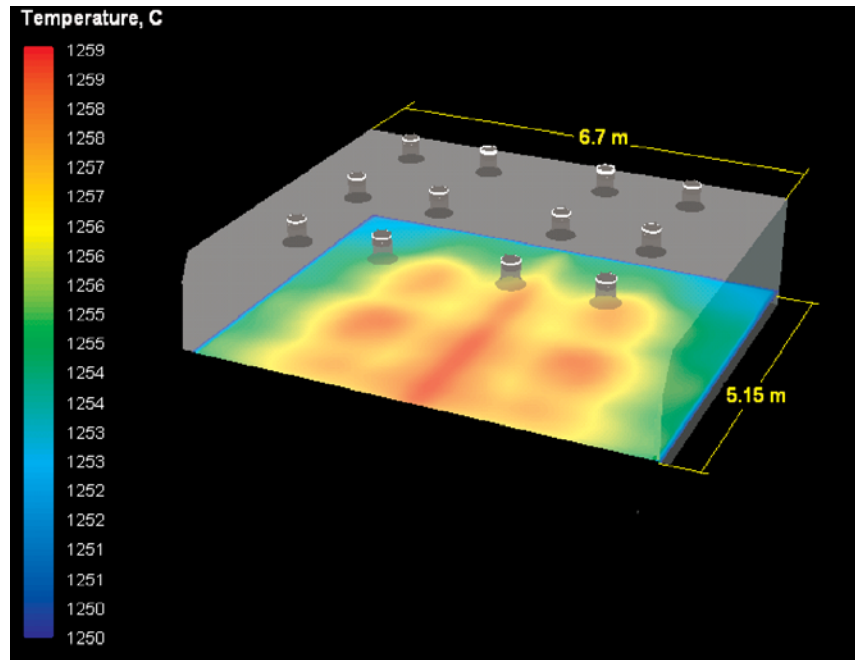


Figure 7. Temperature Contour in Horizontal Section of the Soak Zone at 127 mm Above the Load (WHI Burners).

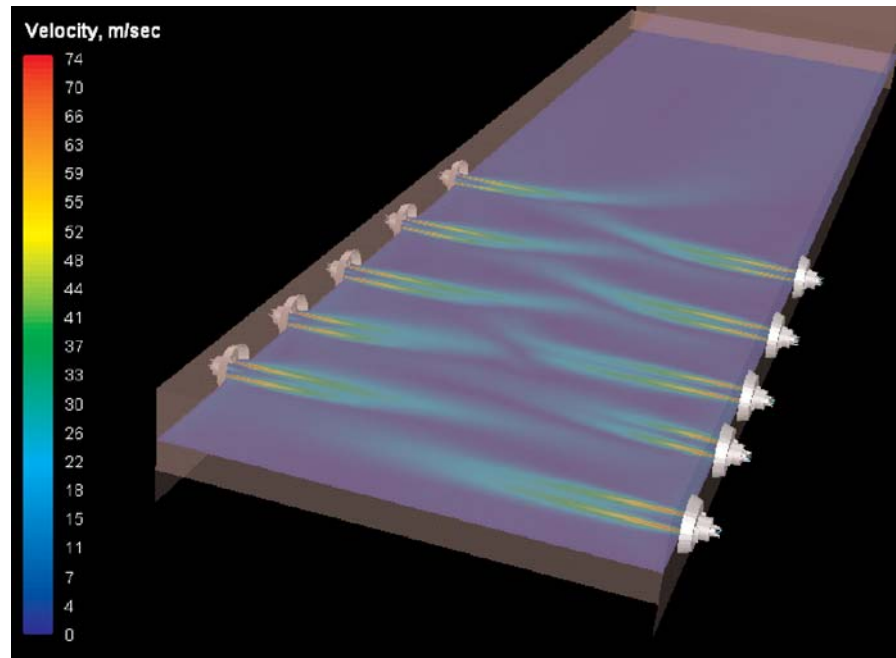


Figure 8. Velocity Contour in Horizontal Section of the Upper Heating Zone Utilizing TriOx Burners.

Furnace modeling verified the utility of these two advanced burner products in enabling the furnace design to meet the performance needs of the end-customer.

ACKNOWLEDGMENTS

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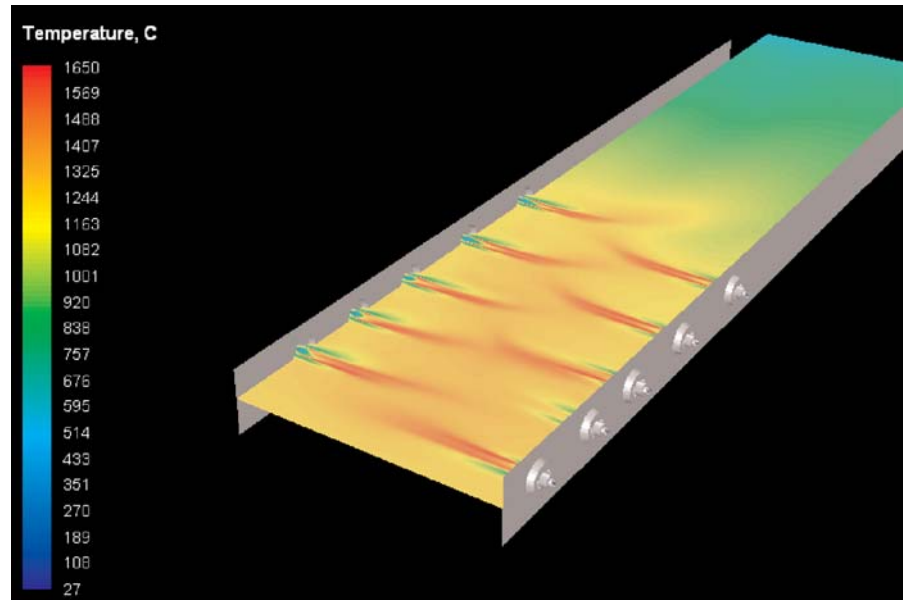


Figure 9. Temperature Contour in Horizontal Section of the Upper Heating Zone Utilizing TriOx Burners.

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