Pusher reheat furnace combines increased production with a reduction in emissions

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Operators of furnace systems in the steel industry are being confronted to an ever increasing degree with rising fuel prices and stringent environmental regulations – regardless of whether their system is an ageing one or brand new. The dream of operators is therefore to find a green heating system which reduces fuel consumption while at the same time increasing production capacity.

What sounds like a target from dreamland can now actually be achieved using high efficiency burner and control systems which, of course, also comply with the relevant safety requirements. The basis of these state of the art heating systems includes an extensive analysis of the expected flow properties within the furnace, a process which is carried out in advance by means of a computational fluid dynamics (CFD) analysis.

In the following we explain an example of how the customer's wish for a "green" furnace could be made into reality while also increasing production capacity.

Background

The well-known American steel producer NUCOR STEEL Inc. produces rolled products in a range of qualities and dimensions, including rebar, rounds, squares, flats, angles and channels at its mill in Auburn (New York State). The company also produces special steel types of various grades and compositions in more than 130 sizes.

The raw material used for the production process is 100 percent recycled scrap.

The hot charge furnace which was previously used at the mill achieved a rated capacity of 50 to 95 tons per hour. The maximum billet length was limited to just 4.6 m.

Investment in a new furnace

Expanding production capacity combined with the expectations described above relating to energy consumption and environmental protection were the main reasons behind the company's decision to invest in a pusher reheat furnace. The furnace reacts to these demands in the form of substantive reductions in energy consumption per ton of steel as well as low NOx values with high preheating of the air.

The NO_x emissions are also monitored permanently by a Continuous Emissions Monitoring (CEM) system. At 120 tons per hour, the rated capacity of the furnace is also well above the capacity of the previous equipment (**Fig. 1**).

Fig. 1: Nucor Auburn pusher furnace

Implementation

The company with which the order was placed for the furnace, FORNI INDUSTRIALI BENDOTTI S.p.A, decided to use heating equipment with a direct heating system and central air preheating.

The pusher reheat furnace is fired with natural gas and, in addition to the current emissions protection regulations, must also comply with the limit values which are expected to apply in the future.

Main data of the new furnace

Length:	approx. 19 m
Width:	approx. 13 m
Rated capacity:	120 tons per hour
Combustion air preheating:	central recuperator
Burner control:	mass flow control
Typical billet length:	approx. 12 m

Furthermore, the design of the furnace and heating systems had to take into account the possibility that the capacity

Fig. 2: $TriO_X$ burner

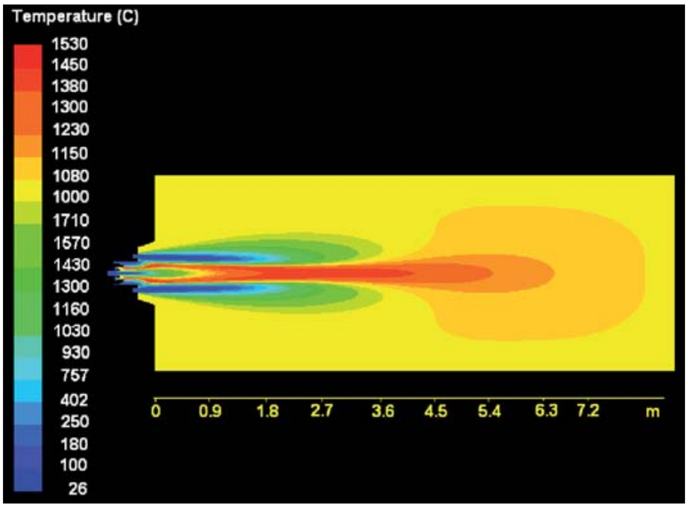

Fig. 4: $TriO_X$ burner temperature profile

might have to be increased at a later date and to make sure that this would be possible without major modifications.

Before the order was placed with ELSTER HAUCK, the customer demanded a theoretical presentation of the flow properties in the furnace. This was then used as the basis for the validation of the furnace design. For this purpose, ELSTER HAUCK carried out a detailed CFD analysis which also included a discrete consideration of the various heating zones.

The successful Fluent® software was used for the CFD analysis. The expert knowledge required for the program was already available from the heating system supplier from its modeling of several furnaces.

The results of the CFD analysis were then added to a previous CFD modeling for individual burners and other laboratory data. This made it possible to calculate the following expected characteristic values in the furnace:

- Heat transfer
- Temperature distribution
- Flow fields
- Velocity fields
- NOx emissions

Following the CFD study, the number, type and layout of the burners to be used were then defined:

Number: 22 burners

Layout: Six side-fired burners in the bottom heating zone, each with a rated capacity of 3500 kW.

Six side-fired burners in the top heating zone, each with a rated capacity of 2800 kW.

Ten burners in the soak zone, each with a rated capacity of 800 kW.

Expected air preheating temperature on the burner: approx. 450°C.

Selected burner type for all sizes:
Low NO_X $TriO_X$ burner.

In general the burner geometry largely dictates the flame shape, efficiency of burning, heat transfer, and NO_X formation. The $TriO_X$ burner from Elster HAUCK (**Fig. 2**) [1] has triple air staging to ensure that the lowest possible NO_X values can be achieved even with high air preheating temperatures.

The various air stages are achieved internally using a specially divided air housing and by a switchover valve mounted on the air connector. The air staging for the $TriO_X$ burner is designed so that in heating mode very low levels of carbon monoxide (CO) are generated and the NO_X is minimized above a certain furnace temperature. In startup mode, the burner then operates in so-called flame mode when the furnace temperature is below 870°C. This can be monitored by a UV sensor and can also be modulated within its capacity range using the characteristic operating range. Flame mode therefore enables the furnace to be heated while generating the lowest possible CO emissions.

Above a temperature of 870°C the air staging is then changed using the switchover valve. Almost the entire volume of air is injected straight into the furnace at a high air outlet velocity and only a small proportion of the combustion air generates a pilot flame on the mixing unit for gas and air, which once again can be monitored using the UV sensor (**Fig. 3**). This burner operating

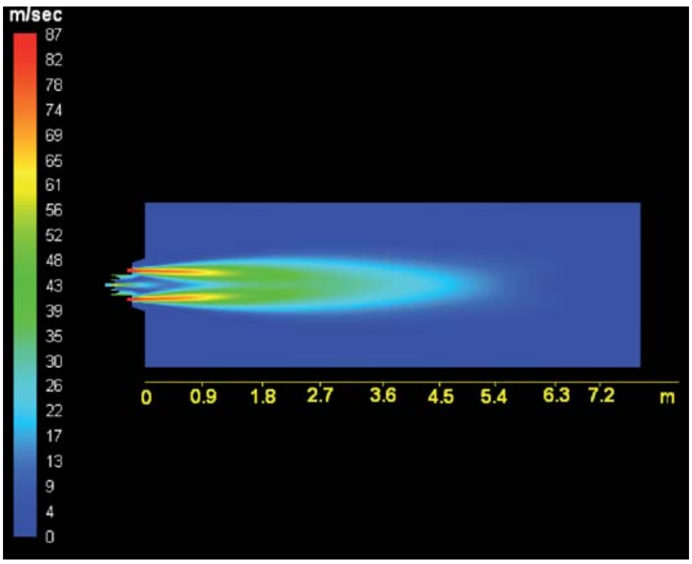

Fig. 3: $TriO_X$ burner velocity profile

Table 1: Production data

Production data	
Furnace production rate	140 t/h
Natural gas calorific value	11,3 kWh/m³
Natural gas total flow rate	3160 m³/h
Furnace firing rate	35606 kW
Preheated air temperature	442 °C
Flue gas exhaust temperature	785 °C
Billet discharge temperature	1100 °C
Overall excess air	5 %

mode is known as Invisiflame® mode. The burner design was developed and optimized with the help of Fluent® CFD calculations and laboratory tests.

The optimal gas and air injection combined with the air staging described above and the high outlet velocities at the burner quarl outlet result in a long reaction zone within the furnace, into which large volumes of furnace atmosphere are drawn. Compared to conventional burner equipment, this avoids peak temperatures in the reaction zone and very low NO_x emissions are generated despite the fact that the air is preheated (**Fig. 4**) [1]. Laboratory tests have shown that at a furnace temperature of 1127°C and with an air preheating temperature of 427°C in high fire mode NO_x emissions of approx. 34 ppm [ref. 3% O_2] are possible.

Results

The new pusher reheat furnace was commissioned in April 2005. The following data were recorded during normal production operations:

- Load type, size and weight of the material used
- Furnace production rate
- Material surface temperature at furnace discharge
- Nominal temperatures in the various zones
- Gas and air flow rates for each zone
- CO, O_2 and NO_x emissions

The production data of the furnace at maximum load are shown in **Table 1**.

The furnace temperature profile was recorded over the full length of the furnace to determine the billet surface temperature and the billet core temperature (**Fig. 5**) [1]. The surface and core temperature of the billet could be calculated on the basis of this profile using an appropriate software package.

The billet heating process occurs smoothly with a mean rate of 10°C/min in the middle of the heating zones and 2,5°C/min in the soak zone. This indicates that good furnace temperature distribution and heat transfer is achieved by the enhanced furnace design. A production capacity of 140 tons/hour is possible although the furnace was originally designed for a capacity of 120 tons/hour.

The detailed distribution of the furnace temperatures was examined using the Fluent® CFD analysis.

Fig. 5 shows the temperature distribution in a horizontal section through the burner centerlines in the heating zone. Only one-half of the furnace width is shown in this for the sake of clarity (**Fig. 6**) [1]. The burners are in Invisiflame® mode and it is clear that the only

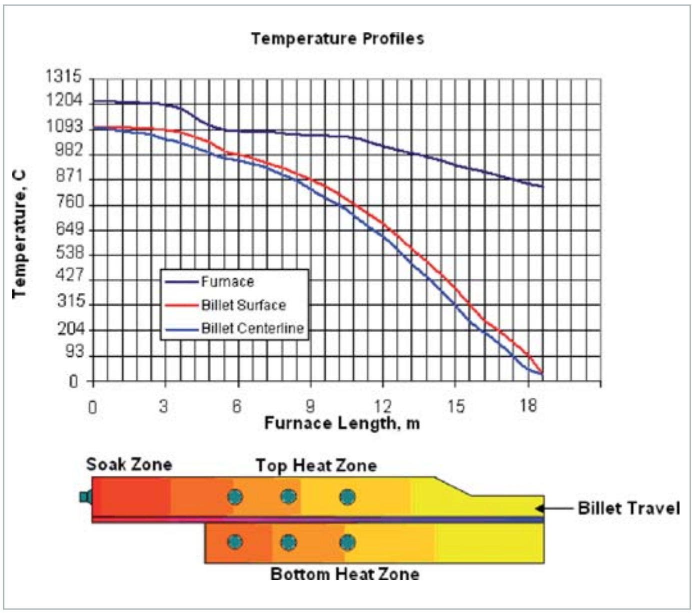

Fig. 5: Furnace temperature profile

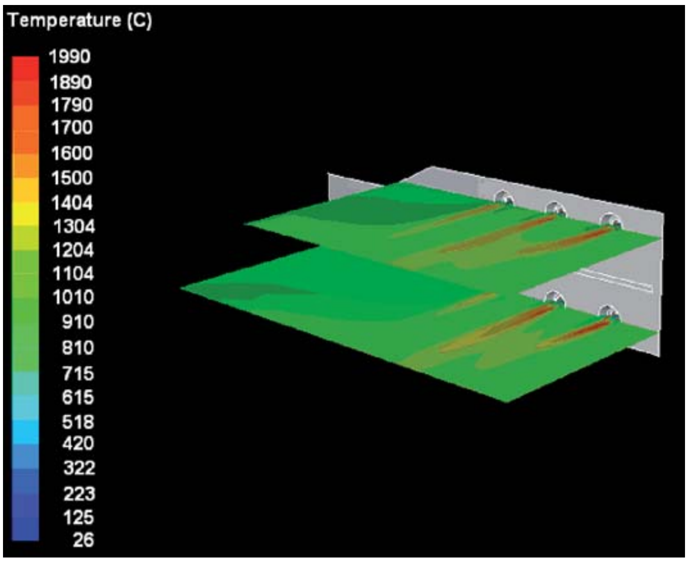

Fig. 6: Horizontal temperature profile through burner centerline

Table 2: Pusher reheat furnace heat balance

Pusher furnace heat balance					
Input		**%**	**Output**		**%**
Heat from fuel	35606 kW	87,8	Heat of product	26704 kW	65,8
Heat of preheated air	4948 kW	12,2	Heat of flue gas	11712 kW	28,9
			Furnace wall heat loss	323 kW	0,8
			Heat of water cooling	1815 kW	4,5
Total	**40554 kW**	**100,0**	**Total**	**40554 kW**	**100,0**

areas with a high temperature are in the burner tile and occupy only small volumes with short residence times. This results in very low NO_x emissions.

The overall heat distribution in the burner zone shown approximately follows the model calculation of a single burner. The single burner consideration has previously been confirmed in laboratory tests. The temperature uniformity of the flue gases over the entire width of the furnace is very good. The low influence of the soak zone on the flue gas flow direction (slight distortion from right to left) was also given due consideration in the simulation calculation.

The uniformity of the billet temperature and the consistent high quality of the rolled products confirm the results produced by the Fluent® software package. The overall furnace heat balance was computed on the basis of the data collected (**Table 2**). The hot air capacity (hot air temperature 442°C) amounts to 12.2 percent of the total energy supplied to the system. Furnace wall losses are very low at less than 1% of total heat input.

Overall, the furnace design has been a complete success, in particular if we consider the fact that the energy absorbed by the billets amounts to around 75 percent of the total gas energy input or 66 percent of the total heat input. In addition, total gas consumption at 255 kW/t is lower than the target value for the project which was previously set at 293 kW/t. The emission values recorded by the CEM were well below the permitted limit values throughout every phase of production. This applies both to a cold start of the furnace and also for various production rates between 60 tons/h and 140 tons/h (production rate 140 t/h and air temperature 427°C: NO_x < 73 mg/m^3. NO_x emissions of less than 63 mg/m^3 were measured at lower production rates with an air temperature of less than 427°C. CO emissions during production were practically zero).

Outlook

Increasing prices for fuel and raw materials together with growing competition are just two of the challenges which steel producers currently have to face, and the situation is due to get even worse in the future. Using the example presented by NUCOR Steel, we can see that close cooperation between the parties involved ultimately produced the desired result. The use of modern, NO_x-reducing burner technology led to a situation in which it was possible to comply not only with current regulations, but also with the emissions and efficiency standards which are likely to apply in the future.

Investment in new technology will therefore provide steel producers with long term competitiveness in a fiercely competitive market.

Literature

[1] Hauck Manufacturing Company, Inc., James Feese and Dr. Felix Lisin, A Success Story – Pusher Reheat Furnace Collaboration, Industrial Heating, June 2006 ■

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