Direct fired strip preheating

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Abstract

A new design of a preheating unit for electrical steel strip has been developed and installed in front of a continuous radiant tube furnace. The unit uses self recuperative FLOX® burners arranged in a "nozzle field" and is designed to preheat the strip up to 400 °C. The required heating length is reduced to one fourth of a comparable radiant tube furnace section. This implies a large reduction in specific furnace length and therefore in lay-out and investment costs. The present article describes the new fast heating unit, the feedback from industrial tests and the conclusions derived from the successful installation on the continuous annealing line.

Electrical steel

The BNO-Bochum Works (Thyssenkrupp) produce 500 000 t/y of "non oriented grain" (NOG) electrical steel strip. The required heat treatment, required to recrystallize the material after rolling, takes place in three independent horizontal continuous furnaces, with an average length of 240 m each. The furnace temperature profile is controlled by up to 450 radiant tubes. Annealing is carried out under protective gas atmosphere (N_2/H_2) and the maximum temperature can be as high as 1150 °C [1]. Strip width between 700 and 1270 mm, thickness from 0.2-1.0 mm and a maximum throughput of circa 30 t/h can be handled.

Preliminary basic considerations about increasing the furnace capacity with the conventional radiant tube heating have shown that the inlet section of the continuous furnace should be lengthened by about 50 m. This would however involve additional investment to enlarge the factory bay and relocating a lot of equipment.

The following targets were formulated:

- increase of line speed (i.e. process velocity) about 50 %
- strip temperature > 900 °C
- no enlargement of the existing furnace, but possible use of the 12 m free inlet section.

Alternatives

Some producers of electrical steel strip have been using for a long time direct fired zones for preheating the strip. The direct fired zones are installed upstream of those indirectly heated. With the common horizontal layout of burners, an overheating of the edges and therefore also a non uniform temperature distribution across the strip is almost unavoidable.

On the other hand, laboratory tests on electrical steel specimens with variable Silicon contents (up to 3.2%) have shown that a direct heating up to 300 °C followed by a heat treatment with protective gas is possible.

In order to choose the suitable process, further laboratory tests were carried out with a high-powered infrared radiator (electric), with porous burners (gas fired) and with a direct heating system based on gas burners arranged in a "nozzle field". All alternatives were checked not only for the initial investment costs, but also for the required length and the running costs (energy and maintenance), as well as for the effect on the strip quality.

A high-powered infrared radiator implies not only high investment costs, but also extremely high running costs. Introduction of porous radiators was discarded because of the too large length required. The only possibility matching the above conditions was the process with direct heating from impinging gas burners arranged in a *nozzle field*.

Development of the *FLOX® nozzle field*

The reason, why to consider a nozzle field with impinging jets was the possibility to increase the convective heat transfer to a level where the total heat transfer could be increased considerably.

The heat transfer capabilities can be estimated using the following formula for the radiative heat transfer between two parallel plates and forced convection.

$$q(\alpha, \vartheta_H) := \left[\sigma \cdot \frac{1}{\frac{1}{\varepsilon_H} + \frac{1}{\varepsilon_S} - 1} \cdot \left[(\vartheta_H + 273 \cdot K)^4 - (\vartheta_S + 273 \cdot K)^4 \right] \right] + \alpha \cdot \left[(\vartheta_H + 273 \cdot K) - (\vartheta_S + 273 \cdot K) \right]$$

q	- heat flux density [W / m^2]
σ	- Stefan Boltzmann constant
ε_H	- emissivity of the hot side
ε_S	- emissivity of the strip
ϑH	- temperature of the hot side [°C]
ϑS	- temperature of the strip [°C]
α	- convective heat transfer coefficient [W / m^2 K]

Fig 1 shows an analysis of that correlation assuming an emissivity of 0.3 for cold strip and an emissivity of 0.8 for the hot side.

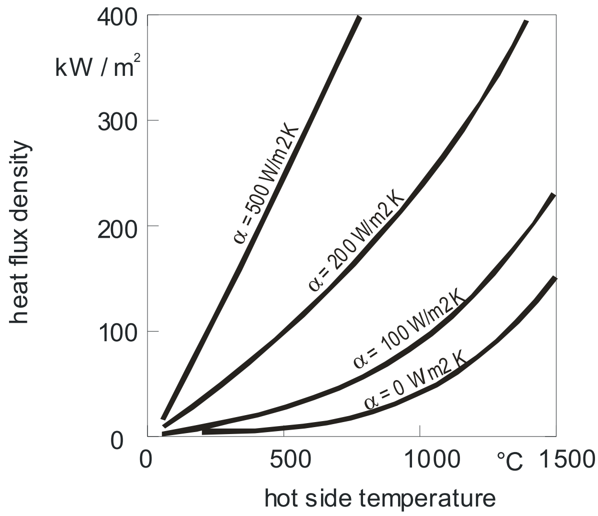

Figure 1: Heat transfer (ε_S=0.3, ε_H=0.8)

Typical radiant tube furnaces operate with radiant tube (hot side) temperatures of 900°C (metal tubes) to 1050°C (ceramic radiant tubes). That results in heat flux densities of 30 to 50kW/m^2 for radiation only. The goal was to increase the heat flux density to > 200 kW/m^2. To obtain these heat flux densities by radiation only, hot face temperatures of >1500°C would be necessary. It is quite obvious, that such high temperatures would be difficult to cope with, especially in case of a strip speed slowdown or stop.

The diagram shows, that the nozzle field has to be arranged in such a way that a convective heat transfer coefficient of >200W/m^{2}K is required to reach that goal with moderate temperatures.

A first experimental unit was developed, designed and built to confirm the achievable heat transfer rates (see Fig. 2).

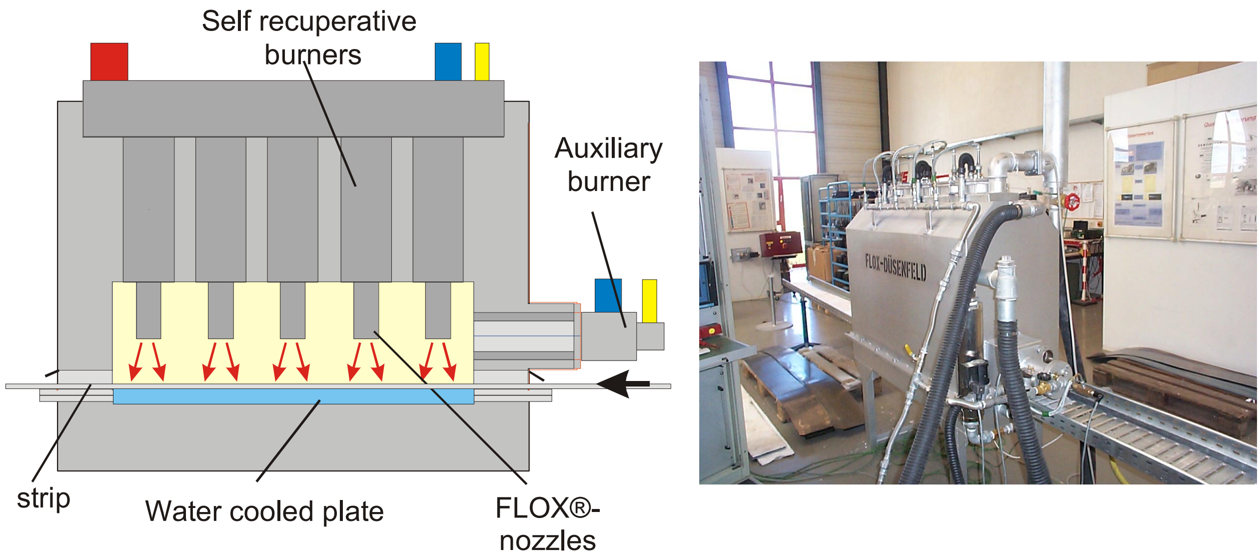

Figure 2: Experimental FLOX® nozzle field

When operating the unit without strip, the heat transfer could be determined using a calorimeter on the cooling water. The data were then confirmed, pulling a piece of strip manually through the unit.

The following data could be measured:

- heat flux density 250 kW/m^2 (min. 150 kW/m^2, max. 300 kW/m^2)
- NOx emissions 25 ppm
- CO emissions not detectable (< 5ppm)
- exhaust temperature ~ 315°C
- chamber temperature ~ 1000°C

The results, achieved with the experimental unit were promising enough to initiate the project to design and build a full scale prototype unit.

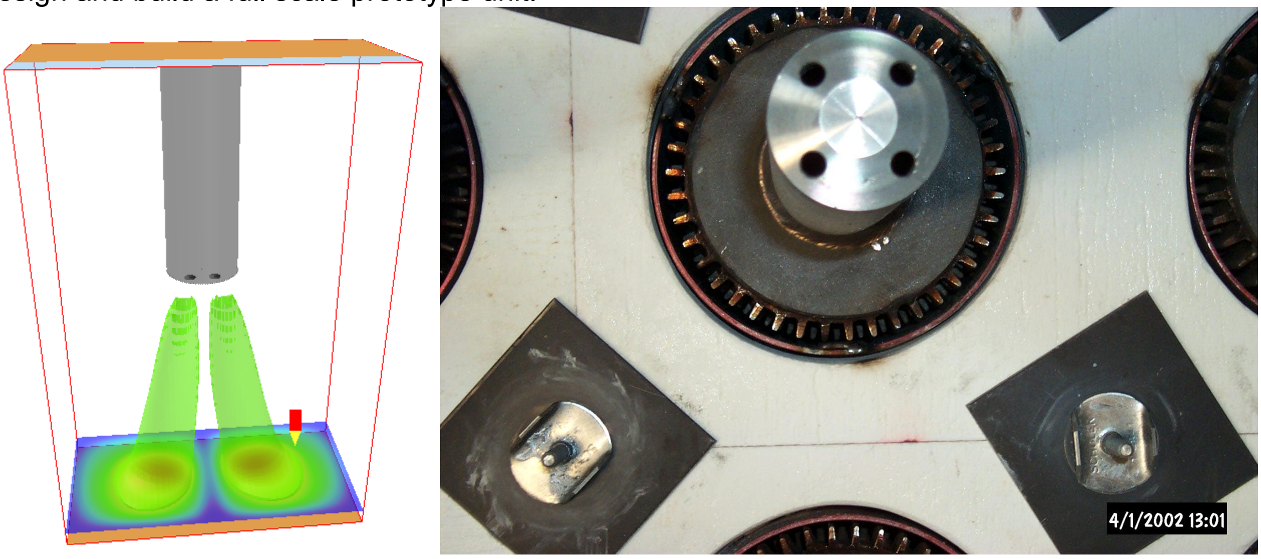

Figure 3: CFD calculations and nozzle arrangement of the prototype

The prototype included burners below and above the strip. Figure 3 shows the one burner with its four nozzles of the prototype and the CFD calculation of one half of one burner. The burners are designed for firing in flameless oxidation mode [2,3,4] only. Two auxiliary burners are used to heat up the unit to operating temperature.

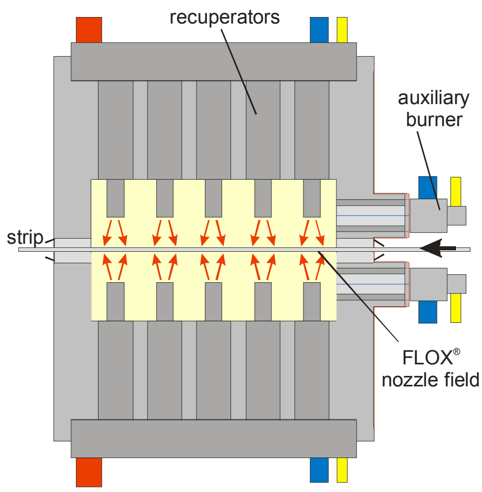

Figure 4: FLOX® nozzle field prototype

The unit is designed to be heated up, using the auxiliary burners, when it is parked in a stand by position. After reaching ~850°C, the auxiliary burners are switched off and the FLOX® burners are in operation. At this time, the unit is ready for being moved into the working position and heating up the strip. In case of a strip slowdown or stop, the nozzle field can go into cooling mode or it can be moved back into stand by position. If the strip has to be pulled out of the furnace backwards after a strip breakage, the nozzle field can be used for strip cooling.

Flameless oxidation provides very homogenous temperature distribution. Nevertheless, due to the high heat transfer rates, the nozzle field (Fig. 5) has to be designed very thoroughly to avoid local strip overheating.

Figure 5: FLOX® nozzle field burner arrangement

Figure 6: FLOX® nozzle field in operation

After certain modifications were made to the nozzle arrangement, strip which was preheated in the FLOX® nozzle field could not be differentiated from strip that was heated in the radiant tube furnace only. Figure 6 shows the unit in front of the annealing furnace.

Conclusions

It can be stated that the FLOX® nozzle field has completely fulfilled the requirements set by the present project. The equipment has been able to heat the strip in the shortest space, with the best efficiency and the lowest emissions. The quality properties of the good for preheat up to 300 °C are by no means harmed.

With the FLOX® nozzle field, the length required for preheating can be reduced by a factor 4 with respect to a radiant tube heated furnace section. The investment for a desired increase of capacity is significantly lower, in initial investment, maintenance and operating cost with respect to a traditional radiant tube furnace.

References

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