The Buderus specialty steel plant uses integrated cycles for hot and cold strip, rolled semi-products, pieces for die casting, and free forging with an annual production of about 85,000 metric tons. The ingots are reheated in gas-fired, automatic controlled car bottom furnaces. Equipment for cutting, annealing furnaces, and vertical or horizontal furnaces for tempering are also part of the plant. The maximum length of the forging to be heated in the car bottom furnace is 15 m (49 ft). For the mechanical treatment, digitally controlled machines (lathe, cutter, boring etc) are at disposal in various sizes. The production portfolio of free forged pieces encompasses worked pieces for general mechanics and energy generating equipment, worked steel rods, and new rods. The largest weight is about 80 metric tons.

**Background**

Car bottom furnaces are designed for the heat treatment of particularly large loads. The furnace discussed in this article is approximately 10 m long by 4.5 m wide (~33 by 15 ft) and was equipped with 18 high-velocity recirculating burners rated at 250 kW each, corresponding to a nominal, natural gas throughput of 450 Nm³/h. Both side walls were equipped with 9 such burners firing straight, hard jet flames. The cars are loaded, pushed into position, and a seal between the furnace bottom and the car bottom is provided automatically.

The flame and hot combustion gases were forced through the bottom car and the forging pieces to the opposite furnace wall, where they were forced upward to the roof and eventually reentrained by the original jet emanating from the burner (Figure 1). With this design, the pieces being reheated for forging could not just lie on the bottom of the car, but instead, they had to be positioned in a prescribed pattern on 400 × 400 mm (~16 × 16 in.) heavy steel supports. It was necessary to position the supports in exactly the right location prior to loading to prevent the combustion flame from directly impinging on the load surface, which would result in additional oxidation and interrupt the heat distribution pattern. Improper placement of the supports also resulted in the workload being locally overheated, as well as the reheating process being interrupted or taking a longer time than necessary. Furthermore, the burner tips also suffered damage due to excessive overheating. The maximum total fuel (natural gas) throughput was 210 Nm³/h,

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**Figure 1 — Cross section of the bogie hearth furnace.**

**Figure 2 — Cross section through the revamped furnace.**
which was limited by the time interval required by the on-off control technique; that is, the burners of one side wall were interchanged with those of the opposite wall every 60 seconds, so only one half of the 18 burners were available at the same time. The furnace was divided into three zones; preheated using air and did not incorporate any low-NOx techniques.

Flat flame REKUMAT burners

Figure 2 depicts the layout after the retrofit consisting of nine REKUMAT burners provided with integrated air preheaters installed in the same locations on each furnace side wall. Each burner is rated at 180 kW. The total maximum gas flow rate input after revamping was 315 Nm³/h with all 18 burners firing, distributed in three zones and fired in a circular pattern. The increased overall power input allows a faster heat up rate of the workload, and provides a larger furnace capacity and higher temperature reheat cycles.

The flat flame burners are sufficiently far away from the bottom edge of the car. Figure 3 shows that heat flow is no longer directed at the workload, and the arrangement of the burner nozzles spreads the heat uniformly over the entire furnace. The figure also shows the flat flame burners are fired in flame mode and the distribution of the side firing jet flames. Figure 4 shows a detailed view of the burner nozzle installed in the middle of the furnace wall lined with ceramic fibers. Because the flame is no longer directed under the load, the steel supports for the workload can be substantially smaller. This provides a faster and more economic reheating process thanks to the reduced support mass (by a factor of almost 4) to be reheated together with the workload.

Flameless Firing in High-Temperature Furnaces

Current burner and heating-system developments are focused on reducing flue-gas losses and noxious emissions. In particular, air preheating is a well-known technique used for high temperature processes. However, the relevant energy saving potential is only partially exploited, and one important result thereof is an increase of flame temperature, which produces excessive thermal NO formation.

A possible method to reduce the flame temperature and, therefore, the NOx emission, is an inertisation of the flame. Therefore, the process relies on the principle of mixing large quantities of flue gases into the combustion air before the reaction with fuel occurs. The entrainment of the inert flue gases (serving as chemical and thermal ballast) is carried out by means of the high momentum of the air jets injected into the combustion chamber. The special design of the FLOX burner nozzles makes it possible to have a controlled, completely flameless combustion without pulsations, visible flames, and typical flame noise.

To carry out this process, fuel is mixed with the combustion air in a place where the required premixing with flue gases has already occurred, but there is still enough turbulent mixing energy remaining to fulfill the combustion reactions. This flameless combustion mode is only possible at a temperature higher than the self-ignition temperature of the fuel, which can be considered 850°C (1560°F) for safety reasons. Because flameless combustion is not visible, a burner safety control based on ionization or UV detection is not possible. Therefore, monitoring furnace temperature above the threshold of 850°C is the only safety control available.

The burners described in this article are equipped to fire both in flame mode (which is also for start-up from cold) and in FLOX mode; switching is made easy and no separate burners are required for the two firing modes at temperatures below and above 850°C. When the furnace is heated above FLOX threshold, flameless combustion can be initiated, and noise is significantly reduced. Most importantly, NOx emissions are drastically abated to less than 10-20% of the value corresponding to flame mode. The problem of increasing NO formation with increasing air preheating is solved by using the flameless process. NOx formation increases exponentially with temperature in a conventional system, while it drops by almost one order of magnitude in flameless conditions. This allows using virtually unlimited high temperature preheated air with very significant energy savings and, therefore, with significant economic advantages.

To achieve these results and to preheat air efficiently, self-recuperative burners are provided equipped with an integrated counter flow heat exchanger (Figure 5). A burner of the REKUMAT series with a specially designed primary combustion chamber was selected for the present case, which produces either four axial flames or four flameless jets at 90 de-
Every combustion air jet has sufficiently high exit velocities to ensure that enough flue gases are entrained from within the furnace before the reaction with fuel takes place and a controlled flameless pattern is established. The outlet momentum of the burner jets and the flow pattern thus generated result in highly effective heat transfer to the forging stock workload and the furnace walls. The convective heat transfer to the wall zone adjacent to the burner overheats the wall, which is then capable of transferring energy by radiation to the load.

In contrast to the previous system, the use of flat flame burners involves no direct impingement of the flame on the workload, so localized overheating is avoided. Furthermore, temperature uniformity is markedly improved by separating the flame into four single jets. Figures 6 and 7 are photographs taken in a test furnace at the Gas Wärme Institute in Essen) showing the burner in flame mode and in flameless, or FLOX, mode, respectively. It is clearly visible that the wall temperature close to the burner tip is overheated in flame mode, while a very uniform temperature distribution can be inferred from the flameless mode. The expected reduction in specific gas consumption has been within the calculated limits (on the order of 20 to 35% depending on temperature, just comparing efficient air preheating with no preheating as shown in Figure 8).

This is even without taking into account the reduction of the mass of the supports that carry the forging stock. This expectation also has been confirmed in practice. Furthermore, the total available power has been increased by a factor of somewhat less than two, allowing higher productivity and/or higher temperature cycles, which increases furnace availability for high-performance operation.

Conclusions

The properties and advantages of the flat flame burner applied to the forging furnace are summarized as follows:

- An increase of the thermal efficiency of more than 30% with respect to no air preheat has been easily achieved
- Thermal NO formation is substantially abated even with very high air preheat
- The entire temperature range can be covered by a single burner (flame and FLOX mode)
- Troubles caused by oxidation and safety control can be minimized
- The four nozzle distribution heats the load indirectly, minimizing oxidation
- The ceramic construction of the combustion chamber reduces maintenance substantially

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