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PERFORMANCE OF REHEATING FURNACES EQUIPPED WITH HIGHLY PREHEATED AIR

Final report by Birgitta Lindblad, Jernkontoret

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SUMMARY

Burner using highly preheated air combustion (HPAC) technology and designed to produce low NO_x emissions, have characteristics that are different to those of conventional burners. This has potential implications for the performance of steel reheating furnaces. The aims of this project have been to test the effectiveness and long-term reliability of HPAC burners. Jernkontoret, SSAB Tunnplåt and MEFOS have collaborated in the project. The project is a part of a ECSC-project.

A long time test with one pair of regenerative burners in a 300 t/h walking beam furnace at SSAB Tunnplåt, Borlänge shows a very good reliability and that the necessity of maintenance has been low. A comparison with an ordinary recuperative burner system indicates that the fuel savings is approx 12%. Computational fluid dynamics (CFD) -modelling at MEFOS showed that the installation of the HPAC burners gave rise to a change in the flue gas temperature in the bottom zones of the same magnitude as caused by the removal of one full length slab in the dark zone.

The consumption of oil and gases for reheating and heat treatment furnaces was 3,7 TWh during 2002. If regenerative burners can be installed in furnaces with ca 50% of this consumption the energy saving will be between 200 and 300 GWh. A drawback with these burners is the investment cost. The decreased costs for energy can rather seldom alone compensate the higher investment cost. Therefore higher productivity in the furnace and lower emission of nitrogen oxides are important factors.

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1. INTRODUCTION

The development of burners, which claim to achieve high thermal efficiency and low NO_x emissions, has generated interest in the steel industry because of their potential use in reheating furnaces. The burners employ highly preheated air combustion (HPAC) technology and generate flames with characteristics different to those of conventional burners. Although these burners have been available from a number of manufacturers for some years, there is limited experience of their use within the steel industry and concerns exist that they may present problems when fitted to some existing steel reheating furnaces. To address the issues of their use, a collaborative project between Corus UK and Jernkontoret (Sweden) was initiated and the work carried out with a financial grant from the European Coal and Steel Community

Despite advances in casting and rolling technology the requirement to reheat steel products is likely to remain an integral part of the steel industry's process route in the foreseeable future. Increasingly stringent product quality requirements, the need to maximise production and minimise costs, and legislation limiting gaseous emissions into the environment, is placing high demands on reheating furnace design and operation.

Legislative limits on the emissions of oxides of nitrogen (NO_x) is of particular relevance to steel reheating furnace operators because it poses a conflict between minimising NO_x emissions and maximising fuel efficiency. The use of 'first generation' designs of regenerative burners has resulted in significant improvements in the efficiency of fuel use, and thus reductions in CO_2 emissions, but emissions of NO_x generally exceed current legislative limits or emissions guidelines. Unless measures are taken to reduce NO_x, produced by such burner systems, their energy saving potential is unlikely to be fulfilled and the growth of highly preheated air combustion (HPAC) technology will be curtailed.

The development of 'low NO_x' regenerative burners offers reheating furnace operators the most cost effective solution, in most situations, for reducing NO_x whilst maintaining the benefits of highly preheated air. However, there is limited experience of HPAC technology in steel reheating furnaces. Several burners of this type, available commercially, claim to produce NO_x within current legislative limits and emissions guidelines. The manner by which high air preheat temperatures are achieved is generally the same as with conventional regenerative burners but the method of mixing of the air and fuel is different. This occurs primarily within the furnace chamber, rather than in a traditional burner quarl or tunnel, and it results in a 'flameless oxidation' combustion reaction. The characteristics of the flames produced are different to those of conventional nozzle mix or pre-mix burners and this has raised concerns about the compatibility of HPAC technology and the existing methodology of furnace design.

The use of high temperature combustion is expected to give the following long term benefits.

- A decrease of the energy consumption in reheating furnaces by 30% in relation to combustion with cold air. In relation to normal praxis today with preheated combustion air the saving can be about 15%. This will also decrease the emission of carbon dioxide.
- Improved gas flow in the furnace, which will give a better temperature distribution in the heated steel and therefore a higher quality of the finished product.
- The possibility of an increase on production in existing furnaces by 20%. The whole furnace length can be used for burner installation and effective heating.
- New shorter furnaces, which could decrease the investment cost.
- Emissions of nitrogen oxides, which will be in accordance with very strict demands from the environmental authorities.

2. OBJECTIVES OF THE PROJECT

The principle objectives of the project have been

- to confirm and demonstrate the possibility of technological innovation in which both high thermal efficiency and low nitric oxides emission can be achieved simultaneously
- to demonstrate the reliability and effectiveness when HPAC technology is used

A full-scale industrial test of HPAC burners in a 300 t/h oil-fired walking beam furnace at SSAB Tunnplåt, Borlänge has been performed in the project.

3. DESCRIPTION OF ACTIVITIES

The primary objective of the industrial installation of regenerative burners at SSAB Tunnplåt AB was to demonstrate the reliability and effectiveness when HPAC technology is used. The installation also provided possibilities for measuring emissions, furnace pressure etc. in an actual plant.

3.1 Burner Installation

SSAB Tunnplåt AB in Borlänge has installed one pair of regenerative burners in a walking beam furnace (furnace 302), which is heated with heavy fuel oil. The installation consists of two burners, which in regenerative mode burns in a sequence of 60 seconds each interval (changeover between burning fuel and suction of waste gas every minute).

The furnace in which the new burners have been installed (Fig. 6) has a production level of 300 tons per hour (nominal). The HPAC burners are installed in the preheating zone of the furnace where no burners previously are installed. After the preheating zone there is a heating zone (zone 2). The capacity of the new installation is about 10 % of the capacity in zone 2. Each HPAC burner has the capacity of ~2MW. Burners with higher capacity were too voluminous to fit in the available area at the furnace without major changes in the furnace construction. Above zone 2 there is also a burning zone (zone 1) which has the same capacity as zone 2. The total number of burners in the furnace is 119.

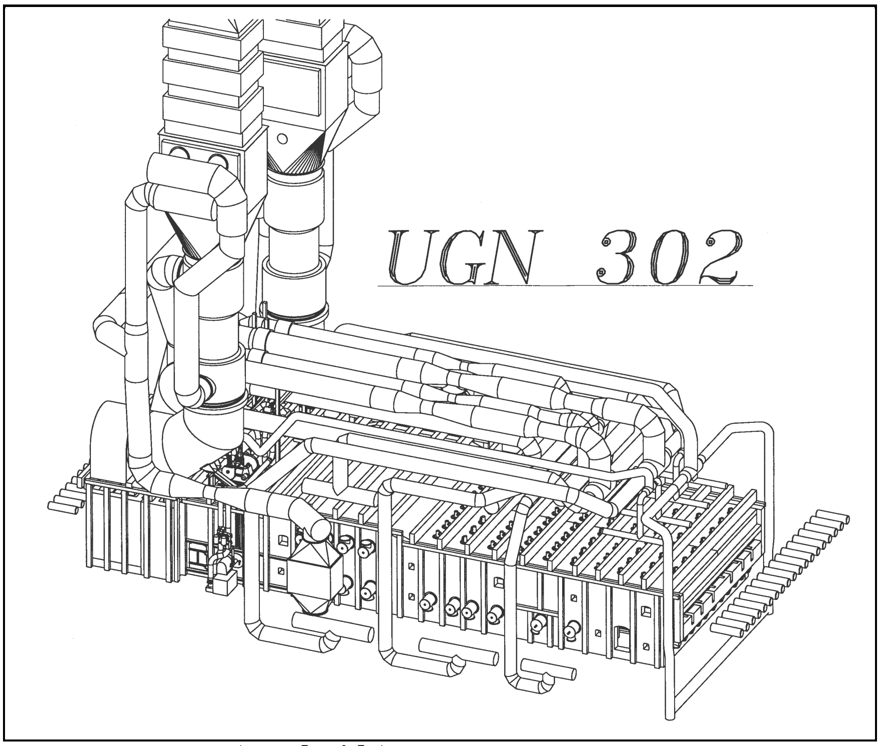

Fig. 1. Furnace 302 at SSAB (north side)

The HPAC burners (Fig. 7) are in regenerative mode when the atmosphere temperature in the preheating zone is over 800 ^{o}C. When the atmosphere temperature is lower, both burners will burn at the same time without using preheated air. The atmosphere temperature in the preheating zone was around 1050-1000 ^{o}C and the preheated air was about 900-1000 ^{o}C.

Fig. 2. Regenerative burner installation at SSAB (north side)

3.2 Maintenance

Since the installation was made a long time test has been running. The scope of this test was to check the reliability of the HPAC technique and the necessity of maintenance on the installation. The long time test has until 30 June 2002 been running 6634 hours in regenerative burning mode consuming 1 065 000 litres of oil. The long time test was done without any preventive maintenance with the main aim to show the reliability and check the limits of the burner.

3.3 Heat Transfer Temperature Efficiency

Two tests have been made for evaluating the heat transfer temperature efficiency of the ceramic balls heat exchanger. One “simple”test to see if cleaning of the ceramic balls during the summer stop 2001 had any effect and one with more accuracy to see the efficiency of the heat exchanger.

3.4 Slab test

The slab test, co-ordinated by MEFOS, has been carried out in December 2000. The test consisted of recording the heating curve inside the furnace and the level of the furnace pressure, CO, O_2 and NO_X. To be able to record these parameters two thin heat-resistant tubes was attached to the test slab during the experiment. The test itself was done in a very successful way. No unexpected delays occurred and all measuring equipment was working in the right way.

During the experiment logging files were created by the Furnace Optimising Control System for Reheating Furnaces FOCS-RF. Slabs and tracking data were stored in an event file. The measured gas and wall/roof temperatures, the fuel and air flows to the control zones, etc. were stored in a signal file. These two files can be used by STEELTEMP® 3D to recreate the furnace operation during the trials.

4. RESULTS AND DISCUSSION

4.1 Maintenance

The maintenance has mainly been related to four specific fields, the fans, the waste gas valve, the so thermocouple and the cleaning of the ceramic balls in the heat exchanger.

The thermocouple for this test must have a rather fast response time, this means small dimensions and short life time. In normal applications the fast response time is not so important the thermocouple can be made for longer lift time.

One of the waste gas fans broke down 11^{th} of June 2002. The housing of the fan cracked with the result that the impeller and axle was damaged. The fans were installed on the furnace roof where there is relatively high ambient temperature. This is of course not an optimal placement and the exchange of the drive belts and compensators are probably a result of the ambient temperature.

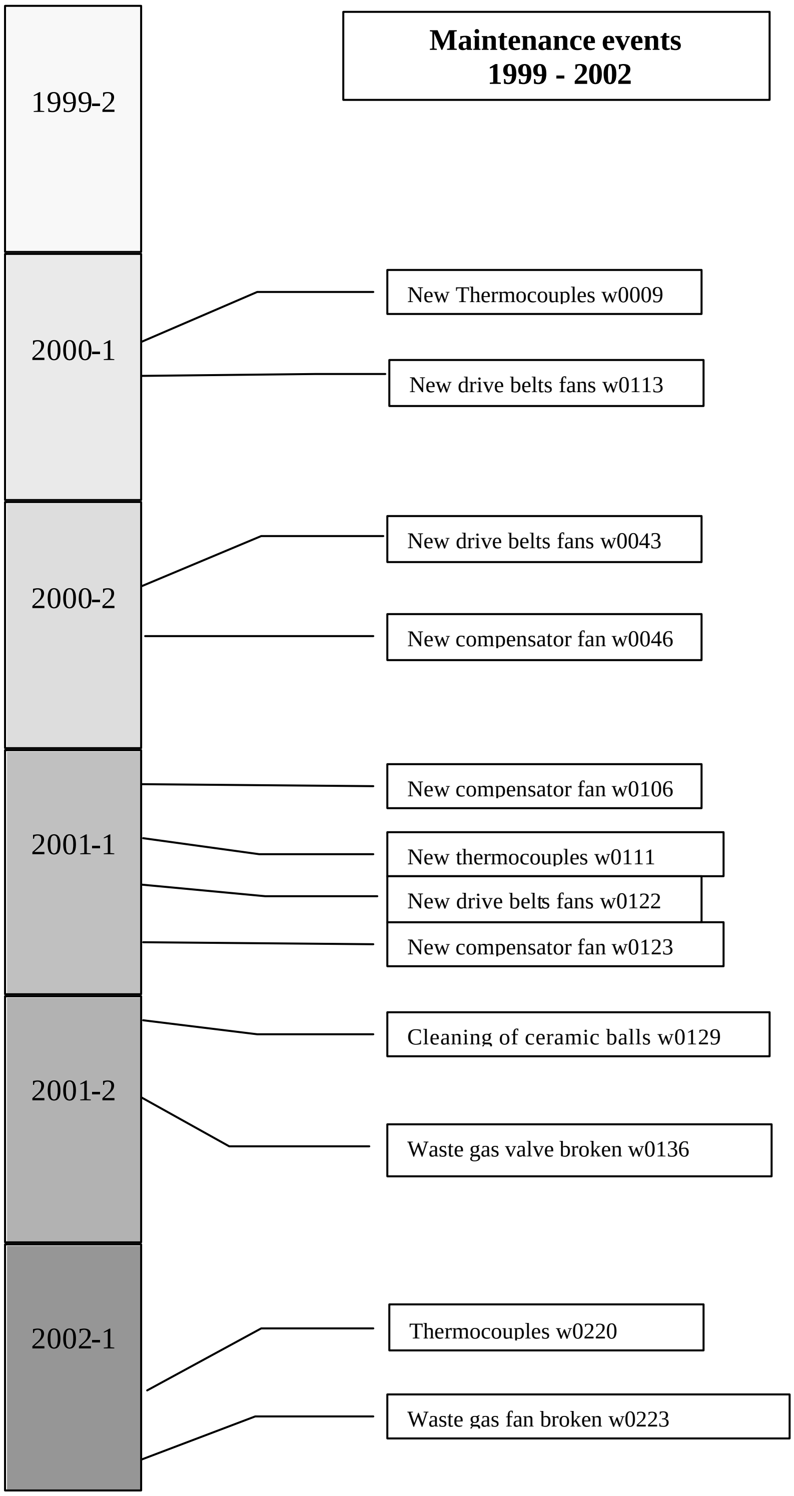

Fig. 3. Maintenance events 1999-2002

In September 2001 one of the waste gas valves sealing broke down. The waste gas valve sealing that was damaged was probably a result of the sulphur content in the heavy fuel oil (0.4%) and can be solved by selecting another material in the sealing.

4.2 Cleaning of ceramic balls

When the temperature element in the bottom of one of the heat exchangers was examined before the summer holidays 2000 it was covered with a greasy substance, probably due to the oil in the waste gas. The ceramic balls where not cleaned during the planned stop in the summer of 2000. During summer 2001 the ceramic balls was taken out from the heat exchanger and cleaned in a pot-mixer. The top layer of balls, 3 – 5 cm, where covered with a layer of easy removable soot, Fig. 25. The soot analyse pointed out iron oxide as the major component .No noticeable pressure drop depending of the soot layer has been seen.

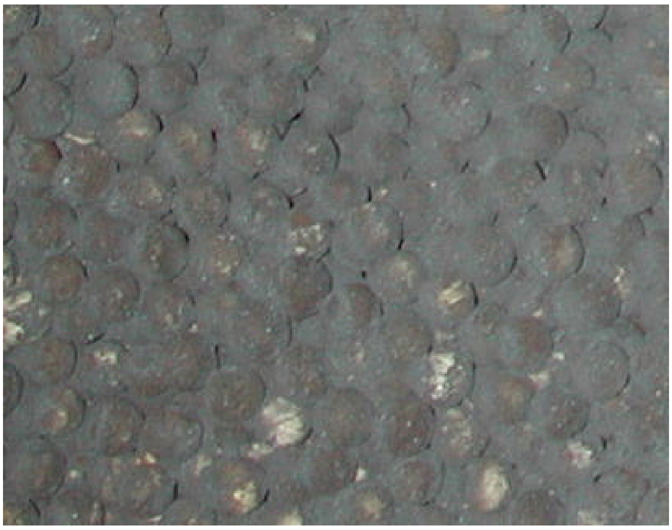

Fig. 4. Detail of ceramic balls before cleaning summer 2001 (diameter 13-15 mm)

The maintenance costs for the test period is shown in Fig. 26. Notice that the cost for purchasing and installing a new waste gas fan, which broke down a few days before end of test (~6000 EUR) is not included in the diagram.

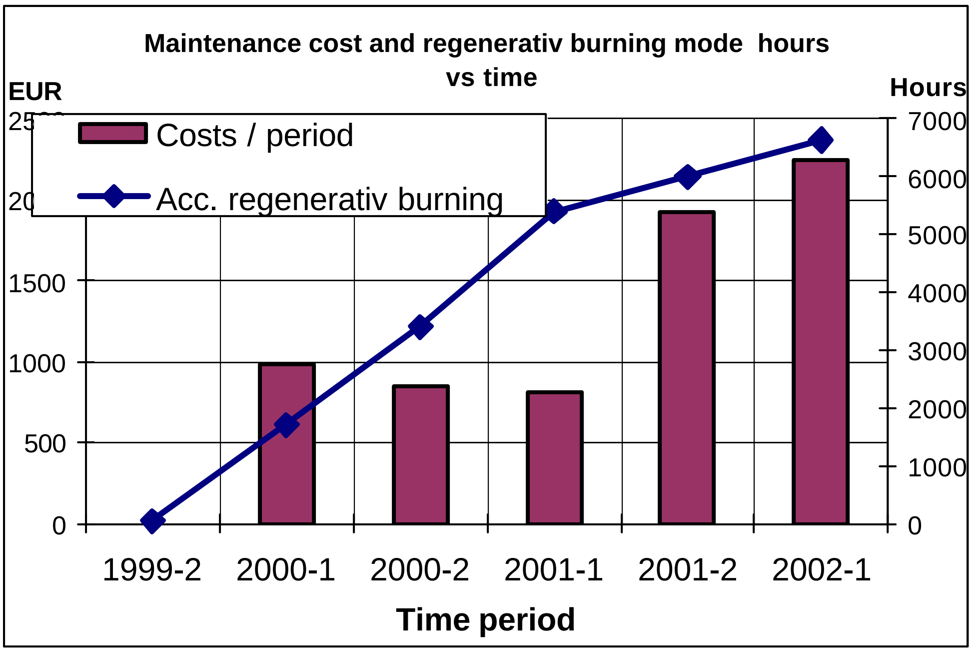

Fig. 5. Maintenance cost at SSAB

4.3 Heat Transfer Temperature Efficiency

The heat exchange after the cleaning of the ceramic balls did not show any measurable changes. A “simple” evaluation of the temperature efficiency did not show any significant changes of the efficiency. In June 2002 a more accuracy test was made to find out the efficiency of the heat transfer for the heat exchanger. Thermocouple with verified time constants was installed in the heat exchanger to overcome the problem that the thermocouples never reach a stabilized temperature. The correct value was then mathematically calculated. The sample time was also shorter then normal data sampling, i.e. 0,5 sec instead of 15 sec, to increase the accuracy. The temperature efficiency and heat recovery ratio were in order of 87.7% ±2% and 75.9% ±2.3% respectively at standard cycling (60 seconds) time.

A test at constant load with different burning interval (50 - 70 seconds) was also made. The burning interval did not show any effect of the heat recovery rate and the airside temperature efficiency.

4.4 Slab test

The results of the measurements of the O_2, CO, SO_2 and NO_x contents in the flue gases and the furnace temperature on the bottom surface of the test slab have can be seen in Fig. 27. To simplify the evaluation of the measurements the position of the HPAC burners and the boundaries between the dark zone, the preheating zone, the heating zones and the soaking zone have been marked in the plotted diagram. The diagram shows clearly the influence on the flue gas temperature and O_2 contents from the changeover of the HPAC burners between burning and suction mode. The oxygen contents in the flue gases vary up and down around 4 vol % O_2 with a time period of 2 min, before the test slab has reached the HPAC burners. Then the fluctuation ceases. However, the fluctuations in the flue gas temperatures can be seen in almost the whole dark zone, caused by the radiation from the flames of the burners.

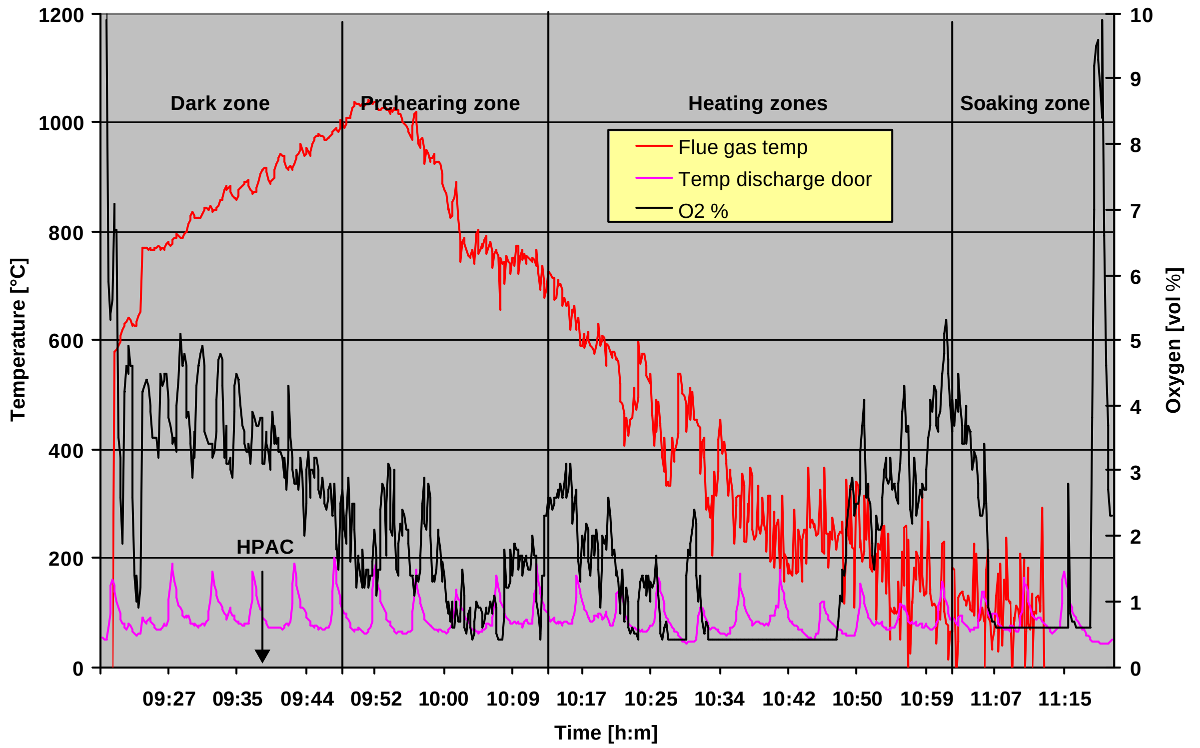

Fig 6. Furnace conditions measured at the bottom surface of a test slab in the walking beam furnace

The STEELTEMP® 3D dynamical heating model was used to calculate the heating curve of the test slab. the trial and to generate input data for STEELTEMP® CFD for a submodel, consisting of the dark zone with HPAC burners. The gas velocity fields can be seen in Fig 28 in a plane at the level of the burner. Generally, the velocities are high in the vicinity of the HPAC burners and the two waste gas outlets. The HPAC burner flame is deflected by the upstream coming flue gases, which also can be observed during operation. The gas temperature field at the same level can be seen in Fig 29.

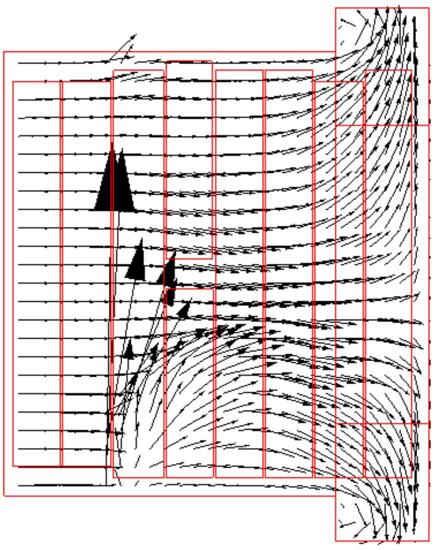

Fig 7 The velocity field ... SAB’s furnace # 302 at burner level. The velocity scale is 0.2 relative to the furnace. Viewpoint is from a position above the furnace.

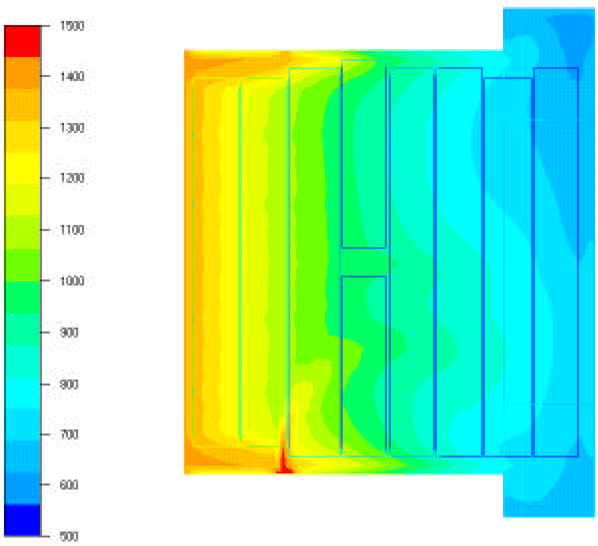

Fig. 8 The temperature fields in yz-planes of the dark zone of SSAB’s furnace # 302 at burner level. The temperatures are given in °C. Viewpoint is from a position above the furnace.

The increase of productivity obtained with a pair of HPAC burners installed in dark zone 10 was evaluated for a *steady-state* case. The calculations are made with the complex heating model of STEELTEMP® 3D.

First the heating curve of the slabs is calculated without the pair of HPAC burners installed. In the discharge position the mean temperature in cross-section 4 of the slabs is 1172 °C. Then the same calculation is made with the HPAC burners installed in dark zone 10. At the discharge position the slabs will now have a mean temperature of 1190 °C in cross-section 4. Finally, a number of calculations are made when the drop-out interval is decreased until the mean temperature in cross-section 4 reaches 1172 °C, valid for the case without the HPAC burners installed. The drop-out interval obtained is 5 min 3 s. Hence, it is concluded that the installation of a pair of HPAC burners in dark zone 10 gives rise to an increase in productivity of approximately 2 %.

5. CONCLUSIONS

The work, which has been carried out in a production furnace shows that regenerative burners be considered for application to existing steel reheating furnaces.

The long time test of a pair of regenerative burners in a oil-fired furnace shows a very good reliability and that the necessity of maintenance on the installation has been low. To avoid some maintenance problems it is important to choose the right materials and places for the equipment. The test shows also that it is possible to run this burner more than a year without cleaning the ceramic ball in the heat exchanger without any significant loss of performance. The effect of cycling time on the performance of the burner has been measured. It is certain that the heat recovery ratio and temperature efficiency are almost not affected with cycling time for this type of regenerator.

A comparison with an ordinary recuperative burner system gives that the fuel savings is approx 12% due to the higher heat recovery ratio. The one pair of regenerative burners has been modelled to increase the productivity in the furnace with 2%. The measurement of the NO_x contents in the flue gases in the vicinity of the HPAC burners also showed that the pair of HPAC burners did not add any extra contribution to the total amount of NO_x concentrations of ca. 150 ppm (4 % O_2 content).

Modelling techniques, such as computational fluid dynamics packages, can be used as a tool to optimise furnace design and the position of burners. However, caution should be practiced in the modelling approach and consideration given to the cyclic nature of HPAC burner operation. Time dependent, rather than steady state, solutions may be appropriate in some cases.

The consumption of oil and gases for reheating and heat treatment furnaces was 3,7 TWh during 2002. If regenerative burners can be installed in furnaces with ca 50% of this consumption the energy saving will be between 200 and 300 GWh. A drawback with these burners is the investment cost. The decreased costs for energy can rather seldom alone compensate the higher investment cost. Therefore higher productivity in the furnace and lower emission of nitrogen oxides are important factors.

6. ASSESSMENT OF EXPLOITATION AND IMPACT OF THE RESEARCH RESULTS

Many existing steel reheating furnaces are designed and operated to maximise fuel efficiency and productivity. This is most often achieved by the use of an unfired stock recuperation zone, which minimises the exhaust gas temperature leaving the furnace, and an exhaust gas recuperator for preheating the combustion air. However, most furnaces can benefit from the application of HPAC technology and regenerative burners.

Taking a general case, the combustion efficiency of a furnace using natural gas with an exhaust gas temperature of 1200ºC and operating with 10% excess air at the burner preheated to 1000ºC, was calculated at 73.4% on a gross basis. If the combustion air is supplied at ambient temperature, the combustion efficiency reduces to 36.8%, almost doubling the fuel energy required to satisfy the heat released within the furnace. In modern furnaces with external recuperators the energy saving is less. The fuel savings can be translated into reductions in CO_2 emissions and, with 'low NO_x' HPAC technology, there are additional benefits from reduced NO_x emissions.

Although the economic justification for the application of HPAC technology can often be based on energy savings alone, other benefits can be realized. These include increased productivity, improved product quality and increased product yield (reduced scaling) but these are specific to each application and are difficult to quantify in general terms.

Some of the results of the work undertaken have been presented to relevant parties within the steel industry through conferences and seminars. These include,

- STÅL 2002 (STEEL 2002) conference held on 15-16 May 2002 in Stockholm, Sweden
- Challenges in Reheating Furnaces. The Institute of Metals' Conference, held on 28-29 October, 2002, in London, England.