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Energy-efficient furnace heating – Regenerative heat recovery with flat flame burners

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Energy-efficient furnace heating – Regenerative heat recovery with flat flame burners

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The use of thermal regenerators in industrial furnaces produces major savings in fuel costs and allows high value fuels such as natural gas to be substituted by process and bio gas. Furthermore, flat flame burners are often used to achieve a required heating quality. A new type of heating system consisting of tubular regenerators and flat flame burners has therefore been developed for this purpose. The system was initially studied on an experimental basis using numerical simulation and then tested in operating conditions with great success. With both natural gas and with process gases from steelworks, fuel savings of 20 to 30 % were documented compared to systems which are commonly in use today. In addition, the entire system features low flow resistance while the pressure loss at high-fire rate is only approx. 20 mbar.

The high exit temperature of flue gases in high temperature process systems means that a major part of the energy used in the process is simply wasted. One idea to minimize these losses is to use an efficient heat recovery system which is installed in the stream of flue gases and uses the heat contained in the flue gases to preheat the combustion media. In a firing system which uses natural gas, the combustion air constitutes around 90 % of the gas mass flow. It makes a good deal of sense to preheat this combustion air. The lower the air requirement of the combustion gas, the less heat can be recovered from the flue gases and returned to the process. If LCV gases, such as blast-furnace gas, are used, it also makes sense to preheat the combustion gas using the heat from the flue gases.

The central recuperators which are commonly used today are primarily made of steel. The flue gas from these high temperature process systems is emitted from the furnace at a process temperature of over 1,000 °C. Since the maximum material temperature in the recuperator is well below this level, the hot flue gas is mixed with cooling air before being

fed into the recuperator. This means that the large potential of flue gas heat is not being used efficiently. The majority of the heat energy contained in the flue gas stream is simply lost from the process.

Fig. 1 shows an example of the potential savings for a furnace powered by natural gas with a flue gas temperature of 1,200 °C using various heat recovery techniques. To obtain a heat flow of

1 MW in the process, around 3 MW of energy must be provided by the combustion gas in a furnace without a heat recovery system, while in a system with a recuperative heat recovery system, the figure falls to around 2.2 MW. When using a regenerative heat recovery system, it falls to around 1.5 MW. Converting an existing furnace from recuperative to regenerative heat recovery therefore allows additional savings of up to 30 % to be achieved.

In heating furnaces in forging and rolling mills, for example, goods are heated to a temperature of approx. 1,200 °C. The annual production of a medium-sized forging mill is around 30,000 t. With a typical specific energy requirement of the forging furnaces of between 2.0 and 4.0 GJ/t, this means that the energy consumption rate is around 100,000 GJ/a (**Table 1**), with the appropriate fuel costs. In large rolling mill furnaces, this means that the fuel costs alone reach a level of several million Euros per annum. Massive potential savings can be made on these systems.

Fig. 1: Savings potential by heat recovery by means of combustion air preheating

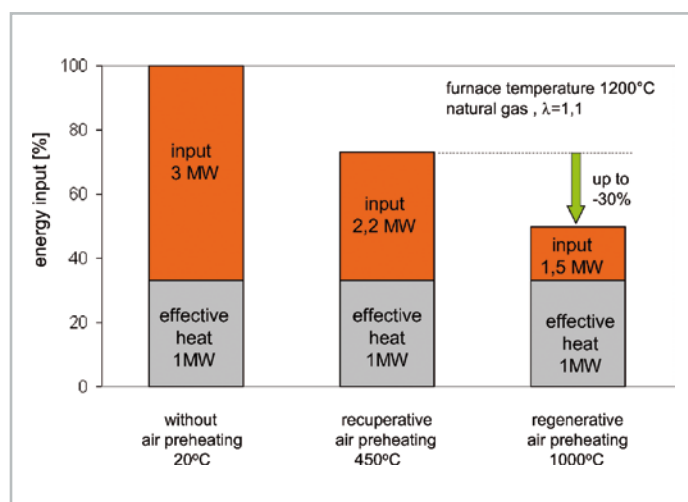


Table 1: Typical operational characteristics of existing plants

		Forging mill	Rolling mill
production	t/a	30,000	350,000
specific energy requirement	GJ/t	2.0 – 4.0	1.4 – 1.8
energy consumption	GJ/a	60,000 – 120,000	490,000 – 630,000
fuel costs	€/GJ	12	12
energy costs	€/a	720,000 – 1,440,000	5,880,000 – 7,560,000

Table 2: Calorific value and air requirement of tested fuel gases

	Natural gas	Coke oven gas	Converter gas
Calorific value	31.7 MJ/m ³	17.7 MJ/m ³	9.2 MJ/m ³
min. air requirement ($\lambda = 1,0$)	8.4	4.7	1.7

Heat recovery using thermal regenerators has been used in many sectors of industry for a considerable time. It is certainly not a new technology. However, to date there has been little enthusiasm for converting to this technology in sectors such as forging and rolling mills since it is assumed that the amortization time is simply too long. Until a few years ago, there were no suitable burners available for this purpose since the extremely high temperatures which occur in the pre-heating of combustion media resulted in increased NO_x emissions and the service life of the equipment available at that time was uncertain. More recently, the large increases in energy prices have considerably improved the economy of regenerator systems. Operational tests have shown that the NO_x problem can be solved using existing technology and a satisfactory service life can be achieved with the components used.

Development of a new heating system for heating furnaces

flat flame burners are often demanded by furnace operators to ensure the high quality heating of the product. The flat flame burners currently available on the market include components which create a torsional effect in the air. This results in a high pressure loss. In a standard combustion air preheating system using a central recuperator, the pressure loss via the burner alone amounts to over 40 mbar. An efficient regenerative combustion air preheating system would almost double this value. The investment and running costs for the combustion air fan increase accordingly. In addition, the components which create the torsional effect are not generally very durable when exposed to the high

temperatures which occur in a regenerative system. This is why there have been no flat flame burners available to date for use with thermal regenerators.

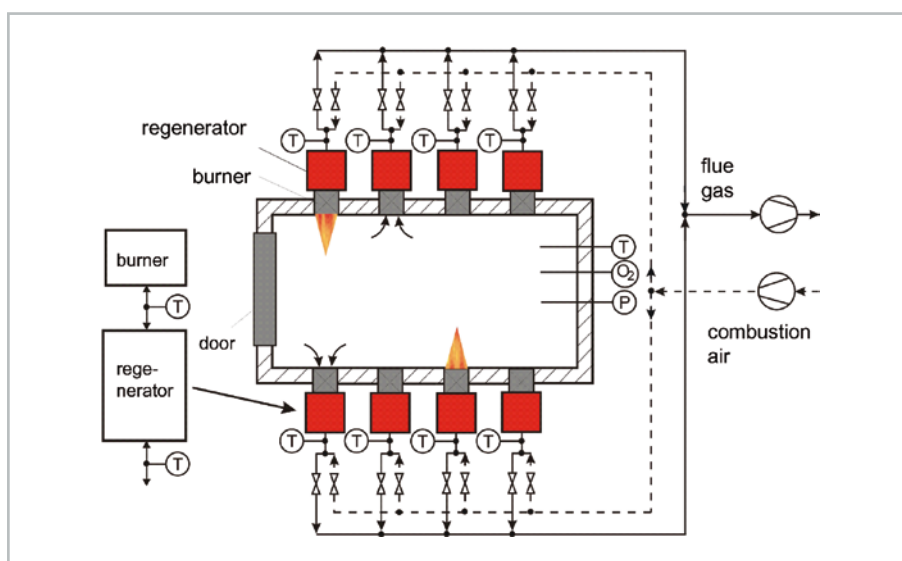
A new flat flame burner has now been developed, produced and tested in operational conditions which does not contain components to create the torsional effect. Together with a compact regenerator a new regenerator-burner system (ROREBS) has been created which combines the benefits of regenerative combustion air preheating with the technology of a flat flame burner. The interior of the flat flame burner is made of heat-resistant ceramic materials. This means that there is no need for cooling and purging air. The pressure loss in the burner if the air is preheated to 1,000 °C is around 15 mbar. With this in mind, the burner has been combined with a compact tubular regenerator which features a honeycomb design

so as to reduce its pressure loss to just a few mbar. This new ROREBS system has been tested on test rigs, improved by means of numerical simulation (CFD) and tested in operating conditions on furnaces in forging mills which use natural gas, coke oven gas and converter gas (BOF-gas) as fuels.

Operational testing of the system on furnaces in forging mills

A batch furnace and bogie hearth furnaces were fitted with ceramic flat flame burners and tubular regenerators. One of these furnaces can be operated with either coke oven gas or converter gas. The others are powered by natural gas. These combustion gases have very different calorific values and air requirements (**Table 2**). A forging furnace fitted with 8 systems is shown in schematic form in **Fig. 2**. Each burner has its own regenerator. The flue gas is extracted from the furnace through the burners and regenerators. The systems operate intermittently. While some of the regenerators preheat the combustion air, the flue gas is extracted through other regenerators. The regenerators are charged and discharged alternately.

The heating system consisting of the regenerator and flat flame burner is shown in detail in **Fig. 3**. Hot flue gas is fed out of the furnace chamber through the burners to the heat accumulator. This is where the flue gas releases the majority of its heat energy and then exits through the bottom end of the regenerator at a temperature of approx.

**Fig. 2:** Schema of an implementation at a reheating furnace

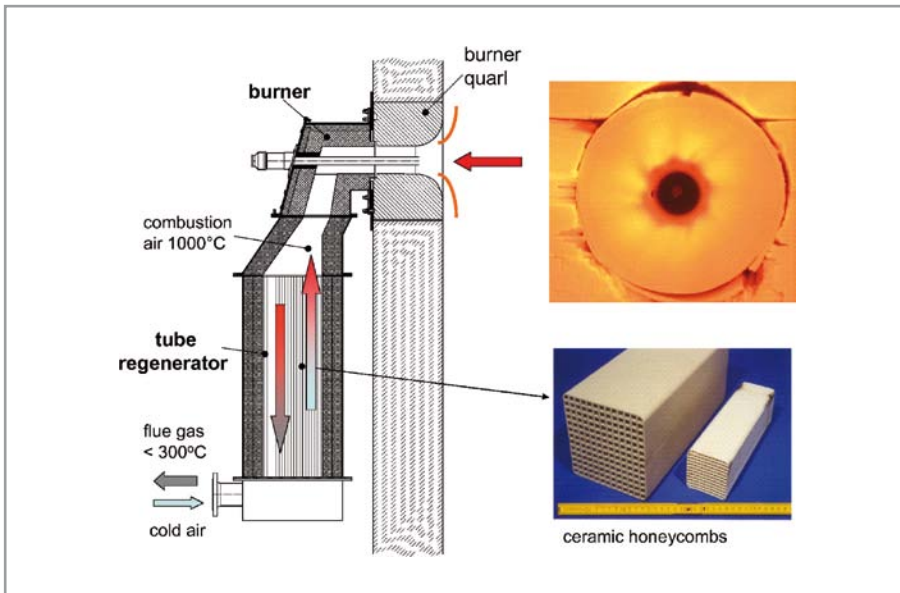


Fig. 3: New heating technology with regenerator and flat flame burner



Fig. 4: flat flame burner in a bogie hearth furnace

300 °C. The flue gas extraction system is then shut down and cold combustion air is pushed in at the foot of the regenera-

tor. This is fed through the heat accumulator and heated to a temperature of approx. 1,000 °C. The hot combustion

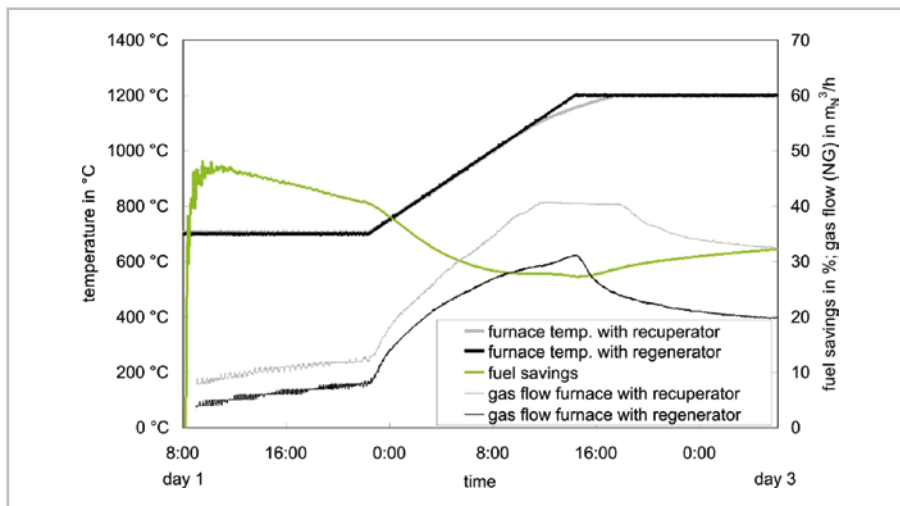


Fig. 5: Attained fuel savings at a reheating furnace

air is then fed straight into the burner. Ceramic honeycombs are used as the heat accumulator.

The burner is designed so that the type of air flow creates a torsional effect which is strong enough to form a flat flame on the burner quarl, no components are required to guide the combustion air flow. This means that this burner features low pressure loss and does not tend to suffer wear caused by the flow conditions.

The flue gas temperature is measured at the foot of the regenerator. If it exceeds a limit value, the extraction of flue gas is stopped to prevent the system suffering damage and prevent a thermal overload in the downstream system components. As an option, it is also possible to record the combustion air temperature upstream of the burner using a thermocouple installed between the regenerator and the burner.

Fig. 4 shows an example of a bogie hearth forging furnace powered by natural gas with ten systems with a gas capacity of 300 kW where five have been installed on each side of the furnace. The new heating equipment on this furnace has been operating for around four years. With the furnace operating at a temperature of 700 °C, the combustion air for this system is preheated to between 500 and 550 °C. With a furnace temperature of 1,260 °C, the combustion air temperature reaches values of between 1,000 °C and 1,100 °C. The furnace is operated at maximum capacity within this temperature range. In the subsequent settling phase, the furnace capacity falls to around 20 to 30 % of the connection capacity. Conventional heating systems suffer considerable falls in efficiency at this point. The new heating system, on the other hand, allows the combustion air temperature to be kept at an almost constant level of around 900 °C.

The fuel gas savings achieved by operating a forging batch furnace with four burner- regenerator systems on each side of the furnace have been measured in detail. This furnace has been running for over five years. A comparison to the recuperator operating mode of an otherwise identical neighbouring furnace showed that over the entire furnace cycle, the system made energy savings of up to 30 % (Fig. 5).

All regenerator systems also featured low maintenance requirements during the testing phase together with no down times for cleaning the regenerator.

Conclusion

ROREBS is a new heating system for high temperature process systems which has been developed, built and tested in operating conditions and combines efficient waste heat recovery with the benefits of the flat flame burner design. Savings in fuel requirements (energy costs and CO₂ emissions) of 20 to 30 % compared to conventional systems were made during operational trials. The considerably lower pressure loss of the new system also combined the benefit of a lower electrical fan rating with a considerably increased combustion air temperature. The suitability of the system for both natural gas and process gas was also demonstrated.

The new components of the ROREBS, the tubular regenerator and flat flame burners, will be improved both for use on other industrial firing systems such as rolling mill furnaces and also for use with alternative fuels.

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