

High Temperature Recuperators Cooperating with a Metallurgical Furnace for Heating the Air Under Pressure

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Abstract. In this paper, a system which uses hot furnace gases from a metallurgical process to heat compressed air necessary for another energy process is presented. The applied construction of the recuperator ensures high temperatures of the heated air needed for its utilisation in a separate process. Their levels depend on the processes in the reactor. A limitation to the construction of the installation is creep resistance of the materials used to assemble the recuperator modules which operate under high-temperature regimes. The well-prepared gas dynamic design of the recuperator ensured low pressure loss for the flowing air. Furnace gases leaving the recuperation system still have a high energy potential which can be utilised. As it is not possible to manage such large amounts of additional energy, the problem will be solved in the future when necessary.

Keywords: *recuperators, heating air, metallurgical furnace.*

1 Introduction

Metallurgical technologies are combinations of chemical, thermodynamic and, in some cases, electrical processes which occur simultaneously within the space limited by the furnace reaction chamber. Application of theoretical analyses and mathematical models for modification of the technological process parameters or its deeper modernisation may become a factor of the technological advantage. Technology influences the competitive advantage when it plays a major role in determination of the relative cost position or product differentiation [1, 2]. The overall reduction of energy and raw material consumption in the technological process considerably impacts on the price and competitiveness of the offered product, which is frequently the aim of optimisation [3, 4].

High-temperature furnace gases are carriers of far higher amounts of usable energy. The energy balances show that their enthalpy flux constitutes approximately 40 % of the overall energy delivered to the process. Transformation of the furnace gas (fuel gas) enthalpy into another, convenient to send and use form of energy encounters many technological, constructional and functional barriers [5-8].

A waste-heat boiler which produces hot water or steam is one of the most commonly proposed and applied solutions. Water steam can be used for operating steam turbines combined with electric generators [9, 10]. Electrical energy production in a turbine set with water steam requires the use of appropriately treated water which must be systematically replenished. This generates additional costs associated with functioning of the system of circulating water preparation and its growing prices. Another inconvenience is the requirement of continuous heat reception from the water steam condensation system regardless of its periodic demand in combined recovery systems. Frequently, waste energy from technological processes can be utilised in another project following appropriate conversion in the energy recovery system. Growing prices of energy carriers make all activities aimed at their more efficient use very desirable.

The aim of this paper is to present a system which uses hot furnace gases from a metallurgical process to heat compressed air necessary for another energy process.

2 Description of the recuperation channel

Six recuperator modules combined within a serial-parallel system were placed inside the outlet furnace gas channel. Each serial air flow system is composed of three modules: 6-5-1 and 4-3-2. This solution aims to achieve comparable air heating temperatures in the serial flow sequences. The scheme of module combinations in the recuperator is presented in Fig. 1. The recuperator is located in the channel with furnace gases delivered to

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the dust collection system. The air and furnace gases pass through in counterflow, which ensures optimal flow and heating characteristics of the recuperator.

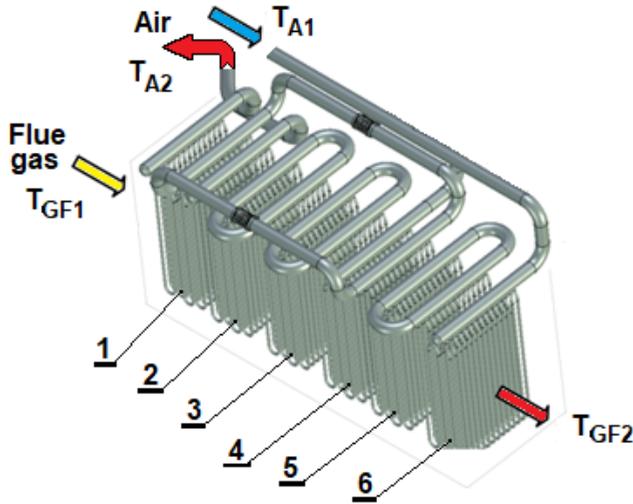


Fig. 1. Scheme of the recuperation system.

The recuperator and the furnace gas channel have been designed to meet a series of requirements being a compromise of many parameters. The major inconvenience in the project resulted from a limited available space in the process facility. Moreover, required minimisation of the furnace gas and air flow resistances in the recuperator pipes had to be ensured. The flue gas channel in the model calculations is presented in Fig. 2.

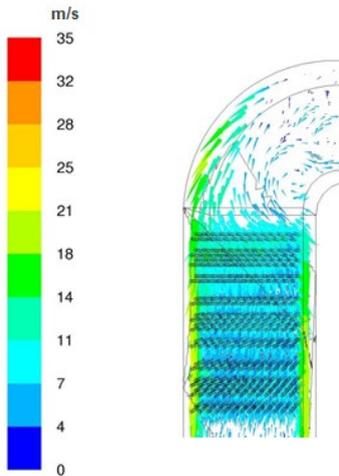


Fig. 2. Computational velocity distribution in the flue gas channel.

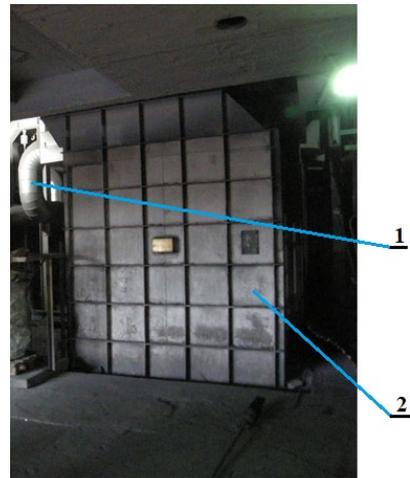


Fig. 3. Recuperation channel: 1 - air pipeline, 2 – the flue gas channel of the furnace.

The mean 24-hour temperature T_{GF1} of the afterburnt furnace gases (flue gases) flowing to the first recuperator module is 800 °C. Due to the recuperator channel size, it is measured by means of three thermocouples located within the vertical axis of the channel at three different levels (heights). The value shown in Fig. 3 presenting the T_{GF1} temperature changes versus time is the mean value of the three measurements. The mean 24-hour temperature T_{GF2} of the flue gases leaving the recuperation system is 556 °C. It is measured by means of two thermocouples located within the channel axis.

The initial measurements showed that the impact of the measurement point level (height) in the channel was considerably smaller due to the strong mixing of streams between the recuperator pipes and a lower temperature of the gases. Two thermocouples are sufficient to obtain representative results. The 24-hour T_{GF2} temperature change as the mean value based on measurements with two thermocouples is presented in Fig. 4. After reaching the assumed working parameters, temperature fluctuations of the flue gases are recorded in the channel. They result from the course of technological processes in the furnace and current conditions of the combustion of furnace gases.

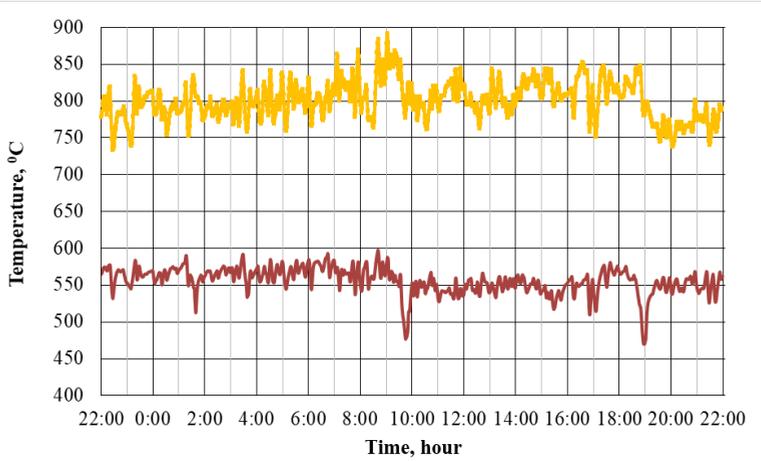


Fig. 4. Mean temperatures of the furnace gases at the inlet and the outlet of the recuperator : T_{GF1} — T_{GF2}

The flues gasses in the recuperator pass their energy to the compressed air, which decreases their temperature from T_{GF1} to T_{GF2} . The modules of recuperators were designed as U-pipe structures based on many years of experience resulting from the research and implementation works carried out at the Department of Process Energy, Silesian University of Technology [11-13]. The diameter and number of the pipes in the module were selected as a compromise between the requirements of acceptable air flow rates and geometrical limitations of the flue gas channel. The final shape of a single module pipe was similar to the W letter to reduce the air pressure in the pipes and for the strength reasons. The overall pipe length in the module was selected so that it was comparable to the available commercial size, which prevented generation of unnecessary waste leading to additional costs.

The air in the compressor is heated up to approximately 385 °C and delivered to the recuperation system. The air temperature sensors were placed in the compressor outlet port as well as at the recuperation system inlet (T_{A1}) and outlet (T_{A2}) (Fig. 1). For control purposes, temperatures of two air streams at the outlets of the module sequences 6-5-1 and 4-3-2 are additionally measured. The air flowing through the two module sequences in the recuperator heats up (energy taken from the flue gases) from the mean temperature of approx. 385 °C to far above 620 °C (the mean 24-hour temperature of 650 °C), which is illustrated in Fig. 5.

The mean 24-hour temperature of the air at the outlet of the first module sequence (6-5-1) was 667 °C while the temperature for the second sequence (4-3-2) was 641 °C. The temperature difference between the module sequences was less than 4.5 % in relation to the air temperature in the first module sequences, which indicates a very good design of air flow distribution and the order of module connections. The measured 24-hour temperature courses at the outlets of the module sequences are presented in Fig. 6.

Effectiveness of the system of furnace gas energy utilisation depends not only on the achieved air heating temperature, but also on reduction of pressure generated in the recuperator and the other installation components. The level of pressure loss results from the applied technical solutions which influence gas dynamics of the system. The necessary air pressure in the pipelines is ensured by the compressor and the energy consumption associated with its operation depends on e.g. flow resistances that must be overcome.

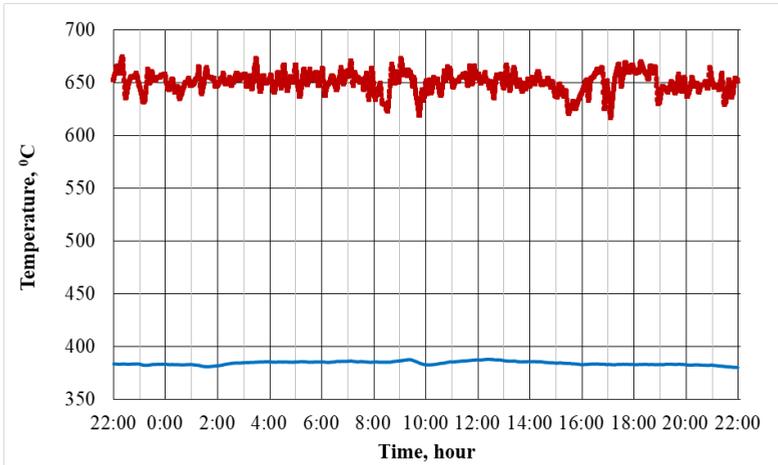


Fig. 5. Temperatures of compressed air: — T_{A1} the inlet to the recuperator, — T_{A2} the outlet from the recuperator.

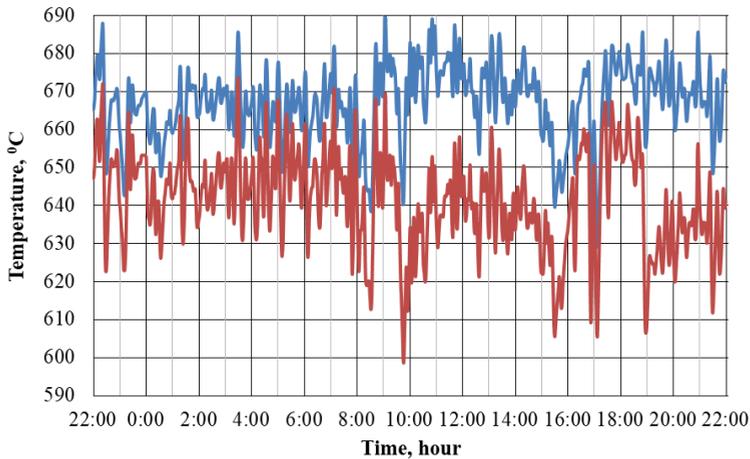


Fig. 6. Temperatures of compressed air at the outlets of the sequences 1 and 2 of the recuperator modules: — sequence of modules 1 (6-5-1), — sequence of modules 2 (4-3-2).

The relative pressure loss in the air heating system for the pressure measured at the outlet port of the compressor is illustrated in Fig. 7. The mean pressure loss is 1.09 % of the pressure generated in the compressor, which is an over three-fold smaller value than that estimated in the models for the initial geometrical solutions.

The pressure loss measured in the recuperator was 48 % on average of the overall value recorded during the operation of the compressed air heating system. The measurements performed during the system operation indicated that the mean absolute increase in the air enthalpy flux was 1100 to 1200 kW.

An additional effect of the application of the energy recovery system from post-process gases was the reduction of their temperature by an average of 245 °C, what is shown in Fig. 4. Reduction of the exhaust gas temperature without excessive dilution of ambient air caused the reduction of their flow rate flowing through the dusting exhaust fan. This enabled the fan to operate with changed operating characteristics.

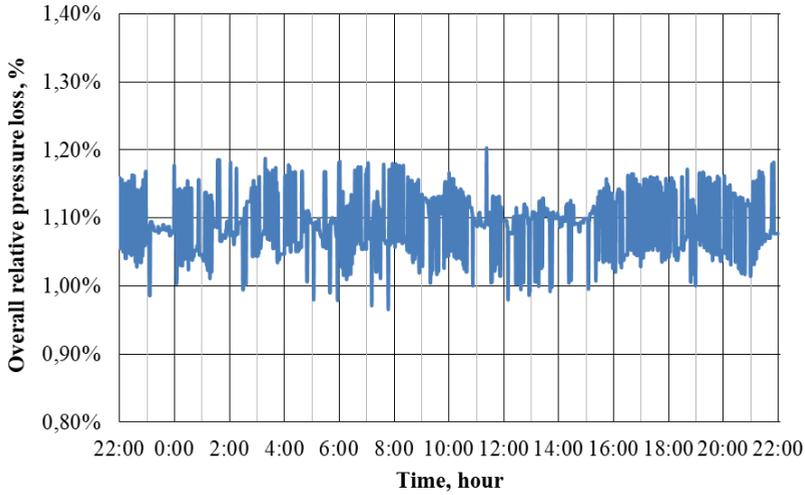


Fig. 7. Overall relative air pressure loss recorded between the compressor and the receiver.

As a result, the power of the electric motor was reduced, which was 750 kW before the modernization. Thanks to that, an additional effect of reducing the energy consumption of the technological process was achieved. The measured power of the fan motor during the recuperator's operation is shown in Fig. 8.

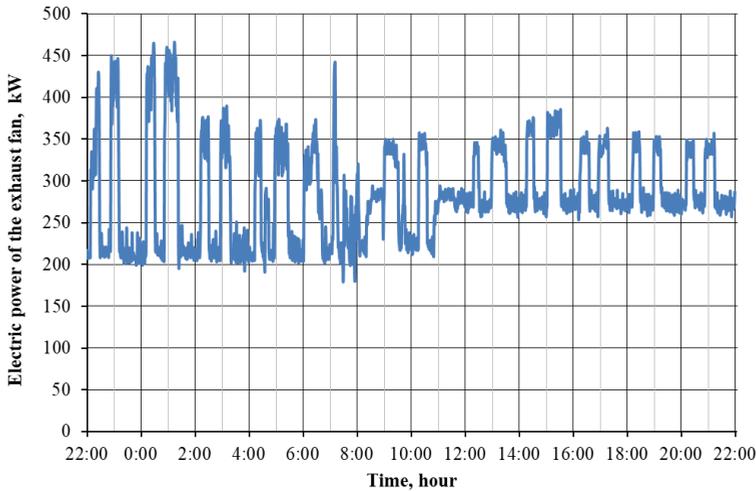


Fig. 8. Stream of electric energy supplied to the exhaust fan engine.

The system for regulating the negative pressure of post-process gases in the furnace affects the operating conditions of the fan and changes its operating characteristics along with the rotation of the rotor. The amount of the produced post-process gases changes over time and depends on the frequency of feeding new portions of batch materials to the furnace, their weight and the manner of its handling. Therefore, in Fig. 8. cyclical changes in fan operating conditions are visible. The influence of cyclical changes in the thermal parameters of the process is also observed in the other charts.

3 Conclusions

1. The applied construction of the recuperator ensures high temperatures of the heated air necessary for its utilisation in a separate process. The temperature level depends on processes in the metallurgical reactor and the resulting furnace gases of the appropriate temperature.
2. A limitation to the construction of the installation is creep-resistance of the materials used to assemble the recuperator modules which operate under high-temperature regimes.
3. A cyclic delivery of the substrates to the metallurgical reactor, every 30÷40 minutes, is observable in the profiles of the temperature courses of furnace gases and heated air.
4. The well-prepared gas dynamic design of the recuperator ensured low pressure loss for the flowing air which was only 1.1% on average of the compressor available pressure.
5. Furnace gases leaving the recuperation system still have a high energy potential which can be utilised. As it is not possible to manage such large amounts of additional energy, the problem will be solved in the future when necessary.

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