THE REGENERATIVE BURNERS AS A SIGNIFICANT WAY OF CO_2 EMISSION REDUCTION

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Abstract

Almost every day, from different information source, we can hear about problems dealing with CO_2 emission and its impact on environment and us - people. A few sources from which CO_2 is emitted can be pointed out but this paper focuses on metallurgical industry. The main areas of interest are furnace process technologies where the gas burners are used. The main product of gas combustion in those burners is CO_2, so that in non-optimized combustion processes that emission is very high.

Therefore the world-metallurgical industry keeps looking for some solutions for fuel saving and thus CO_2 reduction. One of the methods which are used to solve this problem is applying high combustion air temperature. What is more and more attractive is the High Regenerative System (HRS). It can achieve an air temperature of more than 1000 °C. It saves more fuel and it is more environmental friendly. The HRS makes use of the regenerators as heat exchangers. This system has become increasingly popular in the aspect of reducing CO_2 emission.

Based on research results the paper presents the selected data, dealing with the combustion air temperature obtained for the honeycomb type of regenerator filling. The reduction of both fuel consumption and CO_2 emission has been presented finally as an economic and environmental aspect according to the air preheated.

Keywords: Heat regenerator, regenerative burner, high air temperature, CO_2 reduction, environment protection

1. INTRODUCTION

Currently, environmental restrictions (related to the emission of pollutants) imposed on enterprises require more and more energy optimization of technological processes and in particular heat treatment processes. In the era of rising energy prices and diminishing fossil fuel resources special attention should be paid to those processes during which gaseous fuels, such as natural gas, are burned while the main product of its combustion is CO_2. Carbon dioxide is a significant environmental pollutant and it is a reason for looking for solutions to reduce its emissions.

The high energy efficiency of thermal devices required for the conduct of the metallurgical technologies is one of the ways to reduce CO_2 emissions. The method of increasing energy efficiency for natural gas combustion technology is using a high temperature of air combustion. It is known that the air temperature increase causes the reduction of fuel consumption and thus decreasing the exhaust gases in that CO_2. The metallurgical industry commonly uses the heaters to preheat an air delivered to combustion process. The recuperative exchanger system is most often used. Generally, the air preheat of 300-500 °C is used.

Another solution can be proposed for the high temperature heating furnaces - it is the regenerative system which can preheat the air to the very high temperature - much higher than regenerator [1,2]. This solution is called High Temperature Combustion (HTC), High Temperature Air Combustion (HTAC) or High Preheated Air Combustion (HPAC). A temperature of more than 1000 °C can be obtained in this system as indicated in some literature [3,4,5]. The combustion with the high air temperature needs the regenerative system which is called High-cycle Regenerative Systems (HRS). At present the HTAC technology with regenerative burners system is successfully used in hundreds of different industrial applications all over the world and provides many advantages e.g. more effective heat recovery, reduction of energy consumption, low pollutants emission, cheaper production and high products quality [6,7,8]. The paper presents data obtained for regenerative gas burners with HPAC system. The significant decrease of fuel consumption and thus CO_2 reduction is caused by high temperature of air combustion. The honeycomb regenerative filling has been considered. Finally, the economic and environmental effects of using the regenerative burners with high combustion air temperature have been presented.

2. REGENERATOR FILLING AS AN OBJECT OF CONSIDERATION

In many metallurgical industry applications the one big central regenerator is used. This solution usually gives temperature losses of exhaust and air preheated. They are caused by the exchanger location or poor insulation of the distribution system. The exhaust temperature losses very often reach even 200 ºC. The individual regenerators for burners are better solutions where the very high combustion air temperature can be reached [2,5,9].

The regenerator always works in a pseudo-steady state. Its outlet air temperature fluctuates within a certain temperature range. This range depends on the time constant of the regenerator and its reversion time. The most significant regenerator parameters which affect heat transfer and thereby the outflow temperature are: surface of heat transfer and volume of filling. These quantities depend on the regenerator construction parameters (**Figure 1**). All these parameters influence the regenerator mass, the heat transfer area and heat transfer coefficient. It is very difficult to say what parameter values should be used because there are a multitude of combinations of geometrical parameters. So it is better to use some simplified methods for choosing a few solutions (referring to a simplified theory of heat regenerators) and then to check them in the dynamic model. Only this model can indicate the appropriate results [10,11]. Therefore, the algorithm for selection of regenerator parameters (referring to a simplified theory of heat regenerators) was developed and used in the numerical assistance - in the author's software.

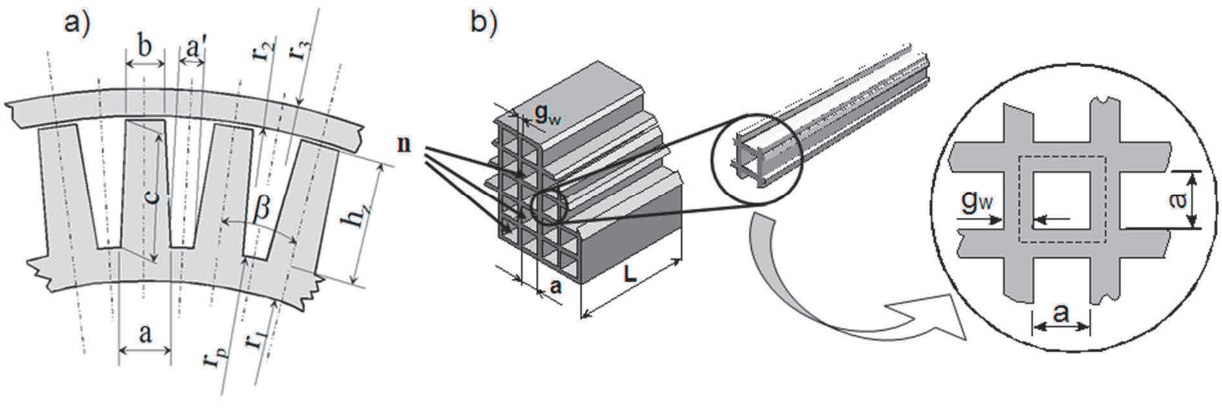

Figure 1 Construction parameters of regenerative filling: a - sunflower type, b - honeycomb

There are a few criteria, in the software algorithm, which should be used during designing process to get a good product:

- Surface condition the real surface of the heat transport A_{real} should be bigger than calculated, theoretical surface area A_{theor} necessary to exchange heat flux resulting from assumptions

$$A_{real} = \mathrm{f(Construction\ parameters)} > A_{theor}\mathrm{f}(\dot{Q}, k, \Delta T_m) \quad (1)$$

where:

A_{real} - real surface of the heat transport (m²)

A_{theor} - calculated, theoretical surface area (m²)
k - heat transfer coefficient (W/(m²·K))
$\dot{Q}$ - heat flux exchanged by the regenerator (W)
ΔT_m - logarithmic mean temperature difference (-)

- Minimum regenerator filling weight

$$m_R = \mathrm{f}(\text{Constructi on parameters}, q_R) \rightarrow \text{minimum} \tag{2}$$

where:

m_R - mass of regenerator filling (kg)
ρ_R - density of regenerator filling (kg/m³)

- Maximum coefficient A_S (specific surface area) which defines the relation of heat transfer area to the volume of the regenerator filling

$$A_S = \left(\frac{A}{V}\right) \rightarrow \text{maximum} \tag{3}$$

where:

A - heat transfer area (m²)
V - volume of the regenerator filling (m³)

The heat flux exchanged by the regenerator and heat transfer coefficient are calculated from energy balance and heat transfer for the regenerator filling. The heat transfer coefficient is defined as (4), while the convection heat transfer coefficients for fluids depend on a number of parameters, which generally can be written as (5). All physical properties of fluids are calculated as averages. The logarithmic mean temperature difference in (1) has the form of (6).

$$\frac{1}{k} = (t_{exh} + t_{air})\left(\frac{1}{\alpha_{exh} t_{exh}} + \frac{1}{\alpha_{air} t_{air}}\right) \tag{4}$$

where:

t - time of fluid (air, exh - exhaust) flow through the regenerator (s)
α - convection heat transfer coefficients (for air and exh - exhaust) (W/(m²·K))

$$\alpha = \mathrm{f}(\dot{m}, \rho, \nu, Pr, A_{flow}, O, L) \tag{5}$$

where:

m_R - mass of regenerator filling (kg)
$\dot{m}$ - fluid mass flow (kg/s)
ρ - fluid density (kg/m³)
ν - kinematic coefficient of fluid viscosity (m²/s)
Pr - Prandtl number (-)
A_{flow} - surface fluid flow (m²)
O - wetted perimeter of regenerator filling (m)
L - length of the regenerator ducts (m)

$$\Delta T_m = \frac{\left(T_{exh\_in} - T_{air\_out}\right) - \left(T_{exh\_out} - T_{air\_in}\right)}{\ln\left[\frac{T_{exh\_in} - T_{air\_out}}{T_{exh\_out} - T_{air\_in}}\right]} \quad (6)$$

where:

T - temperature (ºC)
air - applies to air
exh - applies to exhaust
in - value at the entrance
out - value on the output

3. EXPERIMENTAL RESEARCH OF REGENERATOR FILLING

The main research aim was preparing the compact construction of regenerator, for low-power burners - 50 kW for natural gas with excess air number λ = 1.05, which could preheat air to the very high value - more than 1000 °C for the exhaust temperature 1200 °C. The high air temperature decreases fuel consumption and thus CO_2 emission. The "honeycomb" has been considered as the regenerator type because of many positive features. Using the author's software a few ceramic materials for regenerator filling were examined. Finally, one of them was chosen.

For the initial data the supporting software pointed the best ceramic material for achieving assumptions and it is characterized by the following parameters: density ρ_R = 2300 kg/m^3, heat capacity c_R = 1255 J/(kg·K), thermal conductivity λ_R = 11.05 W/(m·K). The construction parameters have been determined and the final corrected result was pointed out. It should be noted that a very serious limit are the technical possibilities, especially for a ceramic regenerator and those limitations have to be considered before production. The designed regenerator consists of over dozen ceramic segments with a thickness of 12 mm and a diameter of 90 mm, in which there are 325 circular flow channels with a diameter of about 3 mm. The weight of the regenerative filling is about 3.8 kg and calculated specific surface area (3) has reached 1320 m^2/m^3.

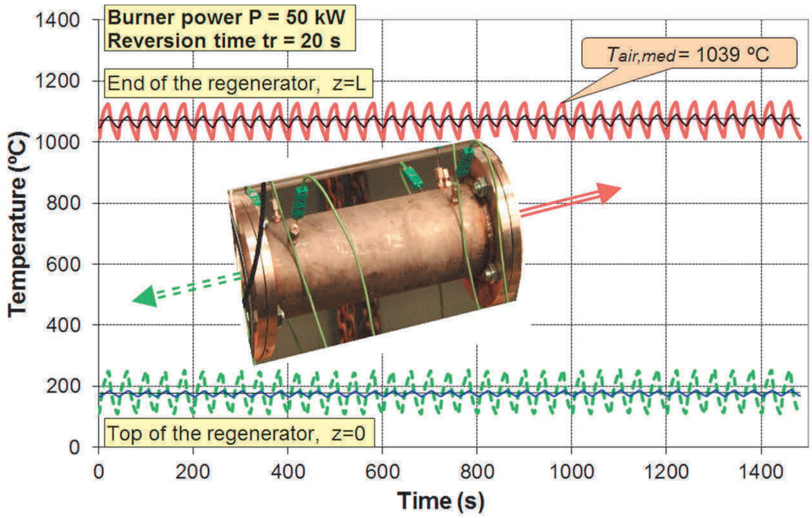

Figure 2 Pseudostatic characteristic of the regenerator - experimental studies

Then the regenerator was examined in the laboratory on the test stage. During research low flow resistance was measured for the regenerative filling. The pressure drop in the ducts of the regenerator for the exhaust flow was 1.28 kPa and for the preheated air 0.90 kPa. Considered regenerator is a good solution because it can achieve very high combustion air temperature as presented in **Figure 2**.

4. RESULTS ANALYSES

The regenerator works in an unsteady state (**Figure 2**). The average temperature can be specified for fluids in the outflow when the pseudo-steady state is achieved and then this temperature can be used for considerations. The regenerator quality can be examined by a few factors e.g.: relative fuel saving factor (7) and relative air preheat κ defined as (8). The combustion-system efficiency η is defined from the energy balance and it may be expressed as (9).

$$\Phi = 1 - \frac{\dot{H}_f^p}{\dot{H}_f^{np}} \tag{7}$$

where:

$\dot{H}_f^{np}$ - fuel enthalpy flow and no preheated air in the system (W)

$\dot{H}_f^{p}$ - fuel enthalpy flow when preheated air appears (W)

$$\kappa = \frac{T_{air\_out} - T_{air\_in}}{T_{exh\_in} - T_{air\_in}} \tag{8}$$

$$\eta = 1 + \frac{\dot{H}_{air}}{\dot{H}_f} - \frac{\dot{H}_{exh}}{\dot{H}_f} \tag{9}$$

where:

$\dot{H}_f$ - fuel enthalpy flow (W)

$\dot{H}_{air}$ - enthalpy flow of the preheated air (W)

$\dot{H}_{exh}$ - enthalpy flow of the fumes leaving the furnace (W)

4.1. The regenerator quality checking

Based on research results the regenerator quality has been checked. The relative fuel saving factor on about 0.5 level was obtained. The relative air preheat factor has been calculated according to the air temperatures in the regenerator outlet. It can be noted that it is about 95 % - the average factor for a recuperative system is usually in the range of 30-40 %. The high value of combustion-system efficiency has been achieved and it was about 86 %. All obtained results of the regenerator quality show that the considered regenerator is an interesting solution because it can considerably reduce the fuel consumption and the CO_2 emission.

4.2. The regenerative system in the high-temperature furnace

The preheating of combustion air up to the high temperature level is the main target of using the regenerator. It is one of the ways to obtain the reduction of fuel consumption and the CO_2 emission. The possibility of regenerative burners used for the heat-treatment furnace has been considered. The most important parameters were as follow: charging window dimension: 0.3 m x 3 m - height and width; charge dimension: 0.25 m x 2.5 m - diameter and width; fuel: natural gas; process temperature: T = 1200 °C; combustion air factor: λ = 1.05; productivity: $\dot{m}_{charge}$ = 12 Mg/h.

The heating furnace was equipped with traditional gas burners with central recuperator. The preheat air temperature of about 305 °C has been obtained. The fuel consumption on the level 826 Nm^3/h has been noted. After furnace modernization the new preheating system has been installed. The combustion air preheat increased up to 1070 °C and the fuel consumption has been decreased to about 532 Nm^3/h. For this case the fuel reduction of 294 Nm^3/h has been obtained which is about 35 % less fuel consumption comparing to the case of 305 °C air preheat. It happened because more efficient system of air heating has been installed (regenerative burners). The furnace efficiency has been increased up to 20 %, as well. The reduction of fuel consumption has resulted in the limitation of CO_2 emissions up to 35.6 % comparing to the emission for 305 °C air preheat - it is an important environmental aspect. It means that about 4887 Mg of CO_2 will not be emitted into the environment (in a year) when the combustion air temperature was increased from 305 °C up to 1070 °C. Each non-emitted ton of CO_2 can be sold at the carbon market like a CER credit units [11], which would give an additional income. Considered fuel reduction and CER credit units give the total savings of more than €500000 per year [11,12]. The presented solution could improve the economy of metallurgical industry instead of the employment reduction which often happens. This case shows very significant profits which could be made when the recovery system is improved (**Figure 3**).

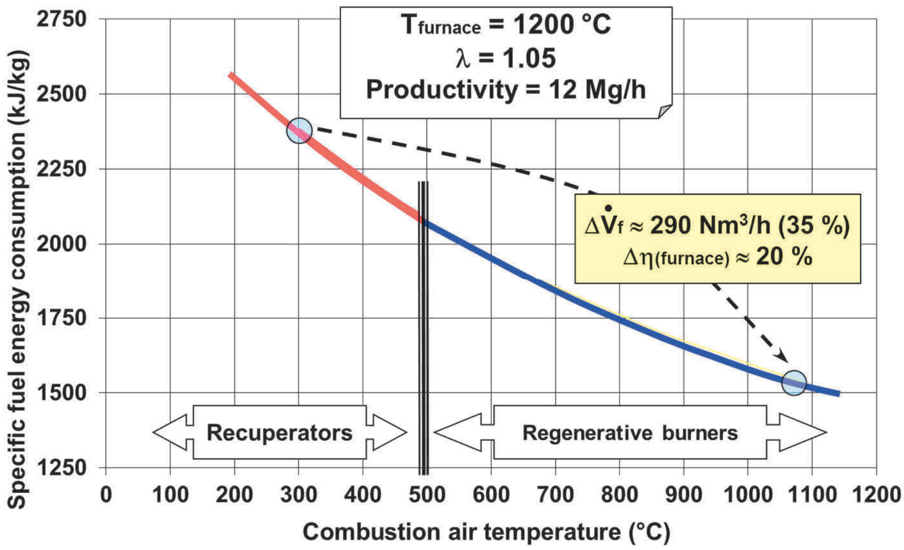

Figure 3 The fuel consumption as a function of the air preheat

5. CONCLUSION

The large CO_2 emission in the metallurgical industry is a significant environmental and social problem therefore, some solutions are looked for to reduce this emission. One of the techniques is applying high combustion air temperature because it gives more fuel saving and thus decrease of the exhaust emission. However, the used solutions should be effective such as a regenerative system.

The most important regenerator parameters which affect heat transfer are: surface of heat transfer and volume (mass) of filling. Choosing the construction of the regenerator filling is not easy because there are a few parameters and their various combinations. The regenerators for small power burners were considered and honeycomb construction filling was adopted.

A few quality factors have been presented and the regenerator quality for obtained results has been checked. All the factors have achieved a very high value and they are satisfactory. They guarantee a significant fuel saving and CO_2 emission reduction.

The appropriate selection of the regenerator geometric parameters has given the high outlet air temperature - higher than 1000 °C in an experimental research.

The case of combustion air temperature increase for 8.5 MW furnace has been presented. Increasing the combustion air temperature from 305 °C up to 1070 °C decreased both the fuel consumption and the CO_2 emission, as well. Generally, the fuel saving has given a significant reduction of CO_2 emission - it means that 4887 Mg/yr of CO_2 were not emitted into the environment.

Considered fuel reduction and CER credit units give the total savings of more than €500000 per year which could improve the economy of metallurgical industry.

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