COMPARATIVE ANALYSIS OF THE ENERGY EFFICIENCY OF METAL RECUPERATORS WITH A DIFFERENT DESIGN

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ABSTRACT

Results from the comparative analysis of the energy efficiency of two representatives of the most wide-spread in the metallurgical practice metal recuperators – a convective one with smooth tubes and a radiation pipe-in-pipe type are presented. The apparatuses are set at equal exploitation conditions and equal preheated air parameters from them are required. In order to achieve comparability between the working regimes of the both units, the heat-technical calculations are performed with an especially created software product.

It is established that the radiation recuperator proves to be with about 30 % lighter than the convective one. The ratio between the convective and the radiative components of the heat transfer coefficient from the flue gas to the wall is analyzed. The comparison between both variants of constructive arrangement of the radiation heat exchanger allows tendencies for an increase of the flue gas emissivity and a considerable growth of the radiation part at simultaneously attenuation of the convection to be noticed.

Keywords: recuperators, energy, efficiency, metal, convective, radiation.

INTRODUCTION

The furnaces and units used in the metallurgical industry have a rather low coefficient of performance (CP). It is a result of the significant heat losses taken out by the flue gas, which are thermal secondary energy resources (SER) and form on the average around 30 % of the total outlet of SER from such sources [1, 2].

The most efficient way for the enhancement of the CP of a given furnace is the adjustment of the utilizing units (regenerators [3-5] and recuperators [6-10]) after it. They ensure the partial return of the flue gas heat in the working area of the basic set by preheating the oxidizing fluid and/or the gaseous energy source before its entrance in the burners.

If the enthalpy of the media outgoing from the high-temperature installation in the technological process is returned by using of regenerators and recuperators, their fluxes should not be considered as outgoing from the system. Hence, through the mentioned utilizing units the outlet of thermal SER is considerably reduced and in the same time the heat losses with the outgoing flue gas are decreased, and the CP of the corresponding installation is improved [2].

The correct design of the recuperative heat exchanging apparatuses is of decisive significance for their efficient functioning. Regardless of the numerous technical developments concerning the most often used utilizing units—the metal recuperators and the research aiming of their improvement, boundary cases exist when it is difficult to estimate the needed type of a concrete device. Sometimes in such situations intuitive decisions are taken that are not always the best.

The present work has the aim to contribute to obtaining of a practical quantitative picture of some predictable from a theoretical point of view objectives in heat exchangers design. It is made by presentation and discussion of the results from the comparative analy-
sis of two of the most widelspread in the metallurgical practice metal recuperators – a convective type with smooth tubes and a radiation pipe-in-pipe type, set at equal exploitation conditions and equal preheated air parameters. Thereby, it is expected to assist the proper and well-grounded decision on such an alternative from which favorable economic consequences for the whole enterprise can be ensured.

CONSTRUCTIVE ARRANGEMENT OF THE CONSIDERED EQUIPMENT

The advantages and the demerits of the utilizing units and especially of the metal convective and radiation ones, is an object of attention of many studies [11-14]. Each device has its own specific peculiarities and traditional spheres of application. However, there are intermediate cases when it is not obvious, which construction is more appropriate. The chosen operating conditions in the present paper cannot be accepted as boundary, but rather the specification of concrete parameters is necessary for the demonstration of the proposed comparative analysis of one typical practical situation.

In order to satisfy the requirements for compatibility of the working regimes of the considered recuperators, the project heat-technical calculations are performed with a specially created software product, based on a standard procedures [7-9, 15, 16] and proven accuracy [17]. In Table 1 the basic characteristics of the two units are presented.

The indicated composition of the smoke is typical for the combustion of natural gas with a low air ratio, which in burners with preliminary mixing of the media [18] is possible.

In Fig. 1 the design of the convective recuperator and in Fig. 2 – that of the radiation one are schematically shown.

RESULTS AND DISCUSSION

Final parameters of the apparatuses

After the finishing of the project heat-technical calculations of the two utilizing units which have a routine character and therefore are not described in the present work, the following basic and most representative indicators were obtained:

• For the convective recuperator

Its heat transfer surface area is 125.59 m², distributed in two sections, each with two modules along each other, and perpendicular to the direction of the flue gas motion. Every one of the separated in this way four bundles has 18 tubes in a row and 12 rows, i.e. the total tube number in it is 216. In each of the sections the amount is 432 and for the whole unit they are 864, respectively, at a single length 0.96 m.

• For the radiation recuperator

![Fig. 1. Scheme of the convective recuperator: 1 – flue gas; 2 – air.](image1)

![Fig. 2. Scheme of the radiation recuperator: 1 – flue gas; 2 – air.](image2)
Table 1. Data for the considered recuperators.

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Symbol</th>
<th>Value/Explication</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heat exchanger type</td>
<td>–</td>
<td>* Convective, with straight, smooth steel tubes</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>** Radiation – pipe-in-pipe type</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Motion scheme of the media</td>
<td>–</td>
<td>* Cross counter-current flow</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>** Counter-current flow</td>
<td></td>
</tr>
</tbody>
</table>
| 3  | Constructive peculiarities                    | –      | * In-line arranged tubes with an inner and an outer diameter \( d_i = 0.044 \) m and \( d_o = 0.052 \) m, respectively; Pitch ratios between them in the both directions \( S_\perp = S_\parallel = 2d_i \)
|    |                                               |        | ** Wall thickness of the inner cylinder \( \delta = 0.006 \) m                     | –       |
| 4  | Inlet flue gas temperature                    | \( T_1' \) | 1473                                                                               | K       |
| 5  | Outlet flue gas temperature                   | \( T_1'' \) | 1144                                                                               | K       |
| 6  | Inlet air temperature                         | \( T_2' \) | 293                                                                                | K       |
| 7  | Outlet air temperature                        | \( T_2'' \) | 673                                                                                | K       |
| 8  | Volumetric flow rate of the flue gas at normal conditions | \( \dot{V}_{1,0} \) | 2.6                                                                                 | \( \text{m}^3 \text{s}^{-1} \) |
| 9  | Volumetric flow rate of the air at normal conditions | \( \dot{V}_{2,0} \) | 2.4                                                                                 | \( \text{m}^3 \text{s}^{-1} \) |
| 10 | Flue gas velocity at normal conditions        | \( w_{1,0} \) | 5                                                                                   | \( \text{m} \text{s}^{-1} \) |
| 11 | Air velocity at normal conditions             | \( w_{2,0} \) | 24                                                                                  | \( \text{m} \text{s}^{-1} \) |
| 12 | Carbon dioxide contents in the flue gas        | \( CO_2 \) | 9.05                                                                                | \( \% \text{ vol} \) |
| 13 | Water steam contents in the flue gas          | \( H_2O \) | 19.17                                                                               | \( \% \text{ vol} \) |
| 14 | Oxygen contents in the flue gas               | \( O_2 \) | 0.89                                                                                | \( \% \text{ vol} \) |
| 15 | Nitrogen contents in the flue gas             | \( NO_2 \) | 70.89                                                                               | \( \% \text{ vol} \) |

Its heat transfer surface area is 96.70 m², which represents a cylinder with an inner diameter 1.5 m, an outer one of 1.512 m and a height of its active part of 20.45 m. In the implementation of the calculations and mostly – in the final composing of each of the products some roundings are enforced, but the initial values of a part of their aerodynamical indicators are negligibly changed. They are given in Table 2 where also some comparisons with their recommended intervals are given. From it the insurance of the maximal possible identity of the conditions in which the exploitation of the two units is intended can be seen.

**Comparative analysis of the obtained results**

The comparison of the two apparatuses only according to their heat transfer surface areas shows that
Table 2. Comparison between the flue gas and the air velocities in the recuperators.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Recuperator</th>
<th>Convective</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval of the recommended flue gas velocities at normal conditions ((w_{1.0}))</td>
<td></td>
<td>1.5-5 m/s</td>
<td>3-5 m/s</td>
</tr>
<tr>
<td>Chosen value of (w_{1.0})</td>
<td></td>
<td>4.8 m/s</td>
<td>5 m/s</td>
</tr>
<tr>
<td>Quota of the chosen value of (w_{1.0}) in the maximal permitted flue gas velocity at normal conditions</td>
<td></td>
<td>96 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Interval of the recommended air velocities at normal conditions ((w_{2.0}))</td>
<td></td>
<td>8-15 m/s</td>
<td>20-30 m/s</td>
</tr>
<tr>
<td>Chosen value of (w_{2.0})</td>
<td></td>
<td>12 m/s</td>
<td>24 m/s</td>
</tr>
<tr>
<td>Quota of the chosen value of (w_{2.0}) in the maximal permitted air velocity at normal conditions</td>
<td></td>
<td>80 %</td>
<td>80 %</td>
</tr>
</tbody>
</table>

the using of the convective recuperator instead of the radiation one, leads to a relative increase of this parameter with \([125.59-96.70]/96.70\)=29.88 %, since simultaneously the volumetric flow rate and the temperature of the air remain the same. Naturally, the load intensity of each of the units exercises an influence on the obtained result, because of the expenses for the transportation of the two gaseous media through them. Information in relation to this indicator can be obtained from the shown in Table 2 calculations. It is obvious from it that practically an equal load of the two heat exchangers is achieved. The small difference of the chosen flue gas velocities is due to the need to obtain a better-composed recuperator.

Another interesting tendency is the change of the ratio between the heat transfer coefficients from the flue gas to the wall, due to the convection and those taking into account the radiation, shown in Table 3.

Table 3 demonstrates the decrease of the radiative heat transfer significance at the expense of the convection intensity enhancement when the flue gas is cooling in the first of the compared apparatuses. In it the convective heat transfer has a priority over the radiation which justifies the name of the equipment. With regard to the radiation recuperator from Table 3 it should be noted that after its recalculation, enforced by its inadmissible height of more than 40 m [15], obtained in its initial dimensioning, with the increase of the inner tube diameter through which the products of burning are moving, the quota of the radiation component in the total heat flux from the smoke to the wall, rises. This is due to the growth of the radiating volume and of the emissivity of the flue gas when simultaneously reducing its velocity [10].

More detailed information about the price of the realization of each of the compared options can be obtained after technical-economical analysis [19-23].

**CONCLUSIONS**

Based on the performance of heat-technical dimensioning and comparative analysis of the energy efficiency of two of the most widespread metal recuperators types – a convective one with smooth tubes

<table>
<thead>
<tr>
<th>Recuperator</th>
<th>Convective</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading conditions</td>
<td>Flue gas inlet</td>
<td>Flue gas outlet</td>
</tr>
<tr>
<td>Value</td>
<td>2,725</td>
<td>4,779</td>
</tr>
</tbody>
</table>
and a radiation pipe-in-pipe type device, the proposed below conclusions and recommendations can be made.

When accepting of the heat transfer surface area as an sufficiently representative characteristic for the mass and – for the price of a given utilizing unit, the radiation recuperator proves to be about 30 % lighter than the convective one, through the same preheated air parameters are achieved in both apparatuses.

The analysis of the ratio between the heat transfer coefficients from the flue gas to the wall due to the convection and to the radiation shows, that the quota of the first mechanism considerably higher (around 3.75 times) than that of the second one in the convective recuperator while in the radiation apparatus the proportion is reversed.

The comparison between the energy efficiency of the two variants of the constructive arrangement of the radiation heat exchanger reveals tendencies of an increase of the flue gas emissivity and for a considerable growth of the radiation part at a simultaneous attenuation of the convection. Those occur because of the enhancement of the occupied with emitting flue gas volume of the inner tube as well as because of the decrease of its velocity.

For a full technical-economical analysis of both units, the total expenses for the implementation of each of the projects by the developed procedure have to be compared, taking in account the capital investments for the constructing of the recuperators as well as the related operating costs.

REFERENCES

18. R.D. Stanev, Perfection of Mixing between Gaseous


