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THE PROFILE OF A PUSHER-TYPE FURNACE AND FUEL CONSUMPTION

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Operating data for two pusher-type furnaces, old and new, of approximately identical length but having different longitudinal profiles were analysed. The old furnace had a partly inclined longitudinal profile and the new one had a rectangular longitudinal profile. Results of analysis showed a higher rate of specific fuel consumption for the old furnace than for the new one. To reduce the difference a possibility was considered of building in an air-preheating recuperator instead of relocating the burners and altering the longitudinal profile of the old furnace. Results of quantification demonstrated that by building a recuperator into the old furnace specific fuel consumption would greatly diminish and would become comparable to that of the new furnace.

Key words: *pusher-type furnace, longitudinal profile, built-in recuperator, fuel consumption*

Profil potisne peći i potrošnja goriva. Analizirani su pogonski proizvodni zapisi dviju potisnih peći podjednake dužine ali različitog uzdužnog profila. Starija peć ima djelomično ukošeni uzdužni profil a novija peć pravokutni uzdužni profil. Rezultati analize su pokazali da starija peć ima veću specifičnu potrošnju goriva od novije peći. U cilju smanjenja navedene razlike razmatrana je mogućnost dogradnje rekuperatora za predgrijanje zraka umjesto analognog rješenja da se premještaju gorionici i promijeni uzdužni profil starije peći. Rezultati provedene kvantifikacije pokazuju da bi se dogradnjom rekuperatora na stariju peć znatno smanjila specifična potrošnja goriva i približila onoj novije peći.

Ključne riječi: *potisna peć, uzdužni profil, dogradnja rekuperatora, potrošnja goriva*

INTRODUCTION

At the strip and billet rolling mill of the Sisak Steel Works there are two pusher-type furnaces of comparable working length but with different longitudinal profiles. In the old furnace, which has a partly inclined longitudinal profile and the burners built into all zones at the front, the rate of fuel consumption was considerably higher than in the new furnace, which has a rectangular longitudinal profile and the burners installed laterally in all zones except in the charge-preheating zone. To cut down fuel consumption the burners in the old furnace were relocated and laterally built into all zones with the exception of the charge-preheating zone. In addition to relocation of the burners a minor reconstruction of the furnace ground was undertaken but its inner profile remained unchanged. There was no alteration concerning the system of natural gas supply to the burners; it operated in accordance with the temperature of the walls which was measured by means of zonal pyrometers. Those were placed at the end of the heating zone, in its upper and lower sections, and in the preheating zone [1]. On the basis of the operating data for the old furnace recorded before and after relocation of the burners the relationship between specific fuel combustion and furnace productivity was statistically analysed. Results of analysis showed that following the relocation of the burners in the old furnace the rate of specific heat energy consumption increased instead of decreasing [1-2]. To solve the problem, instead of relocating the burners and substituting the partly inclined longitudinal profile for a rectangular longitudinal one, a possibility was considered of building in an air-preheating recuperator thus reducing specific heat energy consumption.

The amount of energy required for heating steel semi-products in pusher-type furnaces is part of overall energy consumption in a rolling mill production. A relationship between the rate of specific energy consumption and furnace productivity was determined by regression analysis using the operating data. Specific fuel consumption based on its heating value was recalculated in terms of specific heat energy consumption. Furnace productivity varied with the pressure of natural gas, whereas distribution of heat

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energy by furnace zones remained stable. A change in the rate of specific heat energy consumption in the course of resumed operation following overhaul was assessed from statistical data collected for the period between two overhauls. By structure, the heated semiproducts were slabs having a thickness of 190 mm (65 %), and slabs and blooms with a thickness exceeding 190 mm (35 %). In terms of quality, they were made of low-carbon steel. The relationship between heat power, that is specific heat energy consumption, and furnace productivity was described by the authors earlier [2, 3].

RESULTS AND DISCUSSION

For analysis of operation of pusher-type furnaces the operating data from the strip and billet rolling mill were used. The data pertained to the quality of semiproducts and their dimensions, to the charge heating temperature and to the amount of natural gas of known heating value that was used up. All data for a furnace and its period of operation (e. g. before and after reconstruction) were placed into groups. Each group comprised only the pairs of data (x_i, y_i) referring to identical operating conditions in regard to charge dimensions, steel quality, heating temperature and duration of shift operation of the rolling mill stand. The selected groups of data pairs are shown as clusters of dots in Figure 1. The dependence of specific heat energy consumption (y) on productivity (x) was determined by regression analysis using the computer programs Statistica and Excel and is shown in the form of regression curves also in Figure 1.

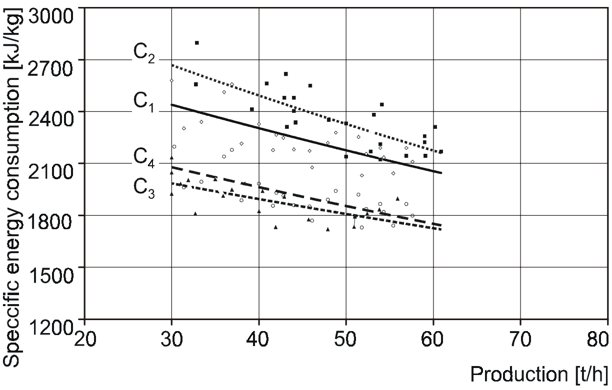

Figure 1. **Empirical regression curves as a result of linear correlation of measured pairs of data for the old furnace (C_1), for the old furnace after reconstruction (C_2), for the new furnace (C_3) and for the old furnace with a built-in recuperator (C_4)**

Slika 1. **Empirijske krivulje regresije kao rezultat linearne korelacije mjerenih parova podataka za stariju peć (C_1), stariju peć poslije rekonstrukcije (C_2), noviju peć (C_3) i stariju peć s dograđenim rekuperatorom (C_4)**

The regression curve C_1 refers to the old furnace before reconstruction and is defined by the equation:

$$Y = 2895.5\ e^{-0.0057\ X} \tag{1}$$

The regression curve C_2 refers to the old furnace after its reconstruction and is defined by the equation:

$$Y = 3274.4\ e^{-0.0068\ X} \tag{2}$$

The regression curve C_3 refers to the new furnace, where no changes were made, and is defined by the equation:

$$Y = 2282.3\ e^{-0.0047\ X} \tag{3}$$

The regression curve C_4 refers to the old pusher-type furnace before its reconstruction assuming that a recuperator for preheating air to a temperature of 350 °C has been built in. In that way the heat effect was expected to increase by 14.8 % and to match that of the new furnace [4].

The regression curve C_4 is based on the pairs of data that were computed from those for the old furnace before its reconstruction and is defined by the equation:

$$Y = 2467\ e^{-0.0057\ X} \tag{4}$$

Figure 2. shows an increase in specific heat energy consumption in the period between two overhauls of the old (S_1) and new (S_2) furnaces. There is a continuous rise in the

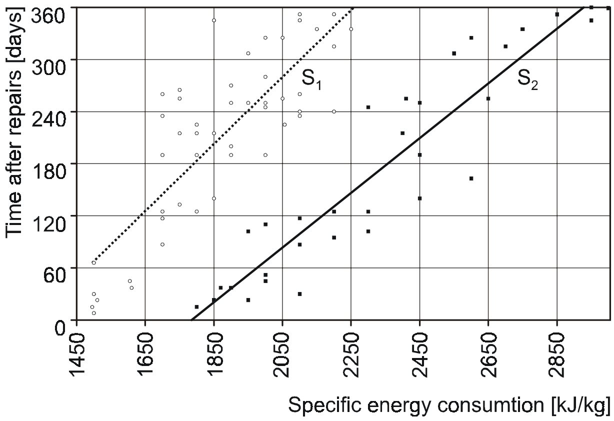

Figure 2. **Empirical regression curves as a result of linear correlation of measured pairs of data in the period between two overhauls for the old furnace after reconstruction (S_1) and for the new furnace (S_2)**

Slika 2. **Empirijske krivulje regresije kao rezultat linearne korelacije mjerenih parova podataka u periodu između dva remonta za stariju peć poslije rekonstrukcije (S_1) i noviju peć (S_2)**

rate of consumption (y) with time (x) i. e. with the approach of overhaul. It should be pointed out that pairs of data for groups in Figure 1. were obtained from the operating data for the first 150 working days after the overhaul of the old and new furnaces. A rise in specific heat energy consumption in the period between two overhauls (360 days) was due to the falling of the refractory lining off the vertical stand pipes of the skid pipes in the first place and to the falling of a major amount of scale off the surface of the heated steel in the second place [5-6]. Pairs of data given in Figure 2. demonstrate that a rise in the rate of specific heat energy consumption in the old furnace following its reconstruction was higher than in the new furnace. The regression line S_1 which pertains to the old furnace after its reconstruction is defined by the equation:

$$Y = 0.3149 X - 561.88 \qquad (5)$$

The regression line S_2 referring to the new furnace is defined by the equation:

$$Y = 0.3858 X - 510.92 \qquad (6)$$

The correlation characteristics can be assessed by means of the criterion R^2

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - y_{ti})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}, \quad 0 \leq R^2 \leq 1 \qquad (7)$$

where

n - number of pairs of data,
y_i - measured value,
y_{ti} - computed value,
$\bar{y}$ - mean value.

If $|R|$ is close to one, a link between X and Y is taken to be very tight, whereas when $|R|$ is close to zero the link is either very weak or non-existent. $|R|$ is equivalent to the correlation coefficient $|r|$, which is a measure of strength of the link between X and Y (Table 1.).

Table 1. **Numerical values of the criteria R^2 and R for regression curves defined by equations (1) to (6)**
Tablica 1. **Brojčane vrijednosti kriterija R^2 i R za krivulje regresije koje su definirane jednadžbama (1) do (6)**

	C_1	C_2	C_3	C_4	S_1	S_2
R^2	0.5548	0.5884	0.4512	0.5522	0.6748	0.8719
R	0.745	0.767	0.672	0.743	0.820	0.934

For groups of data referring to charges of variable thickness and to different heating capacities and inadequate temperature regimes the strength of the link between X and Y is satisfactory. With the help of equations (1) - (4) it is now possible to evaluate the effect of realized heating capacity on specific heat energy consumption. A rise in consumption along with a diminished realized heating capacity of the old furnace after reconstruction could be expected. One of the reasons for that was a drop in heating efficacity caused by an increased ratio between the heating surface of a charge and the inside surface of the furnace walls (Y, [7]), which was due to the rising up of the furnace ground level. The latter was the result of intensified falling off to the ground of the refractory mass from the skid pipes and of the scale forming on the surface of the steel charge owing to inadequate temperature regime in the furnace [1]. The position of the regression curve C_2 above the regression curve C_1 as shown in Figure 1. allows to conclude that the furnace reconstruction failed because the rate of specific heat energy consumption increased over the entire working space of the furnace. This was taken to confirm the starting hypothesis that the specific heat energy consumption in the old furnace could become comparable to the one in the new furnace provided an air-preheating recuperator, to serve for fuel combustion in the furnace working area, were built into the old furnace. In that case the regression curve C_4 would lie immediately above the regression curve C_3 (Figure 1.). Each rise in the air-preheating temperature above 350 °C would reduce the distance between the regression curves C_4 and C_3. This shows that the problem of reducing specific heat energy consumption by furnace reconstruction was not examined in sufficient detail and that not all possibilities at disposal were analysed.

In socialist countries, before the introduction of market economy, no serious consideration used to be given to the costs of production. Failures have been known to occur many of which are still waiting to be put right. The construction of the above mentioned new pusher-type furnace stands as an example. The furnace was built for the purpose of heating a larger amount of steel charge than previously, because the capacity of the rolling mill stand increased in the meantime owing to reconstruction. From the technological and economic standpoints the construction of a new furnace was unnecessary, because it was possible, by building a recuperator into the old furnace, to increase its heating capacity by heating a continuously cast charge of appropriate thickness and by inserting it in the furnace in a hot state. According to literature data [8] slabs of 150 mm thickness were more acceptable than those that were used in the old furnace until then. Inserting 150 mm thick slabs into the furnace would raise its heating capacity from the current 70 t/h to over 100 t/h. Specific heat energy consumption would become lower by about 35 % as computed from the difference in consumption rates obtained using equation (4) by inserting first one numerical value for productivity and then the other. The required temperature of the slabs before their processing by rolling would be lower than the temperature for rolling thicker slabs, and that would additionally reduce specific heat energy consumption. Apart from a drop in heat energy consumption in the course of heating, the power consumption during the rolling operations would also diminish as a result of fewer passes through a blooming mill. In general, the entire rolling mill production calls for optimum control of energy consumption as essential to maximum energy saving [9-10]. A saving of heat energy of about 2.4 % reported in literature [11] was a result of control of fuel combustion by means of continuous analysis of oxygen in waste flue gases. Depending on the temperature of waste flue gases up to 5 % of energy can be saved. Today, optimization of a given production is facilitated with the use of computing technique. From the regression curves S_1 and S_2 (Figure 2.) which show the rate of specific heat energy consumption as related to its cost, it is possible to make an assessment of the profitability of furnace overhauls that are aimed at removing major amounts of scale and refractory lining [6], as well as of the profitability of its reconstruction.

CONCLUSION

The justifiability of relocating the burners in the old pusher-type furnace in order to reduce heat energy consumption was assessed. The burners were moved from the front of the heating zone to the sides of the heating and preheating zones, following the example of the new pusher-type furnace. Results of assessment were opposite to those expected. Instead of decreasing the rate of specific heat energy consumption increased. Investigation showed that an air-preheating recuperator should have been built into the old furnace. In that case specific heat energy consumption would have been comparable to the one in the new furnace. A relationship between the length of time passing between two overhauls and the rate of specific heat energy consumption was also investigated. Results showed that specific heat energy consumption during operation following overhaul increased as a function of time. The increase was mainly a result of falling of the refractory lining off the vertical stand pipes of the skid pipes in the furnace heating zone owing to the smelting of scale and its reaction with the lining. The amount of scale falling on the furnace ground grew larger as a result of inadequate temperature regime and of a greater length of time a charge was held in the furnace due to unexpected interruptions of operation. Verification of the duration of the period between two overhauls in terms of cost effectiveness is therefore called for. By heating up a thin and hot charge in one furnace instead of a thicker and cold charge in two furnaces the amount of scale would be more than doubly reduced [5, 12], because the slab temperature before rolling would be lower and the heating time more than twice shorter. In this manner a rise in the rate of specific heat energy consumption as a function of time elapsing between two overhauls would become lesser as would charge losses due to extensive scaling of iron from steel.

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