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Preliminary communication

THE INFLUENCE OF THE INCREASE RATE OF TEMPERATURE SURFACE OF STEEL CHARGE ON CO_2 EMISSION

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CO_2 emission is one of the factors, which in addition to the consumption of thermal energy and the loss of steel by oxidation also affect the costs of heating process in a reheating furnace. The analysis of influence of the increase rate of temperature surface of steel charge on the CO_2 emission and the furnace productivity was conducted with regard to the increase in heating costs. The results of numerical modelling of the heating process in the pusher type steel reheating furnace were presented in this article.
Key words: reheating furnace, heating process, steel charge, CO_2 emission.

Utjecaj brzine porasta temperature površine čeličnog uloška na emisiju CO_2. Emisija CO_2 je jedan od čimbenika koji uz potrošnju energije i gubitak čelika odgorom imaju utjecaj na troškove procesa zagrijavanja u zagrijevnoj peći. Provedena je analiza utjecaja brzine porasta temperature površine zagrijavanog čeličnog uloška na emisiju CO_2 i proizvodnost peći povezano s povećanjem troškova zagrijavanja. U radu su prikazani rezultati numeričkog modeliranja procesa zagrijavanja čeličnog uloška u potisnoj zagrijevnoj peći.
Ključne riječi: zagrijevna peć, proces zagrijavanja, čelični uložak, emisija CO_2.

INTRODUCTION

The heat consumption and oxidation loss of steel affect the costs of heating process of a steel product as well as the emissions of greenhouse gases to the environment. The development of new instruments of environment protection have brought the rise of the financial mechanism in form of transferable authorizations of emissions. Emissions of these gases which cause the formation of greenhouse effect show a growth of the carbon dioxide emission in particular. The combustion systems are a major source of carbon dioxide emissions [1]. On the basis of the Directive of the European Union the trade authorizations according to the emissions of greenhouse gases and different substances were resolved [2]. It refers to the emission of steel industry, which amount to14.4 million tones CO_2 annually [3].

On the 26th March 2007, the European Committee reduced the total limit of emission authorizations for Poland from 284,6 million tone to 208,5 million tone in the period from 2008 to 2012 [4]. In the new decree the project of Polish cabinet in the case of National Plan of Chapter Authorizations (KPRU II) according to CO_2 emission in the period of 2008-2012 the limit of authorizations was limited for the steel sector from 14,4 to 11,8 million tone annually [3]. This limitation can cost the steel industry from 75 to over 250 million EUR annually.

THE OBJECT OF MODELLING

In order to perform computer simulation of the effect of heating rate and furnace productivity (production rate or throughput) on the heat consumption and oxidation steel loss, a mathematical model for charge heating and heat exchange in the working chamber of reheating furnace was developed.

The elementary balance method was used for the numerical computation of charge heating and the brightness and configuration ratio method for the computation of temperature field in furnace chamber. The material loss of heated charge was determined by the substitute temperature method, while the heat consumption was computed using the zone balance method. The numerical computation procedure was carried out by the CAS (Computer Algebra System) type application [5].

The object of modelling was the pusher reheating furnace (fig.1). It was assumed that the heating chamber of the furnace was represented by a rectangular prism with a length of *L*, a height of *2H*, and a width of *B*. Also, the furnace was conventionally divided into 5 identical technological zones.

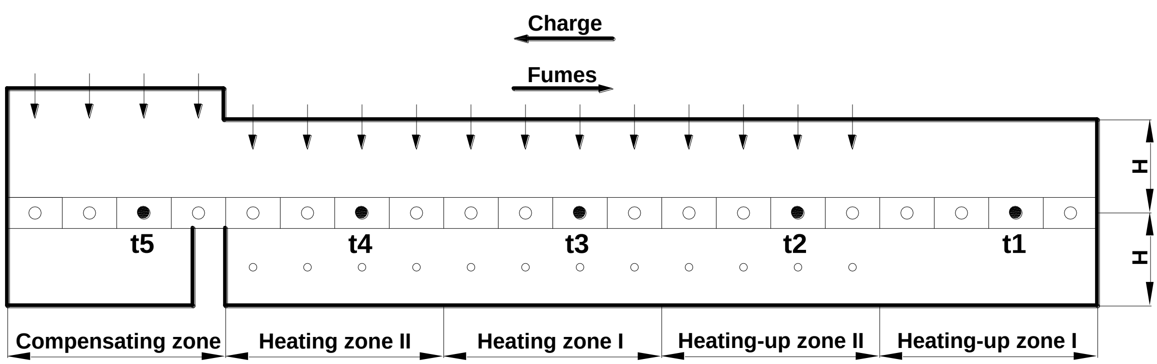

Figure 1. Schematic representation of pusher furnace model
Slika 1. Shematski prikaz modela potisne peći

For computation purposes, the pusher furnace was reduced to a simple model, in which the charge moves along the working chamber over the length *L* with uniform motion in the direction opposite to that of furnace gas movement. It was assumed that the transfer of heat to the charge takes place bilaterally over the whole length *L*.

In view of the assumed symmetry of this heat transfer, only the heat exchange in the zones above the charge axis is considered.

The furnace was assumed to be equipped with a recuperator so that a part of the enthalpy of waste gases is used for combustion air preheating.

For each of the assumed technologies the furnace chamber temperature fields were determined in order to achieve the necessary heating conditions relating to the heated charge, i.e.:

- the final surface temperature, $t = t_k$,
- the final temperature difference in the charge cross-section, Δt_k.

THE NUMERIC CALCULATION OF CHARGE HEATING, LOSS OF STEEL AND HEAT CONSUPTION

The numerical procedure of charge heating was done using the elementary balance method [6, 7]. The oxidation loss of steel was calculated by the method of supplementary temperature in every interval of time according to the expressions [8, 9]:

$$z_{k+1}^{N} = z_{k}^{N} + \Delta z_{k+1}^{N}, \quad (1)$$

$$z_{k+1} = \left(z_{k}^{N} + \Delta z_{k+1}^{N}\right)^{B}, \quad (2)$$

where $N = \frac{1}{B}$. (3)

The increment in steel loss in time $\Delta\tau$ was determined by the formula

$$\Delta z^{N} = A \cdot \Delta\tau \cdot \alpha^{C} \cdot \exp\left(-\frac{D}{T_z}\right). \quad (4)$$

The fuel (natural gas) volume flux for an arbitrary computational zone *i* was determined from the relationship

$$\dot{V}_{g_i} = \frac{\sum \dot{V}_{g_{i+1}} \cdot V_{sp.} \cdot \left(c_{p_i} \cdot t_{g_i} - c_{p_{i+1}} \cdot t_{g_{i+1}}\right) + \dot{Q}_{u\dot{z}_i} + \dot{Q}_{str \cdot i} - \dot{Q}_{zg \cdot i}}{Wd - V_{sp.} \cdot c_{p_i} \cdot t_{g_i}}. \quad (5)$$

The heat flux into the computational furnace zone *i* was determined from the relationship

$$\dot{Q}_{i} = \dot{V}_{g_i} \cdot W_d. \quad (6)$$

MATHEMATICAL MODELLING OF HEAT TRANSFER IN THE FURNACE CHAMBER

The unit heat consumption was calculated from the equation

$$q_o = \frac{\sum_{i=1}^{n=25} \dot{Q}_i}{w}. \quad (7)$$

It this transformed balance equation of thermal energy it is necessary to determine the flux of useful heat, fluxes of thermal losses as well as the heat flux liberated through oxidation of steel charge.

The useful heat flux for the *i*-th computational zone was determined from the formula

$$\dot{Q}_{u\dot{z} \cdot i} = \frac{1}{2} \cdot w \cdot \left[\left(1 - a_{zg \cdot i}\right) \cdot c_{m_i} \cdot t_{m_i} - \left(1 - a_{zg \cdot i-1}\right) \cdot c_{m_{i-1}} \cdot t_{m_{i-1}}\right] \quad (8)$$

The heat flux carried out with the scale was computed from the equation

$$\dot{Q}_{fzg \cdot i} = \frac{1}{2} \cdot w \cdot \left(a_{zg \cdot i} \cdot c_{zg \cdot i} \cdot t_{zg \cdot i} - a_{zg \cdot i-1} \cdot c_{zg \cdot i-1} \cdot t_{zg \cdot i-1}\right) \quad (9)$$

The heat flux carried away with the sliding rail cooling water was computed from relationships given in work [10], whose general form is described by the equation

$$\dot{Q}_{chl._i} = A_{szyn} \cdot a \cdot \left(\frac{T_{piec}}{100} \right)^n . \quad (10)$$

The heat flux lost by the furnace lining was computed from the equation

$$\dot{Q}_{zew._i} = A_{\acute{s}\acute{c}._i} \cdot k_i \cdot \left(t_{\acute{s}\acute{c}.i} - t_{ot.} \right). \quad (11)$$

The heat flux lost by radiation through the open furnace doors and openings was determined from the relationship

$$\dot{Q}_{pr._i} = C_0 \cdot \varphi_i \cdot \psi_i \cdot A_{ot._i} \cdot \left(\frac{T_{pr._i}}{100} \right)^4 . \quad (12)$$

The heat input from the exothermic metal oxidation reaction was determined by

$$\dot{Q}_{zg \cdot i} = \frac{1}{2} \cdot w \cdot Q_{zg.} \cdot \left(a_{zg \cdot i} - a_{zg \cdot i-1} \right). \quad (13)$$

In the balance energy equation the other different heat losses are to be taken into account. In conducted computations the constant values of these losses were assumed.

THE RESULTS OF CALCULATIONS

The formulated mathematical model allows the calculation of heat consumption and the losses of steel for several variants as follows:

1 With the process of scale formation and without the heat recuperation;
2 With the process of scale formation and with the heat recuperation;
3 Without the process of scale formation and without the heat recuperation;
4 Without the process of scale formation and with the heat recuperation.

As the results of these calculations were:

1. Distributions of temperature along the length of furnace chamber, the charge surface, the charge cross-section, furnace walls, flue gases as well as the thickness and temperature of the scale layer formed on the charge surface;
2. Coefficient of heat consumption expressed in kJ per kg of the heated charge. The value of this coefficient was determined on the basis of furnace energy balance equation.
3. The loss of steel with scale layer expressed in kg per m^2 of charge surface.

The results of calculation of heat consumption are shown in fig. 2 and oxidation loss of steel in fig. 3.

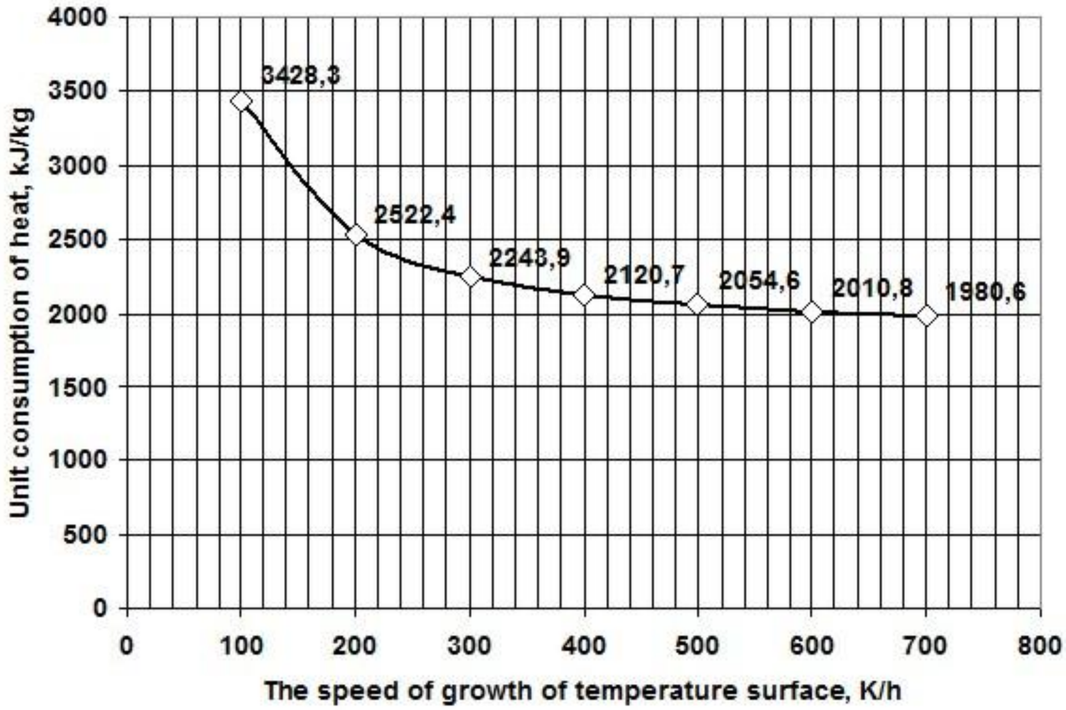

Figure 2. The results of calculation of the unit heat consumption
Slika 2. Rezultati proračuna jedinične potrošnje topline

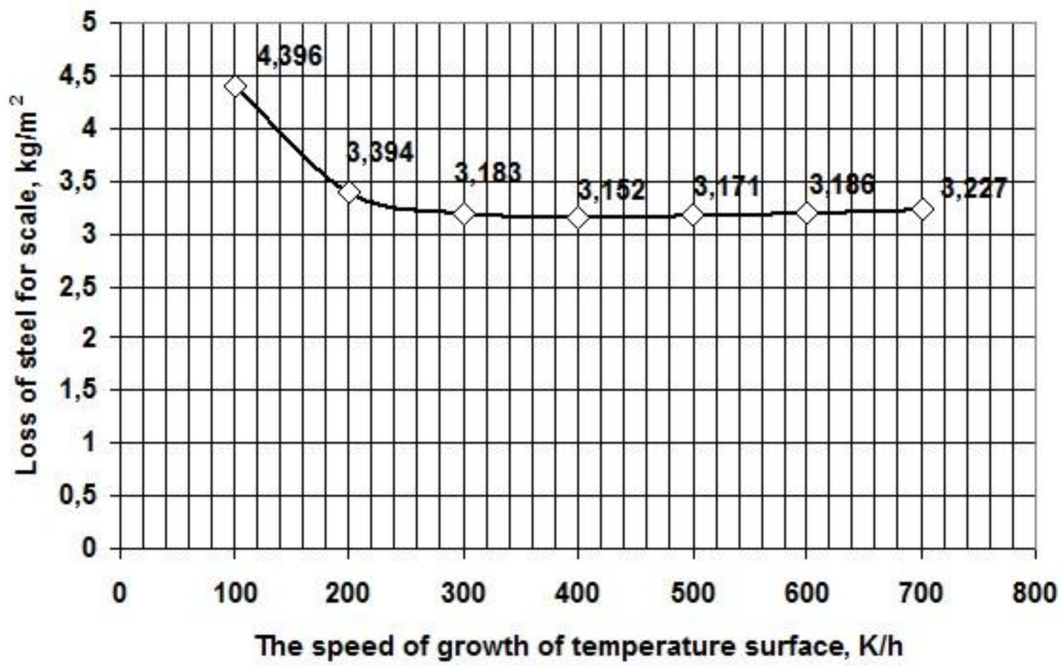

Figure 3. The results of calculation of the oxidation loss of steel
Slika 3. Rezultati proračuna gubitka čelika odgorkom

Each increase rate of temperature surface of steel charge was subordinated by the furnace productivity achieved in the process of heating therein.

THE INFLUENCE OF INCREASE RATE OF TEMPERATURE SURFACE STEEL CHARGE ON CO_2 EMISSION

The CO_2 emission is connected directly with the coefficient of unit heat consumption as well as indirectly with the oxidation loss of steel.
The CO_2 emission in dependence of the value of heat consumption, q, was determined with relation

$$m_{CO2} = \frac{q}{W_d} \cdot \rho_0 \cdot V''_{CO2}\,. \quad (14)$$

For the composition of natural gas: CO_2 0.1%; O_2 0.1%; CH_4 96.7%; C_2H_6 0.6% and N_2 2.5%, the unit volume of carbon dioxide during the combustion process with the value of excess air of α =1.05 amounts $V''_{CO_2} = 0.98$ m^3/m^3_g. The gas heating value of natural gas is W_d = 34 580 kJ / um^3. The emission of carbon dioxide was calculated in dependence of the increase rate of temperature surface of steel charge.
The average value of energy consumption in Polish metallurgy production of iron (no taking account the hammer - mill and the press-mill) is about 35 GJ / t [11].

The calculation was executed for the heating furnace with the heating chamber length of L=28 m. The heated flat charge has the thickness of 2s = 0.3 m and the length l = 5m.
The following was accepted:

- surface of heated charge, A = 300 m^2;
- volume of heated charge, V = 42 m^3;
- specific mass of heated charge, ρ = 7850 kg/m^3;
- mass of heated charge, m = 329 700 kg.

The loss of steel in reference to the mass of heated charge may be described by the relation

$$z' = \frac{z \cdot A}{m}\,. \quad (15)$$

The loss of heat in reference to the mass of steel loss was calculated by the relation

$$q'' = q' \cdot z'\,. \quad (16)$$

The influence of increase rate of temperature surface of steel charge on the individual values of CO_2 emission is shown in fig. 4.

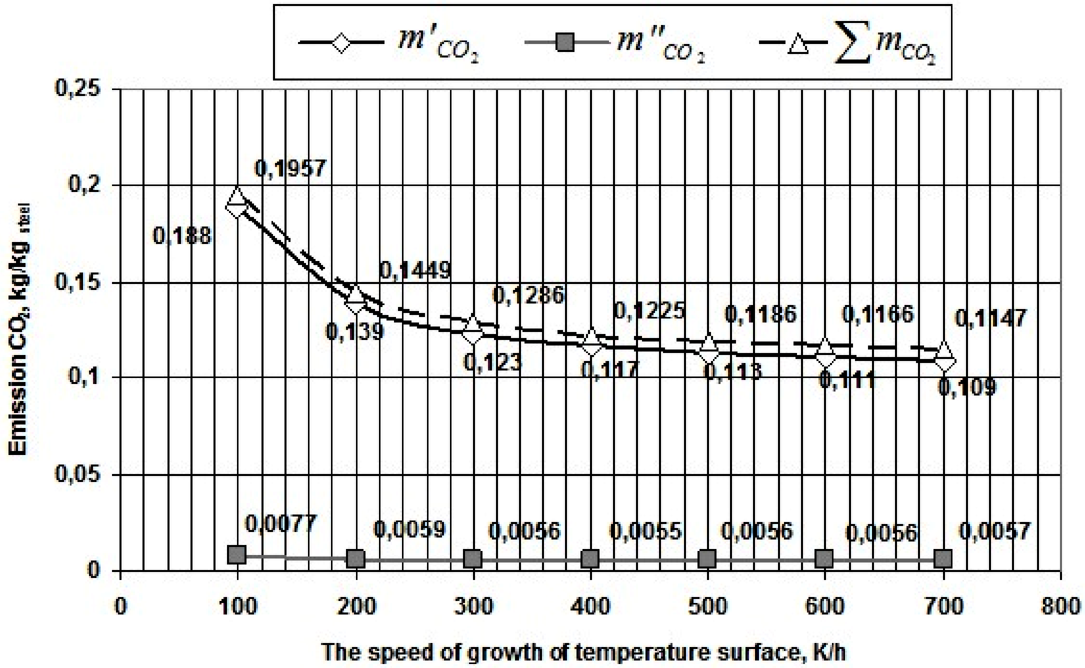

Figure 4. The influence of the increase rate of temperature surface of steel charge on CO_2 emission
Slika 4. Utjecaj brzine porasta temperature površine čeličnog uloška na emisiju CO_2

The influence of furnace productivity on the total CO_2 emission is shown in fig. 5.

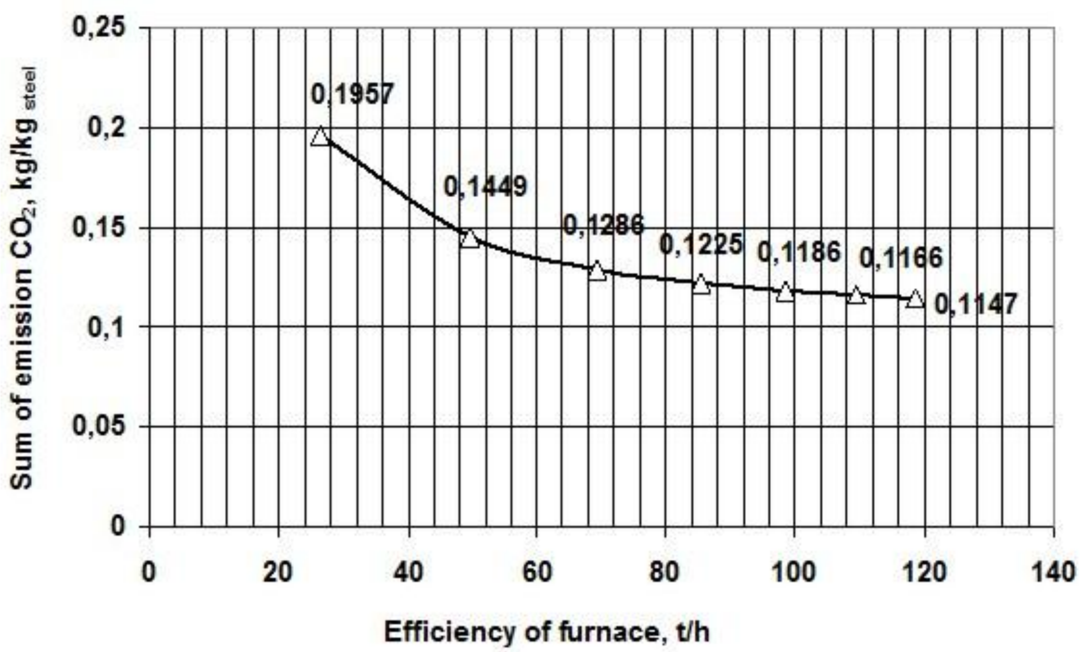

Figure 5. The influence of the furnace productivity on the total CO_2 emission
Slika 5. Utjecaj proizvodnosti peći na ukupnu emisiju CO_2

Taking into account that the rolling-mill produces 1 000 000 tons of steel annually, the emission expressed in kg CO_2 per year will amount

$$m_{CO_2} = \sum m_{CO_2} \cdot 10^9 . \quad (17)$$

For the increase rate of temperature surface of M=100 K/h

$$m_{CO2} = 0.1957 \cdot 10^9 = 195700000 \frac{kg}{year} = 195700 \frac{t}{year} .$$

For the increase rate of temperature surface of M=700 K/h

$$m_{CO2} = 0.1147 \cdot 10^9 = 114700000 \frac{kg}{year} = 114700 \frac{t}{year} .$$

For this rolling-mill the limitation of CO_2 emission will amount 81 000 t / year. The cost of emission authorization is expected to be from 30 to 100 EUR per ton. Taking into account the real overstepping of CO_2 emission, the total cost of emission authorization will be from 2.5 to 7.5 million EUR. The executed calculations show that the reduction of increase rate of temperature surface of steel charge from 700 to 100 K/h or reduction of furnace productivity from 188 to 27 t/h, causes the increase of CO_2 emission of over 70%.

CONCLUSIONS

On the basis of the results of conducted analysis it can be drawn the following conclusions:

a) The rate of heating process has the essential influence on the heat consumption, the oxidation loss of steel and the CO_2 emission.
b) The results of calculations show that the largest emission CO_2 was achieved for small values of the increase rate of temperature surface, i.e. for the small furnace productivity.
c) The quantity of CO_2 emission is connected directly with the coefficient of unit heat consumption and indirectly with the oxidation loss of steel.
d) For the rolling-mill with productivity of 1 million t/year the reduction of increase rate of temperature surface of steel charge, i.e. the reduction of furnace productivity from 188 to 27 t/h, causes the increase of CO_2 emission of over 70%.

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