Advances in Science and Technology Research Journal
Volume 9, No. 27, Sept. 2015, pages 17–22
DOI: 10.12913/22998624/59079

Research Article

THE POSSIBILITIES OF CO_2 EMISSION REDUCTION IN THE PROCESS OF STEEL CHARGE HEATING THROUGH THE SELECTION OF HEATING RATE

Barbara Halusiak[1]**, Marian Kieloch**[1]**, Jarosław Boryca**[1]**, Agnieszka Benduch**[1]

[1] Department of Industrial Furnaces and Environmental Protection, Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, Al. Armii Krajowej 19, 42-200 Częstochowa, Poland, e-mail: abenduch@wip.pcz.pl

Received: 2015.07.18
Accepted: 2015.08.05
Published: 2015.09.01

ABSTRACT
The reduction of carbon dioxide emission is an important aspect of the economic policy of each country. Institutions promoting environmental protection seek to reduce the level of greenhouse gas emissions. One of the main emitters of harmful gases to the atmosphere is the steelmaking sector. The heating technology used in metallurgical works contributes to the amount of emitted carbon dioxide that forms as a result of the loss of steel and the combustion of fuel, whose thermal energy is used during the course of the charge heating process in the heating furnace. Achieving the imposed ecological targets by not exceeding the specified emission level is possible by implementing appropriate pollutant emission reducing technologies in the metallurgical industry. Based on numerical computation results, the effect of heating rate on the emission of carbon dioxide has been determined in the paper. This study demonstrates that by selecting the appropriate steel charge heating technology the emissions of greenhouse gases can be substantially reduced.

Keywords: CO_2 emission, heating of charge, heating technology, heating up rate, numerical modelling.

INTRODUCTION

An important regulatory issue in environmental protection is the economic instrument of a State's ecological policy in a form of transferable emission allowances. The operation of this mechanism consists of specifying the allowable level of emission in a given area and allocating allowances for this emission to the emitters by the institution responsible for environmental protection, and subsequent trading these allowances by the emitters with one another.

The main cause of the increase in the emissions of greenhouse gases, and especially carbon dioxide, is sought in metallurgical processes taking place in the steelmaking sector [5, 6].

Since 2005 the Community Greenhouse Emissions Trading Scheme has been functioning in the European Union. The Scheme has covered the operators of installations associated with the generation of energy; production and processing of nonferrous metals; production of cement clinker, glass and ceramic products; and wood production [5].

By its decision of March 2007, the European Commission reduced Poland's average annual allocation of carbon dioxide emission allowances for the years 2008–2012 from 284.6 mln tons to 208.4 mln tons, of which the limit for the steelmaking sector was reduced from 14.4 to 11.8 mln tons per year [4, 6]. Moreover, the directive of the European Parliament has introduced an auction mechanism as the primary method of allocating harmful gas emission allowances for the reference period of 2013–2020. The basis for the allocation of free emission allowances in this reference period for sectors subject to emission leakage shall be emission factors. The steelmaking sector has been classified into sectors that are considerably endangered by a high emission risk level.

The implementation of regulations on the standards for emissions from installations for metallurgical enterprises encourages the pro-ecological investment projects to be carried out, but also creates the need for purchasing additional carbon dioxide emission allowances, which contributes to the increase in competitiveness in the steelmaking sector [5]. It is noteworthy that by using appropriate greenhouse gas reduction technologies, the steelmaking industry could achieve the ecological goal of not exceeding the specified emission level. This paper shows how the selection of the appropriate steel charge heating technology can contribute to the reduction of the carbon dioxide emission.

THE OBJECT OF MODELLING

The object of modelling is a pusher heating furnace (Figure 1) [3]. It was assumed that the heating chamber of the furnace was represented by a rectangular prism with a length of L = 28 m, a height of $2H$ = 2.6 m, and a width of B = 5.6 m. Also, the furnace was conventionally divided into 20 calculation zones and 5 technological zones [1, 2].

For computation purposes, the pusher furnace was reduced to a simple model, in which the charge moves along the furnace chamber over the length L with uniform motion countercurrently to the direction 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 the phenomena, only heat exchange in the zones above the charge axis is considered. The furnace was assumed to be furnished with a recuperator.

NUMERICAL COMPUTATION OF CHARGE HEATING

In order to perform computer simulation of the effect of heating rate on heat consumption and steel loss, a mathematical model for charge heating and heat exchange in the chamber of a pusher furnace was developed [2, 3].

For the numerical computation of charge heating, the elementary balances method was used, and for the computation of the temperature field in the furnace chamber – the brightness and configuration ratios method [2, 4].

The method of supplementary temperature was used to calculate the loss of steel. The loss of steel in every compartment of time was marked was according to the dependence:

$$z_{k+1}^{N} = z_{k}^{N} + \Delta z_{k+1}^{N} \tag{1}$$

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

where:

$$N = \frac{1}{B} \tag{3}$$

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

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

where: A – constant value.

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

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

The heat flux fed to the computational furnace zone i was determined from the relationship:

$$\dot{Q}_{i} = \dot{V}_{g_i} \cdot W_d \tag{6}$$

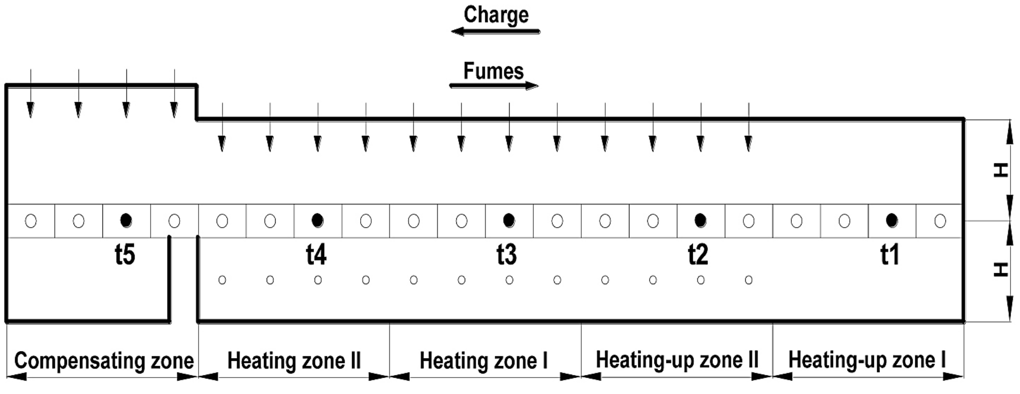

Fig. 1. The account schematic diagram of pusher furnace

The numerical computation of heat consumption of the furnace chamber was computed using the zone balances method. The unit heat consumption was calculated from the equation:

$$q_o = \frac{\sum_{i=1}^{n=25} \dot{Q}_i}{w} \tag{7}$$

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

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

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

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

The heat flux carried away with sliding rail cooling water was computed from relationships given in the work [7]. Its general form is described by the equation:

$$\dot{Q}_{ch^s \cdot i} = A_{szyn} \cdot a \cdot \left(\frac{T_{piec}}{100} \right)^n \tag{10}$$

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

$$\dot{Q}_{zew \cdot i} = A_{śc \cdot i} \cdot k_i \cdot \left(t_{śc \cdot i} - t_{ot.} \right) \tag{11}$$

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

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

In computations, also a constant value of other losses was assumed, and the heat input from the exothermic metal oxidation reaction was allowed for:

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

The balance of energy for different losses of warmth should also be considered . The losses are different for different levels of furnace efficiency.

REDUCTION OF CO_2 EMISSION IN THE PROCESS OF STEEL CHARGE HEATING

Influence of heat consumption on the CO_2 emission

The emission of carbon dioxide is directly connected with coefficient of unitary heat consumption as well as indirectly with the loss of steel [3, 4].

It the emission of carbon dioxide in the dependence from the value of heat consumption (the q) can be calculated from the equation:

$$m_{CO_2} = \frac{q}{W_d} \cdot \rho_0 \cdot V''_{CO_2} \tag{14}$$

The variation of surface temperature charge during the heating period is described by the following general equation:

$$t_p = t_0 + M\tau^G \tag{15}$$

The analysis covered three heating technologies defined by the value of the exponent G (G = 1; G = 0.8; G = 0.6). It was assumed that:

- composition of earth gas: CO_2 – 0.1%, O_2 – 0.1%, CH_4 – 96.7%, C_2H_6 – 0.6%, N_2 – 2.5%,
- the gas calorific value W_d = 34 302 kJ/um$^3_{gazu}$,
- specific mass of CO_2 in conventional conditions ρ_0 = 1.94 kg$_{CO2}$/um^3_g,
- the unit volume of carbon dioxide during burning with value of relation of air excess the gas α = 1.05 carries V”$_{CO2}$= 0.98 m^3/m^3_g.

Based on the adopted assumptions and calculations made, the emission of carbon dioxide (CO_2) has been determined for selected heating technologies. The results are given in Table 1.

The analysis of the obtained results shows that carbon dioxide emission is directly related to the unit of heat consumption index. Changing technologies from G = 1.0 to G = 0.6 causes an increase in heat consumption for respective heating rates, thus resulting in an increase in CO_2 emission. It can be noticed that high effects of heat consumption reduction, and thus CO_2 emission reduction, are brought about by conducting the heating process at appropriate heating rates. Changing over from the heating rate of M = 100 K/h to rational values (M = 500–600 K/h) will result in a considerable reduction of carbon dioxide emission.

Influence of steel loss on the CO_2 emission

The acceptable average value of energy consumption of production in Polish metallurgy of iron is about 35 GJ/t. It was calculated for the heating furnace whose heating chamber length was L = 28 m. Heating flat charge has a thickness of 2s = 0.3 m and the length l = 5 m. It was assumed that:

- surface of heating charge: A = 300 m^2,

Table 1. Results of the calculation of the effect of heating rate on the emission of CO_2 for different heating technologies, depending on the heat consumption magnitudes

No.	M [K/h]	m'_{CO2} [kg_{CO2}/kg_{stali}]		
		G = 1	G = 0.8	G = 0.6
1.	100	0.205	0.349	0.920
2.	200	0.156	0.209	0.393
3.	300	0.142	0.175	0.265
4.	400	.138	0.163	0.219
5.	500	0.137	0.158	0.200
6.	600	0.139	0.159	0.192
7.	700	0.145	0.162	0.193
8.	800	0.151	0.167	0.198
9.	900	0.154	0.174	0.206
10.	1000	0.157	0.183	0.219

- volume of charge: $V = 42\ m^3$,
- specific mass of charge: $\rho = 7850\ kg/m^3$,
- mass of charge $m = \rho \cdot V = 329\ 700$ kg.

Dependence captures in reference loss of steel to mass of heating charge:

$$z' = \frac{z \cdot A}{m} \tag{16}$$

The loss of heat in reference to mass of lost steel was counted was with dependence:

$$q' = q \cdot z' \tag{17}$$

In making calculation, an average energy intensity value of 35 000 kJ/kg was taken. The carbon dioxide emission, as dependent on the steel loss value, was determined from the formula (16). The calculations were made for three heating technologies (G = 1; G = 0.8; G = 0.6). The calculation results for the technology G = 1 are given in Table 2.

The results for carbon dioxide emission, depending on the steel loss value, for the technologies under examination are presented in Table 3.

When analyzing the calculation results it can be noticed that with the increase in steel loss, with the corresponding increase in heat consumption, carbon dioxide emission increases. The values of CO_2 emission through the loss of steel are much lower than those resulting from heat consumption.

The calculation results presented in Table 3 indicate that the value of CO_2 emission at heating rates of M = 600–1000 K/h are nearly identical for each of the heating technologies. Only for the initial heating rates the difference between the heating conducted at the constant surface temperature increase rate (G = 1) and the curvilinear surface temperature variation (G = 0.6) can be seen.

The total carbon dioxide emission, as dependent on the heating rate, for the technologies under analysis is represented in Figure 2.

Table 2. Results of the calculation of the effect of heating rate on the emission of CO_2, depending on the steel loss value for G = 1

No.	M [K/h]	z [kg/m^2]	z'[kg/kg]	q'[kJ/kg]	m''_{CO2} [kg_{CO2}/kg_{stali}]
1.	100	4.396	0.0040	140.00	0.0076
2.	200	3.394	0.0031	108.50	0.0060
3.	300	3.183	0.0029	101.50	0.0056
4.	400	3.152	0.0028	98.00	0.0054
5.	500	3.171	0.0028	98.00	0.0054
6.	600	3.186	0.0028	98.00	0.0054
7.	700	3.227	0.0029	101.50	0.0056
8.	800	3.268	0.0029	101.50	0.0056
9.	900	3.292	0.0030	105.00	0.0058
10.	1000	3.325	0.0030	105.00	0.0058

Table 3. Results of the calculation of the effect of heating rate on the emission of CO_2 for different heating technologies, depending on the steel loss value

Lp.	M [K/h]	m''_{CO2} [kg_{CO2}/kg_{stali}]		
		G = 1	G = 0.8	G = 0.6
1.	100	0.0076	0.0138	0.0361
2.	200	0.0060	0.0076	0.0151
3.	300	0.0056	0.0062	0.0091
4.	400	0.0054	0.0058	0.0070
5.	500	0.0054	0.0056	0.0062
6.	600	0.0054	0.0054	0.0056
7.	700	0.0056	0.0054	0.0054
8.	800	0.0056	0.0056	0.0054
9.	900	0.0058	0.0056	0.0056
10.	1000	0.0058	0.0058	0.0056

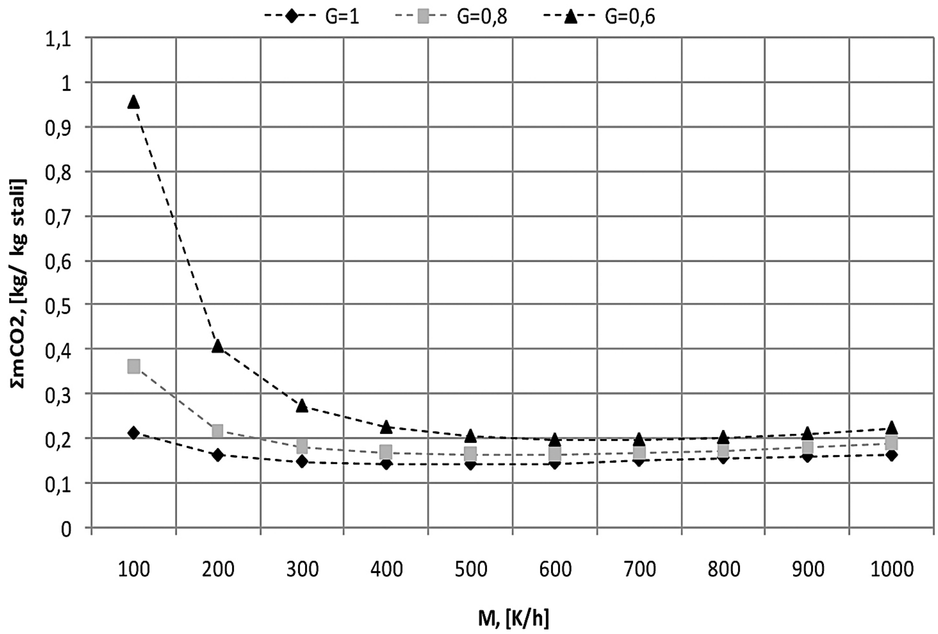

Fig. 2. Effect of the heating rate on the total CO_2 emission for selected technologies

When examining the results represented in Figure 2 it can be found that depending on the method of operation of heating equipment, at rational heating rates and through the selection of the heating technology, the carbon dioxide emission can be substantially reduced. The calculation results indicate that, from the point of view of both ecological and economic assessment, it is disadvantageous to heat steel charge at loss heating rates (low furnace capacities), as this will result in a considerable increase in CO_2 emission. The lowest CO_2 emission indices were achieved for heating conducted at a constant surface temperature increase rate (G = 1).

SUMMARY

From the performed numerical computations and the analysis of the obtained results, the following conclusions can be drawn:

1. The results of numerical modelling show that for each heating case there is a specific heating rate that assures the minimum heat consumption, steel loss and CO_2 emission.
2. The carbon dioxide emission level is directly related to the unit heat consumption index and, indirectly, to the loss of steel.
3. The adopted heating technology exhibits a significant influence on the carbon dioxide emission.

4. The reduction of carbon dioxide emission can be achieved by using rational heating rates (M = 500–600 K/h).
5. The lowest CO_2 emission level is assured by charge heating conducted at a constant surface temperature increase rate, i.e. by using the technology G = 1.

REFERENCES

1. Kieloch M.: Energooszczędne i małozorzelinowe nagrzewanie wsadu stalowego. Częstochowa, Wydawnictwo WIPMiFS Politechniki Częstochowskiej, 2002.
2. Kieloch M.: Racjonalizacja nagrzewania wsadu. Częstochowa, Wydawnictwo WIPMiFS Politechniki Częstochowskiej, 2010.
3. Kieloch M., Boryca J.: Analysis of influence of the speed of growth of temperature surface of steel charge on CO_2 emission. The Holistic Approach to Environment 1, 2011, 19–27.
4. Kieloch M., Klos A., Warwas E., Boryca J.: Badania wpływu szybkości podgrzewania wsadu stalowego na emisję CO_2. Hutnik-Wiadomości hutnicze, 5, 2009, 324–329.
5. Krajowy Plan Rozdziału Uprawnień do emisji dwutlenku węgla na lata 2008–2012 dla wspólnotowego systemu handlu uprawnieniemia do emisji, www.mos.gov.pl.
6. Musiał P., Burchart-Korol D.: Ograniczenie emisji CO_2 w przedsiębiorstwach hutniczych. Hutnik-Wiadomości Hutnicze, 10, 2008, 611–614.
7. Senkara T.: Obliczenia cieplne pieców grzewczych w hutnictwie. Katowice, Wydawnictwo „Śląsk”, 1981.