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MATHEMATICAL MODEL OF THE THEORETICAL TEMPERATURE OF THE BLAST FURNACE

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Abstract: In this contribution we will present a description of the mathematical model of the blast furnace theoretical temperature combustion. The developed mathematical model served for analysis, monitoring, and control of the theoretical temperature. At the end we will present the results of analysis obtained with the model at parameter optimisation of the mixed blast furnace wind parameters.

Key words: blast furnace, theoretical combustion temperature, mathematical model.

1 Introduction

Metallurgical production is high in energy consumption and has serious environmental consequences. Therefore long-time consideration is devoted to decreasing of the energy consumption of this process, as for example optimisation of hot blast stoves [Koštial et al. 1988], optimal sintering control [Koštial et al. 2001], blast furnace control [Malindžák et al. 1997, Koštial et al. 2000, Leššo 2001, 1994].

Blast furnace belongs to the basic equipment of integrated steel plants and decisively influence their economy. A generally accepted indicator of the blast furnace efficiency is the specific coke consumption. Its value depends on the composition of the metallic charge and on the blast parameters. The complex blast parameters are represented by its temperature, auxiliary fuels, moisture, and oxygen content. From the technological point of view it is the theoretical combustion temperature which has a decisive influence on the blast furnace operation such as reduction reactions, fusion and melting of slag and iron. It can be controlled by changing the blast furnace wind parameters. The blast furnace wind temperature should, from the economical viewpoint be held on its maximum level. Its stabilisation by cyclic or parallel operation of heat stoves is realised by cold wind bypass (fig.1).

The disadvantage of such approach is decreasing of medium wind temperature. Through bypass elimination it would be possible to increase the medium wind temperature by 15-20^{o}C. The present blast furnace operation practice requires stable theoretical combustion temperature which can not by achieved when bypass is eliminated (fig.2). Important improvement can by made by heating period organisation, but still it is about ±10 ^{o}C variation which should by compensated. The possibilities to maintain constant theoretical combustion temperature are by using : steam, oxygen, auxiliary fuels, nitrogen, heat stoves waste gas, blast furnace gas.

This paper has the objective to find optimal compensating medium and use it for theoretical combustion temperature control. For this purpose a mathematical model was developed of the combustion process which was used for simulation and analysis of this process [Krebich 1991, Kuyumcu et al. 1991, Pandey et al. 1999].

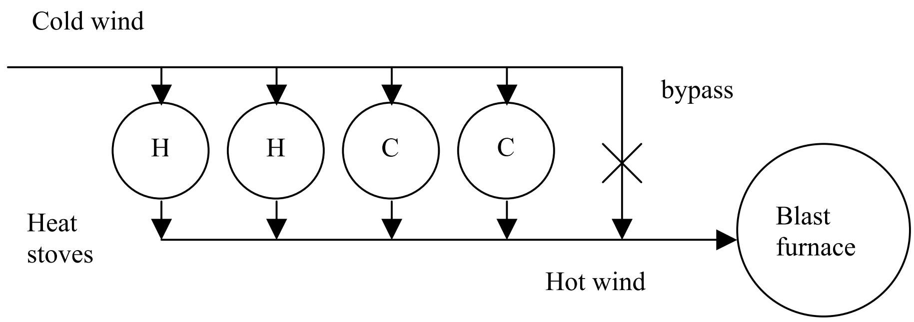

Figure 1. Blast furnace system
H – heat stoves heating, C – heat stoves cooling

2 Blast furnace combustion mathematical model

Blast furnace combustion process takes place in the reaction zone named "raceway" created in front of each tuyere (fig.1). The raceway is created by interaction of blast (velocity 120 - 250 m/s, temperature 1000 - 1300 ^{o}C) with coke charged to the furnace. Raceway reaction products are CO, N_2 and H_2. Theoretical combustion temperature variations are between 2000 – 2400 ^{o}C. The raceway reactions are :

Carbon combustion to CO_2

$$C_{(coke)} + O_{2(g)} = CO_{2(g)} \tag{1}$$

or for other condition (temperature, concentration) to CO

$$2C_{(coke)} + O_{2(g)} = 2\ CO_{(g)} \tag{2}$$

Boudouard's reaction

$$C_{(coke)} + O_{2(g)} = 2\ CO_{(g)} \qquad (3)$$

This reaction takes place at the boundary of oxidation zone and transfer all CO_2 to CO [BROŽ 1988].

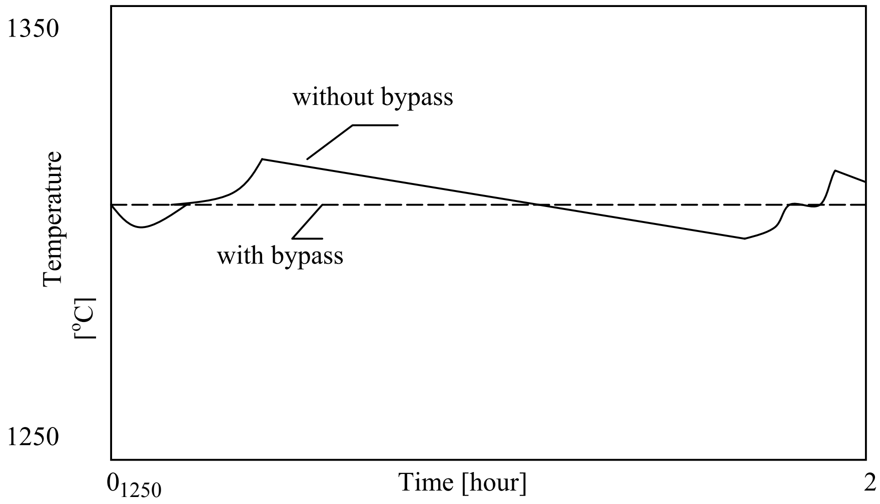

Figure 2. Blast temperature with and without bypass

Other reactions are of carbon with water vapour.

$$C_{(coke)} + H_2O_{(g)} = CO_{(g)} + H_{2(g)} \qquad (4)$$

and carbohydrates oxidation

$$2CH_{4(g)} + O_{2(g)} = 2CO_{(g)} + 4H_{2(g)} \qquad (5)$$

Theoretical combustion temperature is determined from heat balance equation [BROŽ 1988, MAJERČÁK et al. 1980] :

$$T_{teor} = \frac{Q_c + Q_k + Q_v - Q_{dis} + Q_{inj}}{c_{H2}V_{H2} + c_{CO}V_{CO} + c_{N2}V_{N2}}, \ [^{o}C] \qquad (6)$$

where Q_c is the carbon combustion heat from the coke and injected fuel [$kJ/kg_{(coke)}$]

Q_k	– physical heat of coke	[kJ/kg$_{(coke)}$]
Q_v	– physical heat of blast	[kJ/kg$_{(coke)}$]
Q_{dis}	– dissociation heat of water vapour and injected fuels	[kJ/kg$_{(coke)}$]
Q_{inj}	– physical heat of injected fuels	[kJ/kg$_{(coke)}$]
$V_{H2,\ CO,\ N2}$	– volume of H_2, CO a N_2 of in the combustion gas	[m^3/kg$_{(coke)}$]
$c_{H2,\ CO,\ N2}$	– specific heat capacity of H_2, CO, N_2	[kJ/m^3/K]

Table 1. Influence of compensating substances on blast furnace operation (wind=200000 m^3/hour, T_{teor}=2200 ^{o}C)

ΔT_{wind} – increase of wind temperature,
ΔQ – increase of heat input into blast-furnace,
ΔC – change of volume of coke,
ΔV – increase of hearth gases volume,
ΔV_{CO+H2} – increase of CO and H_2 in hearth gases

Substance and volume	Waste gases $10^3 m^3$/hour	Oxygen $10^3 m^3$/hour	Steam 1 g/m^3	Oil $10^3 m^3$/hour
ΔT_{wind} [^{o}C]	14.20	-20.16	8.53	25.9
ΔQ [10^5kJ/hour]	3.33	24.20	23.43	48.88
ΔC [t/hour] [t/hour/ $^o C_{Twind}$]	-0.0714 -0.00503	0.767 0.03805	0.150 0.03805	-0.972 -0.03753
ΔV [%] [m^3/hour]	0.037 0.0913	0.258 0.631	0.204 0.499	0.573 1.4
ΔV_{CO+H2} [%] [m^3/hour]	0.122 0.108	0.852 0.754	0.125 0.111	0.365 0.323

The simulation model consists of the following steps at which are determined :

1. Inputs determination
2. Moist air composition
3. Vapour volume
4. Blast wind composition
5. Carbon from injected fuels and required oxygen for its combustion
6. H_2O, CO_2, O_2 and N_2 volume
7. Carbon from coke and required oxygen volume
8. Carbon combustion heat, blast heat, injected fuels heat, dissociation heat
9. H_2, CO, N_2 volume and their specific heat capacity
10. Theoretical combustion temperature

3 Simulation

The outlined simulations were applied for analysis of different blast wind temperature compensation approaches. The idea is to find convincing compensation for blast temperature deviation. We have compared different substances which could be used for compensation of blast temperature deviation.

The mathematical model served for theoretical combustion temperature calculation for different compensating substances brought into the combined blast. According to the used substance there are different compensation mechanisms. The comparison was made for pulverised coal heat stoves waste gases, water vapour, and oil. The comparison was made for compensation of 1°C blast wind temperature. Compared was blast furnace operation as :

- specific coke consumption,
- hearth gases volume,
- furnace stability
- and economic parameters.

Each substance except oxygen can be used for blast wind temperature compensation. Increase of hearth gases volume is maximal for oil and minimal for waste gases. The reduction potential ($CO + H_2$) of hearth gases is highest for oxygen and lowest for gases.

Unanbiguous are the results for continuos transition of furnace temperature. Here the most effective are the waste gases. As far as compensation of 1 °C blast wind temperature is concered, the waste gases have least effect on other furnace parameters as furnace heat input, coke consumption, volume of both gases etc. The compensation by waste gases can be undertaken without influence on charge composition. The comparison is in table 1.

4 Economic impact

From economic point of view the compensation of blast temperature is most effective by nitrogen and then by waste gases. Oxygen and water vapour are less suitable even with the requirement of the theoretical temperature stabilisation.

This result was proposed for wind temperature stabilisation for VSŽ blast furnace plant.

5 Conclusions

From the economic point of view, the most advantageous is the blast wind temperature compensation with nitrogen, then with wastes gas. Oxygen and steam are less suitable. Oxygen increases the theoretical combustion temperature and is therefor suitable for increased effect.

The results obtained can be utilised, according to the specific blast furnace operation conditions, for temperature stabilisation furnace with non-stabilised blast temperature from hot-blast stoves. This will improve utilisation of hot-blast stoves heat capacity and increase the average blast temperature by reducing the losses through heat stoves waste gases. Higher blast temperature makes it possible to increase auxiliary fuels which is the main coke saving factor.

The results of the model were compared qualitative by and also quantitative by with real measured data. The presentet model is suitable for analyzing the combustion processes in the reaction zone of the blast furnace, for optimal working regime parameters design and for monitoring and control of the theoretical combustion temperature. The model was used also for the pulverised coal quantity and hot wind temperature optimisation.

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