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REDUCTION OF COSTS OF IRON PRODUCTION BY CHANGING PARAMETERS OF THE MIXED BLAST-FURNACE WIND

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The blast-furnace wind from hot-blast stoves is a significant factor of the blast furnace functioning. The technology was analysed in which the hot wind from hot-blast stoves is not mixed with the cool wind to a constant wind temperature, but is blown directly into the blast furnace. However, it is necessary to compensate for the changes of the theoretical temperature of burning in blast furnace as a consequence of non-stabilized wind temperature, by changing composition of the wind. This can be done by adding different media into the wind with different results from the operational and economical viewpoints. Essentially, the following types of media are used in blast furnaces: steam, oxygen, substitution fuels, nitrogen, and waste gas.

Key words: blast-furnace wind, mathematical model, simulation

Smanjivanje troškova proizvodnje željeza promjenama parametara vjetra visoke peći. Vjetar visoke peći i peći za zagrijavanje značajno utječe na rad visoke peći. Analizirana je tehnologija kod koje se vrući vjetar iz peći za zagrijavanje ne miješa s hladnim vjetrom do postizanja konstantne temperature nego se direktno upuhuje u visoku peć. Međutim, potrebno je promjenama sastava vjetra kompenzirati promjene teorijske temperature izgaranja u visokoj peći uzrokovane nestabiliziranom temperaturom vjetra. Ovo se može obaviti dodavanjem različitih medija u vjetar uz postizanje različitih rezultata s pogonskog i ekonomskog gledišta. U biti, kod visokih peći se koriste sljedeći mediji: vodena para, kisik, zamjenskog goriva, dušika i otpadnih plinova.

Ključne riječi: vjetar visoke peći, matematički model, simulacija

INTRODUCTION

The blast-furnace process consists of a large number of processes that are physicochemical, thermal and mechanical interconnected processes. In addition to main processes consisting of iron oxides reduction, pig iron and slag melt creation, also realised are fuel combustion, gas flow, charge and melt flow, dissociation and other reactions in the solid and liquid phases.

Inputs to the blast-furnace process are blast-furnace charge and combined wind. Blast-furnace charge consists of ore charge, coke and slag former. The functions of coke are putting heat and substances reduction to the blast-furnace, pig iron carbonisation, and creation of solid skeleton of the blast-furnace for the gas flow. The combined blown wind is the oxygen source for coke combustion and at the same time hydrogen source as reduction gas that is created by dissociation of steam. Outputs from the blast-furnace process are pig iron, slag and blast-furnace gas.

Overall the blast-furnace process can be characterised as a non-stationary process with distributed parameters. Its basic characteristics are as follows [1- 6]:

- The blast-furnace is counter current reactor.
- The blown wind and off take blast-furnace gas is continuous.
- The input of charge, pig iron and slag tapping is almost continuous.
- The reduction of iron from charge is nearly ideal, negligible loss of iron is to the slag.
- Heat exchange in the blast-furnace is basically finished. It is related to high level of heat utilization.
- Relatively low level of utilization of carbon chemical energy from coke comes not from process incompleteness, but from its essence.

MATHEMATICAL MODEL OF THE THEORETICAL TEMPERATURE

From combustion point of view coke combustion in front of the blast tuyere is important. Coke is heating from 1500 to 1600 °C and next is burning with blast-furnace wind that has temperature from 1000 to 1300 °C and velocity from 120 to 200 m/s. The final product of incomplete combustion of carbon is mixture of carbon monoxide, nitrogen and hydrogen.

Maximum temperature in oxidation area is where the concentration of the carbon dioxide is maximal according to the following reaction

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

while in all another areas the temperature of gas is lower because of incomplete combustion of carbon from coke

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

or because of reduction of carbon dioxide according to Boudouard's reaction

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

This reaction takes place at the boundary of oxidation zone and transforms all carbon dioxide to carbon monoxide [2, 3].

The wind humidity and steam interact with carbon from coke generating carbon monoxide and hydrogen

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

Both gases are created by combustion of methane that is the main part of natural gas [7]

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

Similar reactions occur at oil injection as substitute fuel.

The theoretical temperature of burning is a basic parameter to estimate the state of previous processes. It is basically about the thermal balance that includes incomplete combustion of carbon from coke, physical heat of the blast-furnace wind, coke and substitute fuels, and consumption heat for the dissociation of steam, substitute fuels, and heat for waste gas heating.

The theoretical temperature of the burning is given by the following equation [1]

$$T_{teor} = \frac{Q_c + Q_k + Q_v - Q_{dis} + Q_{inj}}{c_{H_2}V_{H_2} + c_{CO}V_{CO} + c_{N_2}V_{N_2}} \,/\, \mathrm{K} \qquad (6)$$

where

Q_c is the carbon combustion heat from coke and injected fuel / kJ/kg$_{(coke)}$,

Q_k is physical heat of coke / kJ/kg$_{(coke)}$,

Q_v is physical heat of blast-furnace wind / kJ/kg$_{(coke)}$,

Q_{dis} is dissociation heat of water vapour and injected fuels / kJ/kg$_{(coke)}$,

Q_{inj} is physical heat of injected fuels / kJ/kg$_{(coke)}$,

V_{H_2}, V_{CO}, V_{N_2} is volume of H_2, CO and N_2 in combustion gas / m^3/kg$_{(coke)}$,

c_{H_2}, c_{CO}, c_{N_2} is specific heat capacity of H_2, CO and N_2 / kJ/(m$^3 \cdot$K).

A simulation model for the study of impact of heat part on the theoretical temperature of burning or coke consumption was created. A brief algorithm of the model of theoretical temperature of burning is described in the following steps:

1. Input variables reading.
2 Choice of:
   (a)Calculation T_{teor} and wind temperature T_{wind} reading.
   (b)Calculation T_{wind} and T_{teor} reading.
3. Calculation of moist air composition.
4. Calculation of steam volume.
5. Calculation of blast wind composition.
6. Calculation of carbon consumption from injection fuels and oxygen volume for burning this carbon.
7. Calculation of H_2O, CO_2, O_2, N_2 total input volume.
8. Calculation of carbon and coke quantity.
9. Calculation of heat of incomplete combustion of carbon from coke, physical heat of blast-furnace wind, coke and substitute fuels, and consumption heat for dissociation of steam, substitute fuels.
10. Calculation of H_2, CO, N_2 volume and its specific heat capacity.
11. Calculation of T_{teor} or T_{wind}.

SIMULATIONS

Simulations are focusing on the possibility to compensate for the changes of the theoretical temperature of burning as a consequence of non-stabilized wind temperature, by changing the wind composition. It is a technology in which the hot wind from hot-blast stoves is not mixed with cool wind to a constant wind temperature, but is blast directly into the blast-furnace. The operation of the hot-blast stoves is more economical in this case than with the stabilized wind temperature [4].

Simulations were realised for 200 000 m^3/h blast wind volume, 60 % relative air humidity and 20 °C air temperature. The following volume of additional media was used: steam in the range from 0 to 30 g/m^3, 85 % oxygen from 0 to 10 000 m^3/h, oil injection from 0 to 8 000 kg/h, and waste gas from hot-blast stoves (average composition 69,2 %N_2, 0 %O_2, 25,4 %CO_2, 5,4 %H_2O) from 0 to 15 000 m^3/h.

All simulations were realised for constant total wind volume 200 000 m^3/h and for constant theoretical temperature of burning 2200 °C.

MUTUAL COMPARISON OF MEDIA

As a basic unit for mutual comparison we chose 1 K for the wind as a value, which we compensate for by different means and effects.

The mutual comparison was realised according to this criteria:

- The effect on blast-furnace hearth's operation, coke consumption, contribution of heat by the wind, volume and composition of hearth gases, and the stability of the conditions for blast-furnace operation.
- Availability of media and operation conditions.
- Economical comparison.

The effect on the contribution of heat to blast-furnace hearth and coke consumption

Considering the simulation results the most heat contributed to the blast-furnace hearth is under the condition when steam, oxygen, waste gas and oil is added to the wind, which makes it possible to considerably increase the wind temperature, while the oxygen significantly increases coke consumption.

The highest ratio of heat contributed by wind into the hearth occurs when oxygen enrichment of wind is excluded, which makes it possible to further increase the temperature of the wind at the expense of smaller consumption of coke burnt in the area in front of blast tuyere. Here are confirmed the contributions from the enrichment of the wind by nitrogen. It is self-evident that the calculated temperatures of the wind 1493 and 1683 °C are currently unrealistic and the purpose of the above comparison is only to evaluate the mutual combinations of individual media in the wind.

The quantification of influence was realised by the mutual comparison of the difference between the basic variant without additional media and maximal value of only one medium. The base for comparison is linear dependence between change of medium volume and the extent of change in the observed quantity.

The mutual comparison of differences between variants is listed in Table 1. Described in the first row is the impact of unit change of the amount of medium on the change of wind temperature. From this follows that without oxygen other media increase wind temperature by the constant theoretical temperature of burning. In the second row it is shown as media with wind temperature escalate the contribution of heat to the blast hearth. The third row includes change of coke quantity that is burnt at the front of tuyere per hour. From this follows that oxygen and steam increase coke consumption. Waste gas addition decrease coke consumption very moderately.

When recalculating the change of consumption of the combustion coke per 1 K of the wind temperature in the fourth row it is obvious that during the compensation of the change in wind temperature with oxygen or oil a considerable „shock“ in coke consumption in thermal processes occurs. When using the steam, this impact is less than half (46 % from oxygen) and with compensation by waste gas a decrease of coke consumption for thermal processes occurs, however, only about 13,4 % of the decrease when using oil.

Table 1. **Influence of compensating substances on blast-furnace operation**

Substance and volume	Waste gas / $10^3 m^3/h$	Oxygen / $10^3 m^3/h$	Steam / $1 g/m^3$	Oil / $10^3 m^3/h$
ΔT_{wind} / K	14,20	–20,16	8,53	25,90
ΔQ 10^5 / kJ/h	3,33	24,20	23,43	48,88
ΔC / t/h	–0,0714	0,767	0,150	–0,972
ΔC / $t/(h \cdot K)_{Twind}$	–0,00503	0,03805	0,03805	–0,03753
ΔV / vol.%	0,0370	0,258	0,204	0,573
ΔV / m^3/h	0,0913	0,631	0,499	1,400
ΔV_{H_2+CO} / vol.%	0,122	0,852	0,125	0,365
ΔV_{H_2+CO} / m^3/h	0,108	0,754	0,111	0,323

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

From the next rows, where the effect on the volume and composition of hearth gases is considered, it is obvious that addition of any of the four media brings increase in the creation of hearth gases especially through reduction components such as carbon monoxide and hydrogen at the expense of nitrogen.

For the overall amount of hearth gases the largest increase is with oil and the least increase with waste gas. The sum of carbon monoxide and hydrogen at constant amount of hearth gases per time unit has the largest increase with oxygen and the least increase with wastes.

Availability of media and operation conditions

From the media suitable for the compensation of the wind temperature should in principle be excluded enrichment of the wind with oxygen a consequence of which is the need for a decrease in wind temperature.

For practical use in compensation of increased wind temperature can be considered technological steam and waste gas. Operational functioning of technological steam is obvious since this medium is commonly used in practice. As for waste gas, in general, there is a wide variety of choice. It is only natural that it will be waste gas created in the combustion of pure (dustless) gas. In the metallurgy plant there are enough aggregates that produce suitable waste gas. In Japan for example the waste gas from the boiler was used [8].

The decisive factor in waste gas utilization is its composition, stability of its incidence, storage, and transport. The technical solution of the question of practical application should be completed, namely the question of import of waste gas from the source of incidence, adjustment of pressure, analysis of waste gas, measurement and regulation in the addition proper.

In the case the device for adding waste gas in the suction side of turbine is not designed, technological steam and decreasing the consumption of oxygen can be recommended for practical utilization of compensation of increased temperature of wind.

Economical comparison

The evaluation of approximate costs of compensating the increasing temperature of wind by nitrogen, waste gas, oxygen, and steam is given in Figure 1. In the costs is included the proper cost of media and their impact on the consumption of coke in front of blast tuyeres without considering the costs of the heat brought in by

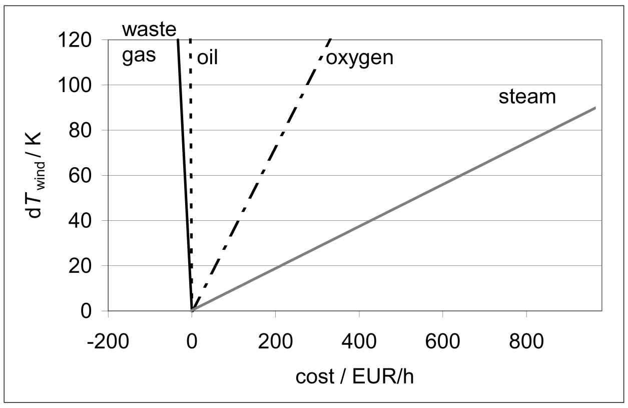

Figure 1. Costs comparison

wind at the change of its temperature. In view of marked changes in the prices of media it is necessary to make overall economic evaluation only after individual prices have been approved. The comparison in Figure 1 should only serve for overall evaluation for the choice of media.

As for the economic viewpoint of compensation of increased wind temperature, the most advantageous is the compensation by nitrogen (without consideration of the costs of N_2 – included in the production of O_2), then by waste gas. Oxygen and steam are less advantageous. Oxygen is not suitable for compensation of increased temperature of the wind since it increases T_{teor} (by increased burning of coke) and at decreased temperature of the wind the produced unused oxygen would have to be cost-inefficiently released into the atmosphere. So in view of technical conditions, steam is exploitable so far.

CONCLUSION

From economic point of view, the most advantageous is the blast wind temperature compensation by nitrogen, then by waste gas. Oxygen and steam are less suitable. Oxygen increases the theoretical temperature of burning and is therefore suitable for temperature increase effect.

The results of the model were compared qualitatively and also quantitatively with real measured data. The presented model is suitable for analysing 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 temperature of burning. The model was used also for the pulverised coal quantity and hot wind temperature optimisation.

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Note: The responsible translator for English language is Ladislav Pivka, Košice, Slovakia