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INJECTION OF BROWN-COAL TAR IN A STATISTICAL RELATIONSHIP WITH THE SIGNIFICANT PARAMETERS OF A BLAST FURNACE

STATISTIČNO RAZMERJE MED VPIHOVANJEM KATRANA IZ RJAVEGA PREMOGA IN POMEMBNIMI PARAMETRI PLAVŽA

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The extremely large energy requirements of blast-furnace iron production and the high levels of pollution in terms of carbon dioxide have resulted in systematic efforts aimed at decreasing the specific consumption of fuels and deoxidizing agents during this process. This paper deals with the injection of alternative fuels into a blast furnace and their effect on the blast furnace's operation. In this case oil injection was replaced by coal-tar injection. A comparison analysis of the brown-coal generator tar injection and oil injection was applied to assess the effect of the injection on the reduction of CO_2 emissions. The daily parameters of the inputs and outputs were available. The statistical relations for the injection of brown-coal tar and the significant parameters of the aggregate are studied. Correlation coefficients indicating the tightness in the tar injection and other significant technological parameters, such as the specific coke consumption, theoretical combustion temperature and the emissions of the blast furnace are calculated.

Keywords: blast furnace, tar, injection

Ekstremno visoke zahteve po energiji pri proizvodnji železa v plavžu in velika polucija z ogljikovim dioksidom zahtevajo sistematično prizadevanje za zmanjšanje specifične porabe goriv in dezoksidacijskih sredstev pri tem postopku. Ta članek obravnava vbrizgavanje alternativnih goriv v plavž in njihov učinek na delovanje plavža. Vbrizgavanje olja je bilo nadomeščeno z vbrizgavanjem katrana iz premoga. Izvršena je bila primerjalna študija vbrizgavanja generatorskega katrana iz rjavega premoga ter vbrizgavanja olja za oceno učinka vbrizgavanja na zmanjšanje emisije CO_2. Na voljo so dnevni parametri vhodnih in izhodnih snovi. Študirano je bilo statistično razmerje med vbrizgavanjem katrana iz rjavega premoga in pomembnimi procesnimi parametri plavža. Izračunani korelacijski koeficienti kažejo tesno povezavo med vbrizgavanjem katrana in drugimi pomembnimi tehnološkimi parametri, kot so poraba koksa, teoretična temperatura zgorevanja in emisije iz plavža.

Ključne besede: plavž, katran, vbrizgavanje

1 INTRODUCTION

An essential prerequisite for specific fuel consumption is coke substitution with an alternative fuel, a reducing agent. Nowadays, coal or gas is widely used as a substitute fuel. In the Czech Republic, oil was also used in past. Today's price of oil has caused oil injection to be very expensive. Coal, gas and the by-products of coke making, such as tars of brown and black coal. are exploitable as alternative fuels. However, the injection of alternative fuels has to respect the heat demands of the blast furnace. It is not possible for it to cause disorders in the subside of the blast-furnace burden. The unburned remainder of the fuel has to be consumed through the blast-furnace aggregate. A decrease in chemical energy exploitation in the blast-furnace gas is not allowed[1]. The augmentation in furnace gases and hydrogen input into the deoxidizing gaseous agent is caused by the injection, which probably results in a reduction of the specific coke consumption and emissions.

2 EXPERIMENT AND RESULTS

Up-to-date physical simulation procedures make it possible to study the behavior of materials under conditions very close to real industrial processing or applications.[2] For a comparison analysis some statistical calculations were carried out. The statistical evaluation of brown-coal tar injection contributes to a technological analysis of the blast-furnace order. The statistical relationships between the process parameters of the blast furnace describe, at the same time, ecological aspects of the utilization of alternative fuels for Czech blast furnaces. This might present possibilities for a decrease of the CO_2 emissions in metallurgy.

The computations were made with the automatic software Statgraphic. The data for the computations were acquired by a Czech metallurgical company; they refer to the real iron-making process, which is summarized in the equations below[3,4]:

$$3\ Fe_2O_3 + CO = 2\ Fe_3O_4 + CO_2 \qquad (1)$$

$$Fe_3O_4 + CO = 3\ FeO + CO_2 \qquad (2)$$

$$FeO + CO = Fe + CO_2 \quad (3)$$

Table 1 shows a chemical analysis of the generator tar[5] produced by Czech brown-coal pyrolysis.

Table 1: Chemical composition of brown-coal generator tar[5]
Tabela 1: Kemijska sestava generatorskega katrana iz rjavega premoga[5]

Element	C	H_2O	O	N	S	H_2O
Amount in mass fractions, *w*/%	83	9.4	3.8	0.5	0.4	1.2

The results of the statistical analysis are presented in **Table 2**.

Table 2: Correlation coefficients indicating tightness in the tar injection and other significant technological parameters of the blast furnace
Tabela 2: Korelacijski koeficienti, ki kažejo tesno povezavo med vbrizgavanjem katrana in drugimi pomembnimi tehnološkimi parametri plavža

Parameter	Tar	$w(H_2)$/ %	O_2 in wind	Coke	Emission	Humidity	TCT
Tar		0.64	0.59	–0.35	–0.36	0.1	–0.1
$w(H_{2\ top\ gas})$/ %	0.64		0.55	–0.5	–0.31	0.53	0.12
O_2 in wind	0.59	0.55		–0.27	–0.43	0.20	0.29
Coke	–0.35	–0.5	–0.27		0.56	–0.10	–0.27
Emission	–0.36	–0.31	–0.43	0.56		0.01	–0.18
Humidity	0.10	0.53	0.20	–0.10	0.01		–0.66
TCT	–0.10	0.12	0.29	–0.27	–0.18	–0.66	

TCT – Theoretical Combustion Temperature
w – mass fraction (%)

3 DISCUSSION

The first statistical evaluation concerns the relationship between the injected amount and the specific coke consumption. The statistical relationship is quite insignificant because the injected amount is low, stable and there are other aspects of the blast-furnace burden and technological properties affecting the coke consumption. The value of the coefficient of the independent variable in the regression equation determines the coefficient of substitution. It is 0.77, which is rather lower than the figure from theoretical calculations and practical experience.

Tar injection results significantly and quickly in hydrogen content augmentation in blast-furnace gas and furthermore in the outgoing furnace gas. Its correlation coefficient is 0.64. At the same time, the linear-regression dependence shows that 10 kg t^{-1} per pig-iron augmentation in tar injection makes a 6 % increase in the hydrogen content. So the speed of hydrogen-content augmentation is unlikely to be caused by the tar injection. For an explanation it is necessary to look at other parameters.

For wind enriched by oxygen, which often accompanies tar injection, the augmentation is $R = 0.59$. The linear relationship in the changes of oxygen content in wind and the hydrogen content in the gas show a medium statistical relationship of $R = 0.55$. As the effect of oxygen was included, the multiple regression H_2–tar, O_2 is used. The correlation coefficient reaches a slightly higher value ($R^2 = 0.45$), the coefficient of the tar variable shows a more probable value of 0.016 (10 kg t^{-1} of tar augmentation results in 0.16 %, 100 kg t^{-1}, 1.6 % augmentation of hydrogen). Similar results were computed by the multiple correlation H_2–tar ($R^2 = 59$ %) because the more the wind is enriched, the less hydrogen is brought by the wind into the blast furnace.

Humidification of the wind by the water steam affects the hydrogen content in the gas ($R = 0.53$). With the tar included in the regression relationship, the correlation level is better. ($R^2 = 63$ %). However, including the oxygen effect in the regression equation does not cause a significant augmentation in the correlation level ($R^2 = 65$ %).

There is an effect of injection, oxygen enrichment and other parameters in the coke's specific consumption. The correlation coefficient H_2–coke, i.e., $R = 0.50$, refers to the relationship between injection and the hydrogen content in the top gas

The tar included in the regression relationship between the coke consumption and the wind humidification (so H_2–humidification, tar) significantly increases the correlation level ($R^2 = 0.17$).

The statistical relationship between the oxygen enrichment and the specific coke consumption is rather featureless ($R = –0.27$) because the oxygen intensification variously affects a wide range of technological aspects of blast furnace's operation. It possibly affects the coke consumption as a global parameter only partially. Within the statistical evaluation, the relation between coke–tar, oxygen analyzed by a method of multiple regression shows a higher coefficient, in comparison with the linear regression without the oxygen content.

The total amount of CO_2 emission includes the CO emission in the top gas, although the CO burns out of the blast furnace process in wind heaters, a coke plant or in other metallurgical appliances. The total emission sources from CO + CO_2 ratio in the top gas, specific gas amount counted by the balance computations. This parameter of the blast-furnace process is very variable and affected by all kinds of items; therefore, it is not statistically significant in low tar injection.

There is a significant correlation between the emissions and the specific coke consumption where the correlation coefficient is 0.56. A polynomial regression results in a slight augmentation of the relationship's tightness ($R^2 = 34.7$ %). The augmentation includes the oxygen-enriched wind effect, where the regressive relationship shows the correlation $R^2 = 40$ %.

The tar-injection effect on the emissions statistically confirms a significant relationship ($R = 0.36$); however, the relationship is weak and is not affected by the polynomial regression. A cause of the augmentation is the

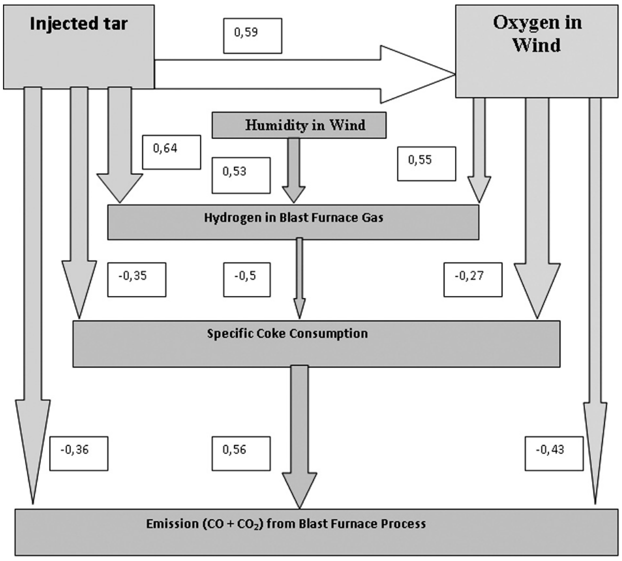

Figure 1: Effect of tar injection as a hydrocarbon fuel on blast-furnace operation and its total CO_2 emission
Slika 1: Učinek vbrizgavanja katrana kot goriva iz ogljikovodikov na delovanje plavža in skupno emisijo CO_2

other parameters included in the regressive relationships. The effect of oxygen enrichment increases the correlation level to $R^2 = 20.2$ %.

The significant indicator of the technological operation is the theoretical combustion temperature (TCT). It is counted from the input and output data values. The statistical analysis confirms a significant effect of wind humidification ($R = -0.66$) and a rather lowly tight relationship between TCT and oxygen enrichment of the wind ($R = 0.29$). The lowest tightness is for the tar ($R = -0.1$). The combination of oxygen effect, humidification and tar in the regression relationship to TCT represents the correlation level $R^2 = 0.75$, so a 75 % change in the TCT indicator is possible to explain with changes in the parameters, such as wind, enrichment, humidification and tar injection.

4 CONCLUSION

Tar, as an alternative fuel, brings to the blast furnace more hydrogen into the reduction gas than the fuel coke, which causes a decrease in the specific coke consumption and blast-furnace emissions ($CO + CO_2$). The compensation of oxygen wind enrichment is intensified by the tar injection. The effect of specific coke consumption on the emission of $CO + CO_2$ is statistically closest, even in the current conditions of a low level of tar injection. The graphical conclusion of the relationship between tar injection and other technological blast-furnace processes is summed up in **Figure 1**.

From the economical point of view, the alternative fuels injection is beneficial because it decreases the costs for fuels.[6] Modern operating and verification methods in ironmaking and steelmaking metallurgy contribute to a further decrease in emissions.[7]

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