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COST EFFICIENCY OF ELABORATING IRON BY USING PULVERIZED COAL AS A REPLACEMENT FOR COKE IN BLAST FURNACES

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Abstract: Currently the world is tending towards a dramatic specific consumption of coke per ton of pig iron by injection of coal dust in blast furnace tuyeres. The purpose of injecting pulverized coal in the furnace is to reduce coke consumption, to replace the liquid fuels and natural gas, to ensure a steady running, increase economic efficiency and improve environmental conditions. The injection of pulverized coal technology in the furnace is justified by: increase furnace productivity, expressed as the amount of iron produced per day in the furnace; reducing the consumption of more expensive coking coal and metallurgical coke, through replacing of coke with energetic coal; maintaining the stability of the furnace; improving the quality and reducing the silica content in iron cast without disturbance of the thermal regime of the furnace; reducing emissions of greenhouse gases.
Keywords: pulverized coal injection, coke, iron, blast furnace, cost efficiency

1. INTRODUCTION

Coal injection helped the steel industry to reduce operating costs, to extend the life of the coke furnace and reduce greenhouse emissions. Once the increasing understanding of the impact of quality of pulverized coal, there was a shift from highly volatile thermal coal to less volatile semianthracite. A heat and mass model was used to investigate the impact of injected coal properties on coke replacement ratio and operating costs under two sets of operating conditions corresponding European and Japanese practices. The pattern was also used to investigate the impact of the injection of ash from coal probable cost of operating a furnace [1,2].Today the world is tending towards a dramatic decrease of the specific consumption of coke per ton of iron by injection of pulverized coal in the blast furnace tuyeres.Injection of pulverized coal as a replacement of coke in the blast furnace is applied currently in over 100 furnaces worldwide, amongst which 44 are in Western Europe. The progress made in the past years, with the injection of pulverized coal in the blast furnaces, is related to the safety of equipment as well as to the ratio of injection achieved, at a present stage a specific consumption of 300 [kg/t iron] of coke is accepted. Currently, efforts are being made to inject 250 kg of coal/t iron in large furnaces, which could lead to o coke consumption of 250 [kg/ t iron].

2. IMPACT OF USING COAL DUST INJECTION IN BLAST FURNACE

The need for coal dust injection in the blast furnace was originally imposed by high oil prices, but now the increased use of coal dust injection is determined by the need to reduce raw material costs, pollution and also the need to extend life of coke ovens.

The injection of coal in the furnace has shown that it increases the productivity of the furnace, the amount of iron produced per day by the furnace; reduces coking coal that is more expensive, by replacing coke with cheaper thermal coal; ensures furnace stability; it improves the quality of iron and a lower content of silica in iron;-reduces emissions of greenhouse gases, life-cycle analysis conducted by Tata Steel showed a 6.2% decrease in CO_2 emissions when coal dust blowing ratio increased from 16 kg/thm to 116 kg/thm. In addition to the above benefits, the injection of coal has been shown to be a powerful tool in the hands of the operator from blast furnaces for adjusting the thermal state much more quickly than it would be possible by adjusting the load from the top. In general, Europeans intend to decrease fuel quantity in order to increase productivity, while Japanese objective is to have a higher ratio of fuel in order to meet the gas demand of the integrated steelworks [4].The development of coal injection systems led to improvement of systems for storage and distribution technologies. The critical goal in the design of the distribution system is to ensure a uniform batch of coal for every tuyeres without fluctuations. Constant development continues to improve through lance model and oxygen injection.British Steel has developed an alternative method for coal injection. Granular Coal Injection (ICG). ICG technology and coal injection (CPI) were assessed at Bethlehem Steel Burns Harbor steel mills corporations in a project funded by the U.S. DOE. Hill and others (2001) reported that the only differences between the PCI and ICG injection proportions of up to 140 kg/t pig iron are those that the ICG had lower requirements, providing savings both in capital costs and in operating ones.

2.1. Types of coal for blast furnace injection

World market is divided into sectors: coking coal, semi-coking and thermal coal after different properties. Coking coal demand hardly needs a special price due to its unique plastic hard coke and limited supply. Semi-soft coking coal has some plastic properties and can be used in mixtures of coke. Thermal coals are generally considered to have good combustibility in coal power plants and fuel ratio (fixed carbon/volatile matter-free) around 2 or less. Low volatile coals may also be regarded as being used for igniting the coal thermal kiln and fluidized bed boilers.

The relative importance of the different aspects of the quality of the coal PCI, varied, while the injection technology has improved and increased injection rate. In the late 1970s, triggered by the oil crisis, interest in coal injection coal reappeared and was considered as an economical replacement for fuel oil. Combustibility was considered important for PCI, thermal coal were used. At that time, thermal coal was available and had a much lower cost than hard coking and semi-soft coking coal. While understanding the impact of coal quality on the performance of the furnace increased, the demand for less volatile coal also increased in the last five years.

2.2. Replacement Ratio

For coal, coke substitution ratio was set to three injections ratios of 100, 150 and 200 kg/t pig iron. This allowed for a rate of injection of coal coke hypothetical zero, as shown in figure 2, for the operation of the high rate of fuel. The maximum rate of coke was tested for two other coal using two PCI rates and then used to calculate the expected replacement rate of the others coals.While the model gave lower ratios of European operations for fuel substitution lower than those estimated by Brouwer and his relationship Toxopeus (1991) [6], which were based on data from furnaces Hoogovens.

2.3. Injected coal gasification

Goto and others (2002) investigated the maximum rate of pulverized coal in a furnace using the carbon balance of material and heat balance model. Unburned coal that is not consumed by the reaction of loss of solution will be trapped in the furnace or will come in the form of dust. Shen and others [7] estimated the maximum rate 230 kg/t pig iron from the combustion efficiency of 75%.

To estimate the likely economic impact of the blast furnace operations Fukushima's model was used to determine differences in the demand for coke for two combustion efficiency (> 80% and 60% <) for a coal with high volatility and a volatility Scout 150 kg/t pig iron. For high volatile coal, there was no difference in the need for coke. For low volatile coal combustion efficiency at low coke demand grew by only 1%. Coking coal requirements for low volatility at low combustion efficiency was still lower than for coal with high volatility. Babich (2002) and Kochura (the productivity in 2002) summarized the measures enhances combustion of coal as follows [8].

2.4. Other influences on the operation of other PCI of the furnace

These calculations do not take into account the possible impact of ash on furnace operations, can affect the productivity and costs. The injection volumes larger than 160 kg/t pig iron, it was observed that changes occur in the operation of the furnace.

Table 1: Average operating parameters of blast furnaces with injection of pulverized coal in Europe and Arcelor Mittal Galati

Description	UM	F 5-ARCELOR MITTAL Galaţi	F9-Thyssen Hamborn	F4-Sidmar Gent	F4-Sollac Dunk.
		Romania	Germany	Belgium	France
Crucible diameter	m	11,6	10,2	10,0	14,0
net volume	m^3	2560	1833	1776	3648
I_u –use index	$t/m^3 24h$	1,777	2,68	2,77	2,40
Load					
- sinter	%	78,71	70,87	91,45	80,48
- pelett	%	12,64	18,50	6,87	-
- ore	%	8,65	5,29	1,62	19,52
- others	%	-	5,34	0,06	-
Coke sp. consum.	kg/thm	461	338	303	316
Cole sp. consum.	kg/thm	102	141	181	174
M.V. of coal	%	~ 35	25,7	26,6	20,6
Oxygen in air	%	23,19	23,7	24,5	23,6
Air temperature	°C	1050	1132	1209	1210
Flame temperature	°C	2210	2155	2187	2114
Pig iron:					
- siliciu	%	0,77	0,408	0,38	0,338
- sulf	%	0,025	0,038	0,018	0,026
- pig iron temp.	°C	1494	1503	1488	1491

All changes are interrelated and are influenced by the properties and quantities of coal and combustion conditions. At higher proportions of 180 kg/t pig iron permeability around the combustion zone is of concern. Ichidai et al (2002) have analyzed the main causes of low permeability caused by injection of coal. These causes are related to unburned coal and slag composition.

Injection of coal will continue to be a means to show the steel industry needs. Highest proportion of replacing coal with low volatile PCI coal makes them prefer the proportions of injection of 170 kg/t pig iron. The high combustion efficiency path is important to achieve higher proportions of 190 kg/iron. To determine the optimal or mixed coal injection on a large scale requires thorough research of various coal combustion kinetics and mixtures under different conditions of the combustion zone.

Injection of pulverized coal as a replacement of coke in the blast furnace is applied currently in over 100 furnaces worldwide, amongst which 44 are in Western Europe.

Table 2 compares the operating parameters of the F5 Arcelor Mittal Galati S.A. furnace with the ones operating in UE. It is noted that both national average parameters and the average parameters of some furnaces, ranks these aggregates amongst the furnaces with high performance through both specific fuel consumption and productivity. By comparison the parameters of F5 blast furnace from Arcelor Mittal Galati indicate an average coke specific consumption of 461 kg/t iron and 102 kg pulverized coal/t iron, therefore a total fuel consumption higher by 60–75 kg/t iron, this difference is found at all levels of injection practiced which helps limit the quantities of pulverized coal injected efficiently.

Table 2: Arcelor Mittal Galati, F5 indicators for the proposed options, in comparison with the real values of blast furnace

Indicator	Composition	Usual reference option	First proposed option	Second proposed option
Load [Kg/t iron]	sinter	1327.5	1327.5	1341.9
	pellet	484.4	484.4	484.4
	Mn ore	7.6	7.6	7.6
	TOTAL	1819.5	1819.5	1833.9
[Kg/t] [Nm^3/t] [Kg/t]	coke	508.7	455	430
	CH_4	53.9	50	-
	coalanh.	-	50	125
	TOTAL	562.6	555	555
Air parameters	flow [Nm^3/t]	1336.5	1168.21	1202.1
	humidity [%]	1	1	1
	O_2 [%]	22	24	23.5
	temp.[^oC]	970	1200	1200
Activity indicator	Iu[thm/m^3day]	1.165	1.805	1.8
	Ia [tk/ m^3day]	0.59	0.8213	0.778
Reduction degree	Rd/Ri	42/58	40/60	40/60
Furnace gas composition	[Nm^3/t]	1888	1749.33	1760.7
	CO_2[%]	18.35	19.76	20
	CO[%]	22.64	23.18	23.3
	H_2[%]	4.01	5.96	4.5
Pig iron quality	Si[%]	0.84	0.84	0.84
	Mn[%]	0.88	0.88	0.88
	S[%]	0.023	0.023	0.023
	C[%]	4.55	4.55	4.55
Slag quality	[Kg/t hm]	451.9	451.6	466
	CaO/SiO2	1.25	1.25	1.32
	(CaO+MgO)/SiO_2	1.33	1.33	1.419
Heat resources	CO[10^3Kcal/t]	79	76.7	77
	H_2.[10^3Kcal/t]	4	4.7	4
	Air[10^3Kcal/t]	17	18.6	18.8
Thermic balance	ht[%]	87.1	87.52	87.63
	hC[%]	61	62.13	69.94
	dif.[10^3Kcal/t]/[%]	192.1/7.6	194/7.5	196/7.5
The temperature in the combustion area of the crucible	[^oC]	1809	1947	1996

Presenting the worldwide situation of the pulverized coal injection will highlight the importance to Arcelor Mittal Galati SA as a prerequisite for improving the PCI, the performance boost of technology in the classic version. This feature is found in all the furnaces using the injection of pulverized coal across Europe.

3. TECHNICAL AND ECONOMIC CALCULATIONS FOR PROVING THE Arcelor Mittal Galati F5 BLAST FURNACE FUNCTIONALITY USING THE PULVERIZED COAL INJECTION

Calculation premises: the use of pulverized coal from ValeaJiului (PALD type) will be taken into account, unsintered, particularly washed (PALD type for semicoke), at 9-10% ash.

Coke composition, determined by the technical analysis: A^{anh}=9,2%; V^{anh}=36,2%; S_t^{anh}=1,01; H_2O=1,1%; $P_{calorific}$=6700[Kcal].

Composition of the volatile matter: CH_4=5%; H_2=6%; CO=37%; CO_2=35%; N_2=17%.

The analysis performed on F5 furnace at ARCELOR MITTAL Galati, was accepted as a starting point for technological calculations, so that in the end the operating intensity index to be adjusted to normal.

Fuel consumption: Coke (k_t) = 478.93 [kg/t]; methane gas = 0 [Nm^3/t]

A replacement ratio of 0.96 [kg coke/kg coal] was used.

The first proposed option: auxiliary fuel methane gas = 50 [Nm3/t]; coal (anh) = 50 [kg/t].

The second proposed option: it is injected only pulverized coal,125 [kg/t], in the tuyeres.

The results of all calculations performed for the proposed variants are recorded in table 2, showing these results compared to real values of operating the blast furnace during the reference period.

4. CONCLUSIONS

The result of the performed analysis is a satisfactory development of the reduction processes and the accomplishment of great efficiency at indirect reductions of CO and H_2. An insufficient temperature was used to pre-heat the air, which lead to decrease in the replacement ratio of the coke through methane gas, evaluated at 0.9.

Economic advantages can be observed by lowering the specific consumption of technical coke from 508.7 kg/t iron (the furnace operating at the reference option) to 455.0 kg/t iron (for the second option). The total quantity of fuels dropped from 562.6 to 555.

The efficiency of CO (η_{CO}) increased from 44.6 to 46.77 and the efficiency of H_2 had dropped in the first option. From here the conclusion that we obtained performances comparable to the ones obtained at furnaces in Germany, USA, Japan, etc. According to these performances a ratio was obtained between the direct and indirect reductions from FeO to Fe of approximately 40/60.

The quality of the iron remained the same with the one from the reference option, the quantity of cinder had a slight increase in the option with 100% coal. The cokes replacement ratio from the auxiliary fuels was able to increase from 0 to 1.01 and 0.97 (for the first option), including to 0.98 (for the second option).

From that mentioned above, the most plausible, for the furnaces in Arcelor Mittal Galati, is considered the first option, although the second option could be used as well form the economic points of view. This is the reason the injection equipment was made based on the option with 100% coal.

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