BASIC STRUCTURE OF THE FUEL RATE OPTIMIZATION MODEL AND ITS PRACTICAL USE AT THE BLAST FURNACE TECHNOLOGY

Mikolaj BERNASOWSKI, Andrzej LEDZKI, Ryszard STACHURA, Arkadiusz KLIMCZYK

AGH University of Science and Technology, Cracow, Poland, EU, mbernaso@metal.agh.edu.pl

Abstract

At the blast-furnace process about 30% of oxygen is removed from the burden by direct reduction. Based on Ramm's principles, the minimization fuel rate model, which is applied at computer-aided support system for blast furnace technology for BF No. 5 at ArcelorMittal Krakow Section, allows effective steering of the direct reduction rate. During the model testing in real condition it's observed than steering of the direct reduction rate is possible by variation of the oxygen or moisture addition. The present paper introduces an comparative analysis for the data of BF No.5 in Krakow for only-coke and PCI technology work periods. There are also presented results of simulation how the model would appeared if the BF No.5 worked with the ULCOS technology.

Keywords: blast furnace, low coke rate, minimization fuel rate model, computer-aided support system, ULCOS technology

1. INTRODUCTION

Since its inception, the blast furnace has had a tremendous impact on the quality and particularly on the unit cost of steel produced. At the same time, for many years, its complexity, size and the level of complexity of the physical and chemical processes occurring in the work area were a limit to obtaining sufficient information on the process. As progress is made in the field of measurement techniques, computer science and as the blast furnace process theory develops, involving a division of the reactions occurring into zones, partial mathematical models have been developed regarding selected aspects of the blast furnace. Initially, most of the models were based on more and more detailed material and thermal balances of the process. Their goal was to stabilize the chemical composition of pig iron through the optimization and stabilization of the range of the individual reaction zones in the working space of the blast furnace. It should be noted, that reduction of coke as well as another BF fuel consumption measurably affects on hot metal cost production and brings environmental benefits [1].

With further technology advancement at the leading centres of metallurgy, computer-aided systems began developing to support the blast furnace technology. These systems were tailored to the specific characteristics of blast furnaces and contributed significantly to improving the quality of the pig iron produced as well as a noticeable reduction in the production costs. The group of these systems includes: Voest Alpine, Rautaruukki, Thybas.

At the same time, the author team of this publication was working on mathematical models of the blast furnace process towards developing a computer-aided technology support system, adapted to the specific needs of the Polish steelworks. The models developed evolved into a single coherent system, implemented at Krakow's steelworks, later converted by ArcelorMittal for the use of pulverized coal injection as a substitute fuel to the blast, working up to now.

One of the major models in the system is the fuel rate optimization model. The model calculates the minimum fuel consumption depending on degree of wustite direct reduction.

During verification of the model in real conditions, we noticed that an oxygen or moisture addition to the blast affects on the degree of direct reduction.

In this work we present the general structure of the model and share our observations of the blast furnace operation.

2. STRUCTURE OF THE FUEL RATE MINIMIZATION MODEL

The structure of the fuel consumption minimization model is based on Ramm's principles [2] and uses elements of zonal, material and thermal balances with elements of dynamic and static factors contained in them.

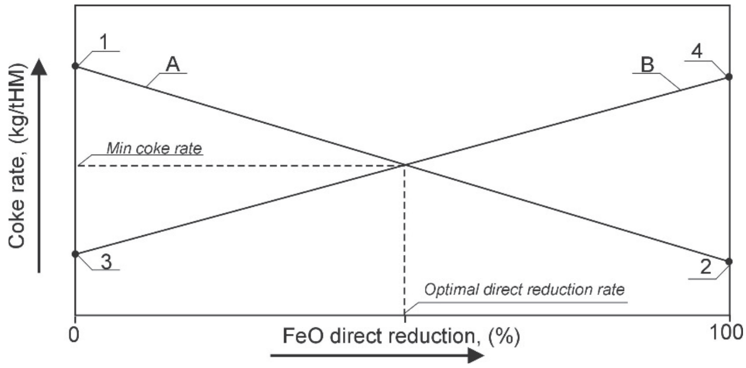

Fig. 1 The structure of Ramm's principles.

The carbon, which comes from the coke and the other substitutional fuels, plays three roles: a heat source, a reduction reagent and an iron carburizer. Fuel consumption depends on many factors and one of the main consumer of energy is a direct reduction of FeO.

Fig. 1 presents basic view of the model building. The model shows dependence of fuel consumption in a blast furnace at various contribution of direct reduction using two straight lines. The line "A" shows a carbon requirement for chemical needs, whereas the "B" reflects carbon requirement for heating. At 100% indirect reduction (or 0% direct reduction) rate carbon requirement for production CO is higher than heat requirement, whereas at 100% direct reduction (or 0% indirect reduction) rate is inversely. Intersection of the lines shows the minimal fuel rate at the optimal share of both types FeO reduction.

According to the equilibrium of iron oxides with Boudouard reaction (**Fig. 2**), indirect reduction of FeO can begin at point "S" [3,4,5] when reduction gas contains 60% CO and 40% CO_2 (%CO/(%CO_2+%CO)=0.6)

So, taking into account the necessary CO excess, for 1mole Fe, reaction of indirect reduction can be written:

$$FeO+2.5CO=Fe+CO_2+1.5CO \qquad (I)$$

and the consumption of carbon as a reductant at 100% rate of indirect reduction, would be written:

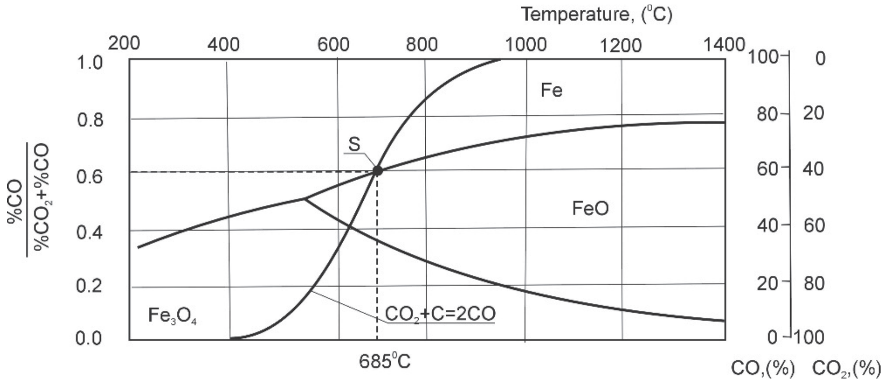

Fig. 2 Equilibrium of iron oxides with Boudouard reaction

$$\frac{12\frac{g}{mol\,C}}{55.8\frac{g}{mol\,Fe}}\cdot 2.5\cdot 1000\ kg = 537\frac{kg\,C}{t\,Fe} \qquad (1)$$

At the same time a heat requirement would be much lower than that obtained from carbon combustion.

However, at 100 % direct reduction rate there are must be consumed about 215 kg C per tonne of pure Fe:

FeO+C=Fe+CO (II)

$$\frac{12\frac{g}{mol\,C}}{55.8\frac{g}{mol\,Fe}}\cdot 1000\ kg = 215\frac{kg\,C}{t\,Fe} \qquad (2)$$

And the heat requirement would consist not only to ensure of melting processes realization but also to cover endothermic reaction (II).

Based on these grounds and taking into account such factors as solution and cooling losses, percentage of carbon in dry coke and other, the ordinates of points 1-4 can be calculated as shown in equations (3-6).

$$y1=\frac{537}{C_{dc}\cdot 0.01}\cdot(100-(Si_{HM}+Mn_{HM}+P_{HM}+S_{HM}+C_{HM}))\cdot 0.01+\frac{C_{HM}\cdot 10}{C_{dc}\cdot 0.01} \qquad (3)$$

$$y2=\frac{215}{C_{dc}\cdot 0.01}\cdot(100-(Si_{HM}+Mn_{HM}+P_{HM}+S_{HM}+C_{HM}))\cdot 0.01+\frac{C_{HM}\cdot 10}{C_{dc}\cdot 0.01} \qquad (4)$$

$$y3=\left(\frac{Q_{HM}+Q_{slag}+Q_{H2O}+Q_{PCI}+Q_{CmHn}+Q_{CL}+Q_{others}-Q_{HB}}{9.196}+C_{HM}\cdot 10\right)\cdot\frac{1}{C_{dc}\cdot 0.01} \qquad (5)$$

$$y4=\left(215+\frac{154\cdot 1000}{55.8}\cdot\frac{1}{9.196}\right)\cdot\frac{(100-(Si_{HM}+Mn_{HM}+P_{HM}+S_{HM}+C_{HM}))}{C_{dc}}+y3 \qquad (6)$$

where:

154 kJ/mol - enthalpy of reaction (II);

9.196 MJ/kg C - heat of coal combustion into CO;

Q - heat required or provided;

HM - index meaning "hot metal";

DC - index meaning "dry coke";

HB - index meaning "hot blast".

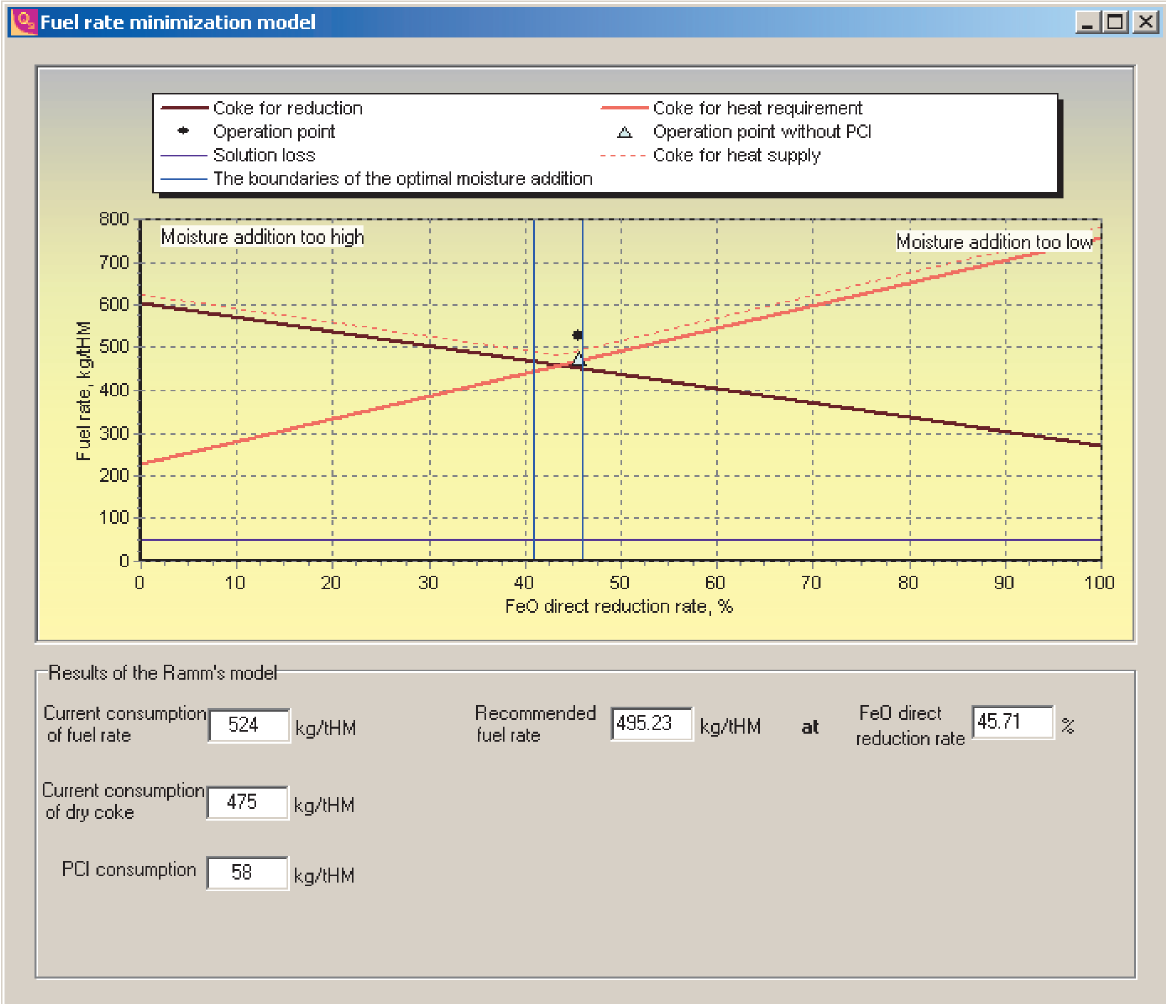

Fig. 3 Appearance of the fuel rate minimization model

Fig. 3 shows appearance of implemented model at BF No. 5 at Krakow steel plant [6]. The operation of the furnace is characterized by the location of the black dot. Coordinates of the dot are presenting measured actual consumption of fuel in the blast furnace and calculated rate of the direct reduction. This dot can only be located over the intersecting black and red straight lines. The theoretical minimum fuel consumption in the furnace is obtained when the black dot is directly at the intersection of the lines. However, the furnace must have a heat reserve for any unforeseen cooling. So the black dot must never be below the red dashed line. The direct reduction rate could be directly changed by the addition of moisture to the blast. Increase of moisture addition caused decreasing of direct reduction rate and moving of the black dot to the right. However, reducing of moisture addition increased the direct reduction rate. The blue straight lines indicate the limits of optimal steam blast additive. The area to the left of the left line is an area of excess steam additive, while the area to the right of the right line is an area of insufficient steam blast additive, which is the controlling agent. The "recommended coke rate" box indicates a value that could be achieved if the black dot appeared on the red dashed line with the current degree of direct reduction. When PCI is using, the state of fuel consumption is reflected by two points. Difference between the black dot and the triangle reflects additive of PCI. When PCI is not used, the two points merge into one and the model works as in the previous version.

3. HYDROGEN INFLUENCE ON WUSTITE REDUCTION

The presence of hydrogen in reducing gas also has influence on iron oxides reduction dynamic [7]. And presented above **Fig. 2**, with taken into account hydrogen effect may appear like showed at **Fig. 4**. We can see that hydrogen increase moves the equilibrium in direction of lower temperature from Boudouard reaction curve. However in real blast furnace hydrogen concentration in reducing gas corresponds with curve marked "BF" at **Fig. 4**. Thus, hydrogen presence will enhance wustite reduction condition and decrease CO request [8]. But this decrease is minimal in the contemporary blast furnace process.

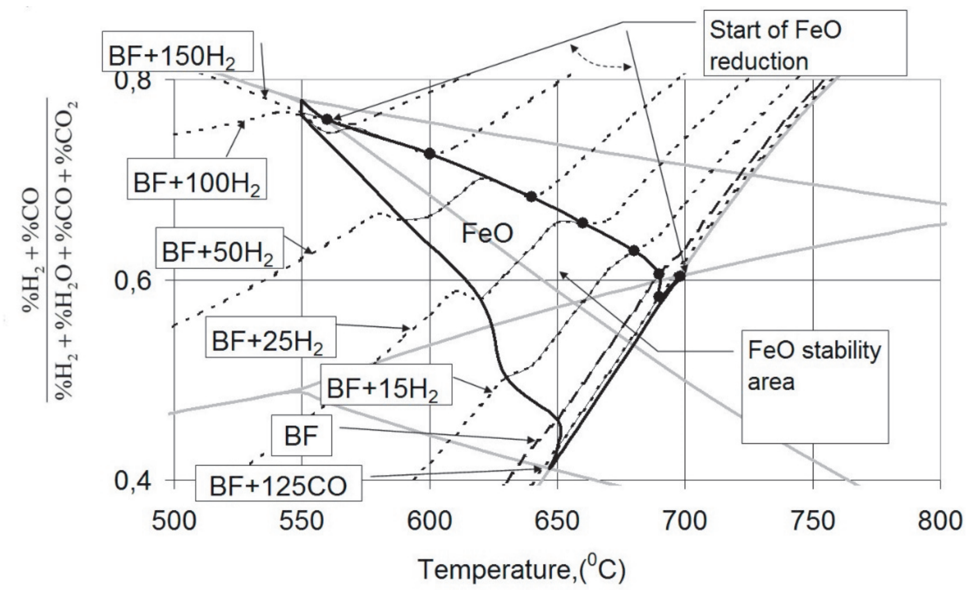

Fig. 4 Appearance of the fuel rate minimization model

4. PREDICTION OF THE MODEL APPEARANCE WITH THE ULCOS TECHNOLOGY

If into the blast furnace blew a heated CO instead N_2, there is would received reagent for Reaction (I) without necessity of the carbon combustion. So, reaction (I) would appeared a reaction (III) and eq.(1) can be rewritten as eq (7).

$$FeO+1.5CO+1CO_{heated}=Fe+CO_2+1.5CO \tag{III}$$

$$\frac{12\,\frac{g}{mol\,C}}{55.8\,\frac{g}{mol\,Fe}}\cdot 1.5\cdot 1000\ kg = 322.6\,\frac{kg\,C}{t\,Fe} \tag{7}$$

There is also changed the construction of the model (**Fig. 5**). The optimal FeO direct reduction rate has reached about 25 %. If, in addition, reduction gas will be blown into the blast furnace stock (over the cohesive zone level) and the lower concentration of nitrogen in the blow will taken into account (as it takes place in the ULCOS technology), the direct reduction rate can reach 10-15 %.

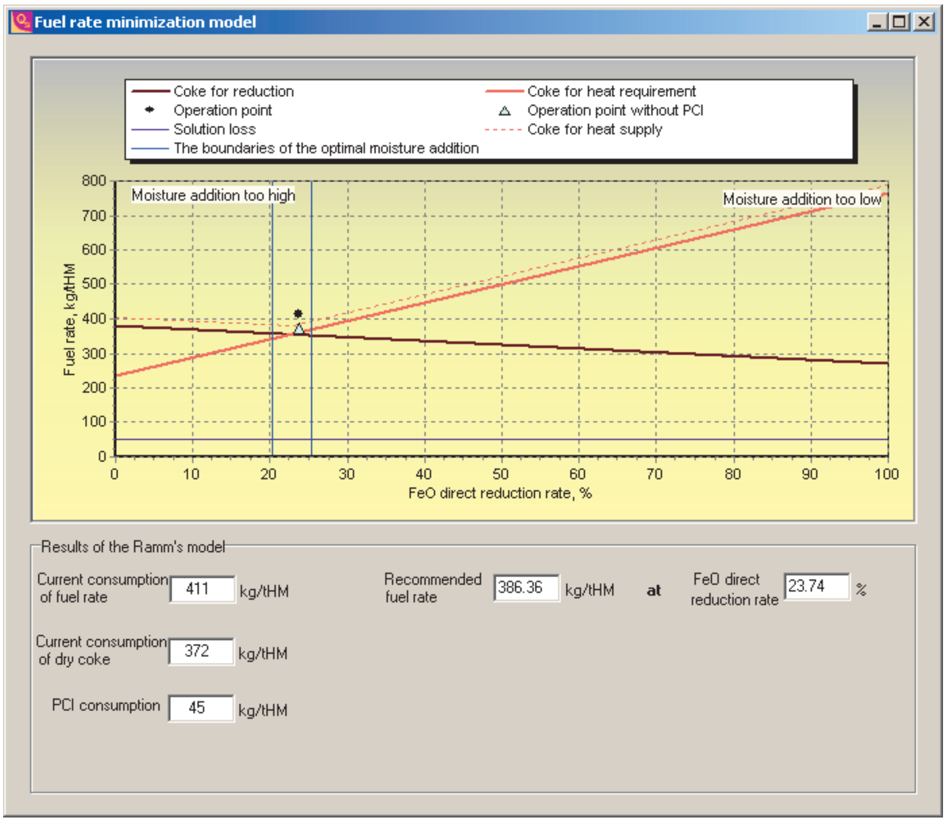

Fig. 5 Example of simulation when blast furnace operates with the ULCOS technology.

CONCLUSION

This paper presented the structure of the fuel rate minimization model, which was designed for needs of the BF No.5 at ArcelorMittal Poland Krakow Section. The staff of the blast furnace has received a simple tool to steering of the direct reduction rate by moisture addition into blow. An application of the model has brought tangible benefits of the fuel consumption. There is also presented the influence of hydrogen and carbon monoxide containing in bosh gas on the direct reduction rate.

REFERENCES

[1] PUSTĚJOVSKÁ, P., BROŽOVÁ, S. JURSOVÁ, S. Environmental Benefits Of Coke Consumption Decrease. *In Metal 2010:19th Anniversary International Conference On Metallurgy And Materials: May 18th - 20th 2010 Hotel Voroněž I,* Brno, Czech Republic, Tanger, Ltd., pp. 79 - 83. ISBN 978-80-87294-17-8.

[2] RAMM, A.N.: About the minimum coke rate in the modern blast furnace process; *Stal* 1964, No. 10.

[3] PAVLOV, M.A.: *Metallurgy of pig iron*; Part II; Metallurgizdat, 1949, P. 74-83.

[4] BENESCH, R., JANOWSKI, J., MAZANEK,E.: *The blast furnace process*; Slask, 1972, P.190-198.

[5] GOTLIB, A.D.: The blast furnace process; Metallurgia, 1966, P. 96-119.

[6] LEDZKI, A., SACHURA, R., KLIMCZYK, A., BERNASOWSKI, M., MIGAS, P., ZIELINSKI, K.: Evaluation of computer-aided system of blast-furnace technology in Krakow department of Mittal Steel Poland, Hutnik - *Wiadomosci Hutnicze,* 2006, No.7, P. 309-312.

[7] BILÍK, J., PUSTĚJOVSKÁ, P., BROŽOVÁ, S., JURSOVÁ, S. Efficiency of Hydrogen Utilization in Reduction Processes in Ferrous Metallurgy, *Scientia Iranica,* Volume: 20 Issue: 2 pp.: 337-342 DOI:10.1016/j.scient.2012.12.028 ISSN1026-3098.

[8] BERNASOWSKI, M. (2013), Theoretical Study of the Hydrogen Influence on Iron Oxides Reduction at the Blast Furnace Process. *Steel Research Int.*. DOI: 10.1002/srin.201300141.