Optimal Distribution of Supplemental Fuel and Oxygen amongst Furnaces in Blast Furnace Shop

N. Spirin¹, V. Lavrov¹, Y. Gordon², I. Gurin¹, L. Lazic³

¹ Department of metallurgy, Ural Federal University, Russia
² Hatch, Canada
³ University of Zagreb, Zagreb, Croatia

Presenter: Yakov Gordon
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Summary

• Introduction
• Problem formulation
• Model structure
• Informational-modelling system
• Conclusions
Introduction

• Each metallurgical company should solve independently questions of optimization of fuel and energy resources in the complex blast-furnace shops.

• Blast-furnace shops are the most energy-intensive, accounting for 50% of the fuel used in iron and steel industry.

• This task is actual for the large blast-furnace shops such as OJSC «Magnitogorsk Iron and Steel Works»
  • 8 blast furnaces
  • 30 thousand tons hot metal per day
  • 45 thousand tons iron-ore materials
  • 13 thousand tons of coke
  • 3.5 million m$^3$ technological oxygen per day
  • up to 4.0 million m$^3$ natural gas per day
Formulation of the problem for optimization of allocation of fuel and energy resources

**Generalized index of a thermal state of a lower part of blast furnace**

\[ Q_{i,b} \text{ min} \leq Q_{i,b} \leq Q_{i,b} \text{ max} \]

**Theoretical temperature (RAFT)**

\[ T_{i} \text{ min} \leq T_{i} \leq T_{i} \text{ max} \]

**Silicon contents in pig-iron**

\[ [S_{i} \text{ min}] \leq [S_{i}] \leq [S_{i} \text{ max}] \]

**Limitations in blast-furnace shop:**

- coke
  \[ \Sigma K_{i} \leq K_{\Sigma} ; \]
- natural-gas
  \[ \Sigma V_{i} \leq V^{\Sigma} ; \]
- production
  \[ \Sigma \Pi_{i} \leq \Pi_{\Sigma} \]

**Gas dynamic regime**

Extent of an equilibration of a charge

\[ C_{y i \text{ min}} \leq C_{y i} \leq C_{y i \text{ max}} \]

**Limitations natural-gas to blast furances**

\[ V_{i \text{ min}}^{\text{NG}} \leq V_{i}^{\text{NG}} \leq V_{i \text{ max}}^{\text{NG}} \]

**Sulphur contents in pig-iron**

\[ [S_{i} \text{ min}] \leq [S_{i}] \leq [S_{i} \text{ max}] \]

**Thermal state**

The ratio of thermal capacities of charge and gas in shaft furnace

\[ m_{i \text{ min}} \leq m_{i} \leq m_{i \text{ max}} \]
Model structure of optimization of allocation of natural-gas in blast-furnace plant

**UrFU model blast-furnace process**

**Coefficients of agency of the charge of natural-gas on:**
- coke consumption (an equivalent of replacement of coke natural-gas);
- furnace production rate;
- theoretical temperature of burning;
- the generalised index of a thermal state of a lower part of the oven;
- the ratio of thermal capacities of streams in stack;
- extent of an equilibration of a charge;
- runout and properties of slag;
- sulphur contents in pig-iron

**Coefficients of agency of input parameters on fusion technical-and-economic indexes (a coke rate and a furnace production rate):**
- air blast parameters (a hot-blast temperature, humidity, an oxygen contents in a positive draught);
- chemical compound and properties iron-ore materials;
- the charge and makeup of fluxing stones;
- makeup and properties of coke

**Coefficients of agency of input parameters (air blast parameters, makeup and properties iron-ore materials, the charge and properties of fluxing stones, makeup and properties of coke) on parameters thermal, gasdynamic and slag regimes of the blast-furnace fusion:**
- theoretical temperature of burning;
- the generalised index of a thermal state of a lower part of the oven;
- the ratio of thermal capacities of streams in stack;
- extent of an equilibration of a charge;
- runout and properties of slag;
- sulphur contents in pig-iron;
- silicium contents in pig-iron

**Base period**
**Rated indexes thermal, gasdynamic and slag regimes of the blast-furnace fusion on sample piece UrFU:**
- theoretical temperature of burning;
- the generalised index of a thermal state of a lower part of the oven;
- the ratio of thermal capacities of streams in stack;
- extent of an equilibration of a charge;
- properties of slag (viscosity of slag at various temperatures, viscosity gradients)

**Optimisation**
- the goal function job
- the optimisation problem solution

**The assaying of the gained solution**
- definition of best values of parameters;
- definition of limiting parameters;
- the assaying of the reasons of lack of the solution (at its presence)

**Forecast period**
**Feeding into of parameters:**
- air blast (hot blast temperatures, moistures, oxygen contents in a positive draught);
- chemical compound and properties железорудных materials;
- charges and makeup of fluxing stones;
- makeup and properties of coke

**Limitations**
- theoretical temperature of burning;
- the generalised index of a thermal state of a lower part of the oven;
- the ratio of thermal capacities of streams in stack;
- extent of an equilibration of a charge;
- properties of slag (viscosity of slag at various temperatures, viscosity gradients);
- sulphur and silicium contents in pig-iron;
- the rock gas charge on ovens;
- coke rate on the oven;
- pig iron production on department
Intelligence system structure of optimization of allocation of natural-gas  

\[ X^\text{in}_B \] – input parameters vector for a base period;  
\[ K \] – adjustment coefficients vector;  
\[ X^\text{in}_F \] – input parameters vector for the forecast period;  
\[ X^0_B \] – counted parameters vector for the base period;  
\[ X^0_F \] – counted parameters vector for the forecast period;  
\[ X^* \] – a vector of best values of parameters;  
\[ Z^* \] – value of the goal function
Display window of the program of the main benchmarks of blast furnaces
Display window of the program to set limits on each furnace
The window of the program displaying the results of calculation of individual furnaces

Результаты расчета по печам (реальные данные, усредненные за 00.00.00)

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Window of the program for change parameters of blast furnaces
Window of the program displaying of calculation results

In tabular form

In a chart
Example of optimal distribution of natural-gas and oxygen in group of blast furnaces

Deviation from the base period, %

- Consumption NG
- Consumption O₂
- Productivity
- Consumption coke

Serial number of a blast furnace in the settlement group
Methodology and mathematical models for optimization of natural gas and oxygen distribution amongst blast furnaces in multi furnace shop was developed, tested and implemented.

Application of the developed models and methodology as a part of overall automatic control system (ACS) of the blast-furnace at OJSC «Magnitogorsk Iron and Steel Works» allowed to improve plant efficiency and financial returns.

The natural gas and oxygen optimization system improved the effectiveness of decision making by technical staff in conditions of changes or limitations of fuel and energy resources, instability in composition and quality of iron-ore materials and market conditions.
Acknowledgements

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THANK YOU FOR YOUR ATTENTION!