EVALUATION OF THE QUALITY OF ALKALINE RAW MATERIAL IN THE BLAST FURNACE PROCESS

BESTA Petr, JANOVSKÁ Kamila

VSB - Technical University of Ostrava, Czech Republic, EU, petr.besta@vsb.cz

Abstract

Fluxes (slag-forming additives) provide the formation of blast-furnace slag of suitable chemical composition. These additives affect not only the technological parameters of the blast-furnace process. Fluxes must have good desulphurisation ability and low viscosity. Metallurgical enterprises in the Czech Republic mostly use acidic ore raw materials. Therefore alkaline (basic) fluxes are exploited in iron working. A frequently used raw material for the preparation of alkaline additives is dolomitic limestone. However, this material can be evaluated by a number of features that significantly influence the blast-furnace process. These properties can then be included in chemical, physical and technological categories. To evaluate one alkaline raw material, it is possible to choose a wide range of parameters. However, it is necessary to propose a principle of evaluation of these raw materials using a complex indicator which will quantify all the key parameters. The article deals with the possibility of evaluating the quality of alkaline raw materials used in the blast-furnace process.

Keywords: Iron, process, sulphur, costs, production

1. INTRODUCTION

The charge in the blast furnace consists of metalline materials, slag formers and fuel. Charge materials into the blast furnace should be characterized by uniform properties, a low proportion of fine-grained particles, narrow grain-size distribution and sufficient mechanical strength. Important input materials are then fluxes which usually have a basic character [1]. Today, metallurgical enterprises must pay great attention not only to the technological parameters of blast-furnace raw materials but also to cost considerations that affect the final price of the metal produced [2, 3].

Metallurgical enterprises in Central Europe must react to intense competitive pressures of producers of iron mainly from Asia. A strong competitive environment is forcing manufacturers to use cheap feedstock [4, 5]. For these reasons, producers in the Czech Republic use cheaper iron ore raw materials, particularly from Russia and Ukraine. The final price is also affected by low transport costs. A big disadvantage of these ore raw materials, however, is their acidic nature. Simultaneously, they generally contain greater amounts of negative elements that can be allocated in the form of slag in the case of an effective course of the technological process [6]. The acidic nature of ore raw materials used then especially leads to the fact that alkaline materials must be applied as fluxes. These additives provide formation of blast-furnace slag with optimal chemical composition and optimal technological qualities. A key function of the slag is its ability to absorb sulphur and other adverse elements [7, 8]. This is only possible if the slag has adequate chemical and physical properties. In general, it is considered that the ideal slag typically contains 0.6 % - 0.7 % of FeO. Within the Czech Republic, widespread alkaline additives include dolomitic limestone which contains key oxides, CaO and MgO. The right choice of fluxes affects not only the technological process itself but also the cost of the entire production [9].

As part of the research conducted, we experimentally assessed the quality of offered alkaline raw materials (dolomite limestone) from suppliers in the Czech Republic, the Slovak Republic and Romania. For this evaluation, we selected criteria that affect both the technological process of iron production and the final price of the metal. The article analyzes the generated model of evaluation prepared under conditions of a metallurgical company. This article aims to analyse the possibility of determining the quality of alkaline raw materials used in the blast-furnace process on the basis of more relevant criteria.

2. PROBLEM FORMULATION

The basic tasks of the slag include iron desulphurisation. The main desulphurisation takes place in the blast furnace hearth where drops of pig iron containing FeS pass through a layer of alkaline slag. Each drop of pig iron has its surface. The sum of the surfaces of individual drops represents a very large interfacial boundary due to which the desulphurisation is very intense. This desulphurisation can be called as upper and removes the bulk of the sulphur. The next stage of desulphurisation takes place in the contact layer between pig iron and the slag. This phase is of less importance because it is limited by diffusion of sulphur and oxygen to the interfacial boundary. In the blast furnace, iron is desulphurised by substances with a higher affinity for sulphur than iron (MgO, CaO). In general, the desulphurisation reaction can be written in the form of the following equation (1).

$$FeS + CaO + C = Fe + CaS + CO \quad (1)$$

The desulphurisation ability of the slag is significantly influenced by the content of alkaline raw materials. For their assessment, it is possible to use a number of different criteria. Fundamental parameters will always be those that affect the very technology of iron production. Huge competition in the production of iron, however, is also steadily increasing the importance of criteria which influence the cost of the entire process. Therefore, the former classification of key parameters of alkaline raw materials is now changing somewhat. The main area to be monitored in alkaline raw materials can then be divided into the following categories of properties:

- Chemical properties (content of alkaline substances and impurities, chemical composition),
- Physical properties (strength, moisture, lumpiness),
- Pricing and logistics aspects (cost, transportation, price maturity, amount of stock).

In terms of chemical properties, it can be said that the dominant characteristic is basicity (alkalinity). Alkalinity or basicity can be defined as the ratio of alkaline and acidic components of oxides. Basicity evaluated using this principle can be expressed by relationships (2), (3). The variable W expresses the mass fraction of the given component in the slag.

$$B_1 = \frac{W_{CaO}}{W_{SiO_2}} \quad (2)$$

$$B_2 = \frac{W_{CaO}+W_{MgO}}{W_{SiO_2}+W_{Al_2O_3}} \quad (3)$$

The physical properties include key parameters such as grain size or moisture of the material [10]. These parameters can be naturally adjusted before using the raw material, which obviously brings extra cost. In addition to the chemical and physical parameters, also aspects relating to pricing and logistics have gained importance in recent years. These then can significantly affect the cost of the entire process and therefore the final price of the metal produced. The presented brief list illustrates the difficulties that can be faced when evaluating the alkaline additives. It is always necessary to find such an evaluation process that takes into account all the relevant parameters. The problem is how to comprehensively evaluate all the properties that are measured in completely different units. One of alternative options is to use mathematical methods of multi-criteria decision making. These methods were also applied in the context of the conducted research.

3. EXPERIMENTAL WORK

For the evaluation of suppliers of alkaline raw materials, we can use many criteria. To find a suitable variant, it is very advantageous to use a system based on a multiple dimensional basis, enabling to take into account more of the relevant properties. As part of this research in the observed metallurgical company, a model of multi-criteria decision making was applied. Within this model, we used criteria from the field of chemical and physical properties as well as pricing and logistics aspects. In the context of the proposed evaluation, the following criteria were taken into account:

Criterion no. 1 - Basicity (%)
Criterion no. 2 - Lumpiness (%)
Criterion no. 3 - Stock (t)
Criterion no. 4 - Price ($ / t)

In view of the nature of those criteria, it is obvious that they represent considerably different factors. From this perspective, it is appropriate to use multi-criteria decision-making methods. This allows including categorically different units of individual criteria into the evaluation. In the case of basicity, the evaluation includes the ratio of alkaline and acidic additives (%). Regarding the lumpiness, the monitored criterion is evaluated as a percentage amount of the alkaline raw material, corresponding to the desired dimensions of 20 - 40 mm (1 - 2 mm in the case of using the sinter). Criterion no. 3 (stock) represents the amount of raw material that the supplier offers to place in the company's premises in the form of consignment stock. The last criterion concerns the actual price of the alkaline raw material. All the above criteria are among the key criteria and may influence the technological course of the entire process as well as the final cost. The price given in **Table 1** represents a weighted average of all types of grain used. The quality of alkaline raw materials was evaluated with regard to materials and suppliers from the following countries: Slovak Republic, Czech Republic and Romania. The values for individual alkaline raw materials from suppliers in the named countries are shown in **Table 1**.

Table 1 The values of criteria in compared alkaline raw materials

Criteria		Limestone suppliers		
		Slovak Republic	Czech Republic	Romania
K1	Basicity (%)	3.2	2.8	4.8
K2	Lumpiness (%)	81	86	79
K3	Stock (t)	1500	2000	3200
K4	Price ($/t)	18.5	17.9	19.1

For a comprehensive comparison of alkaline raw materials, we utilized the method of distance from dummy option. The method uses the principle of measuring the Euclidean distance in space. The evaluation is based on quantifying the distance of individual variants from the fixed variant. This then represents such an alternative in which the values of all the criteria are absolutely ideal. Evaluation of individual suppliers of alkaline raw materials can be made using relations (4, 5).

$$D_j = \sqrt{d_j} \tag{4}$$

$$d_j = \sum_{i=1}^{n} v_i \times \left(\frac{x_i^* - x_{ij}}{x_i^* - x_i^0} \right)^2 \tag{5}$$

The selected four criteria for evaluating the alkaline raw material were identified as most important. In the first step of the evaluation, weights (importance) of individual criteria were determined. **Table 2** shows a specific weight for each reference criterion in column vi. The weights for all criteria were established by a team form, both on the basis of long experience and using the method of pairwise comparison. The given values then represent the weighted average. The observed value of the Euclidean distance is essentially the sum of partial deviations of each criterion from its ideal value. Based on the monitored criteria, the best alkaline raw material is the material with the lowest value. Distance from dummy option (Dj) according to relation (5) was determined for all raw materials. Their evaluation was then performed on the basis of this value (**Table 2**). A lower value of distance Dj represents a better variant. **Table 2**, in line Dj, shows specific values of the distance from dummy option for suppliers of alkaline raw materials from the Slovak Republic, Czech Republic and Romania. The overall sequence (ranking) was determined according to these values. This evaluates the overall quality of the offered alkaline raw material for the blast-furnace process in descending order.

Table 2 Analysis of alkaline raw materials

Criteria		v_i	x_i^*	x_i^0	d_{ij} for individual suppliers		
					Slovak Republic	Czech Republic	Romania
K1	Basicity (%)	0.400	4.8	2.8	0.320	0.400	0
K2	Lumpiness (%)	0.050	86	79	0.036	0	0.050
K3	Stock (t)	0.250	3200	1500	0.250	0.176	0
K4	Price ($/t)	0.300	17.9	19.1	0.150	0	0.300
				$\sum$	0.756	0.576	0.350
				D_j	0.869	0.759	0.592
				Sequence	3.	2.	1.

The compiled order of suppliers of alkaline raw materials thus shows their suitability (quality) for use in the blast-furnace process. The distance from dummy option is based on a synthesis of these criteria: basicity of the raw material, lumpiness, offered stock as well as the price.

4. CONCLUSIONS

In the monitored blast-furnace plant, we analysed the overall quality of the offered alkaline raw materials. These were offered by suppliers from the Slovak Republic, Czech Republic and Romania. The mentioned criteria were used for evaluating the overall quality and ranking individual suppliers of alkaline raw materials. Through the applied mathematical methods, we determined the following order of suppliers from different countries (**Table 2**):

Supplier - Romania (0.592)
Supplier - Czech Republic (0.759)
Supplier - Slovak Republic (0.869)

Values in parentheses represent distances from the optimal (dummy) option. The sequence (order) determined on the basis of this model is interesting in terms of a number of aspects. Generally, the material from the supplier in Romania was identified as the alkaline raw material of the highest quality although this dolomitic limestone was the most expensive material from all monitored raw materials. At the same time, however, it showed a great value of basicity. The second position belongs to the significantly cheapest dolomitic limestone from the Czech Republic although the supplier offered a relatively large quantity within the consignment stock. Dolomitic limestone from the supplier in the Slovak Republic was evaluated as the worst. Identified values of distances from dummy option can essentially represent a dimensionless determination of the quality of the given raw material. The evaluation found can then be also very easily converted into percentages, for example. On the basis of this research, the metallurgical enterprise was advised to use suppliers of the alkaline raw materials in the given order. This will naturally apply if the monitored criteria have the presented values.

5. DISCUSSION

Metallurgical enterprises must increasingly use complex methods for the analysis of many complex problems. Currently, the selection of blast-furnace raw materials and thus the alkaline additives must be implemented based on a number of relevant criteria. Chemical and physical properties can significantly affect the course of the sintering and blast-furnace process. Logistics and price attributes affect the cost of the entire process and therefore the price of the metal produced. If the metallurgical company uses only one isolated criterion to evaluate and select the alkaline raw material, the respective solution may not always be ideal. The proposed evaluation is based on the synthesis and comparison of various criteria. This can be seen as its major benefit. Today, in the production of iron, it is not possible to evaluate only technological properties; it is increasingly necessary to consider also other criteria that affect the final price of the metal. As long as metallurgical companies in the Czech Republic continue to use ore raw materials highly acidic in terms of basicity, decision making on alkaline raw materials will be more and more important.

ACKNOWLEDGEMENTS

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2016/107.

REFERENCES

[1] LENORT, R., BESTA, P. Logistics of End of Life Electronics Equipment Disassembly. *Acta Montanistica Slovaca*. 2009, Vol. 14, No. 3, pp. 268-274.

[2] FREDMAN, T. P. Accretions in the blast furnace stack - background factors. *Canadian Metallurgical Quarterly*. 2002, Vol. 41, No. 4. pp. 475-486.

[3] SIKOROVÁ, A., SAMOLEJOVÁ, A., LAMPA, M. Marketing Innovations in Industrial Firms. In Proceedings of the 22nd International Conference on Mettalurgy and Materials, Hotel Voroněž I., Brno, Czech Republic, May 2013, pp. 2029 - 2035, ISBN 978-80-87294-41-3.

[4] HART, M., RAŠNER, J. & LUKOSZOVÁ, X. Demand Forecasting Significance for Contemporary Process Management of Logistics Systems. In Proceedings of the 2nd Carpathian Logistics Congress, Priessnitz Spa, Jeseník, Czech Republic, November 2012, pp. 199-205, ISBN 978-80-87294-36-9.

[5] HART, M., LUKOSZOVÁ, X. & TOMAŠTÍK, M. Methodics to Create Layout Drawing Documentation as the Foundation for Logistics Management System of a Company. In: Proceedings of the 3rd Carpathian Logistics Congress 2013, Novotel Krakow City West, Krakow, Poland, pp. 179-184, ISBN 978-80-87294-50-5.

[6] HART, M., TARABA, P. & TOMAŠTÍK, M. Drawing of Layout Documentation as the Basis of Logistics Management System of a Company - Literature Review, New Methodics, Case Study. In Proceedings of the 3rd International Conference on Advanced Logistics and Transport 2014. Hammamet, Tunisia, May 2014, pp. 356-361, ISBN 978-1-4799-4839-0.

[7] NEŠPORKOVÁ, R., SIDOR, J. Comparison of countries by the systems of health insurance. *Journal of Applied Economic Sciences*. 2015, Vol. 10, No. 2, pp. 301-310.

[8] KUTÁČ, J., JANOVSKÁ, K., SAMOLEJOVÁ, A., BESTA, P., VILAMOVÁ, Š., VOZŇÁKOVÁ, I. The impact of production capacity utilization on metallurgical companies financing. *Metalurgija*. 2013, Vol. 52, No. 1, pp. 135-137.

[9] DOHN K. The configurational apprach in supply chain management (scm) of steel goods. Metalurgija, April-Juny 2014, vol. 53, no. 2, pp. 265-268.

[10] BLASKO, M., TITTEL, V., RIDZON, M. CAE analysis of conformal cooling application-case study. Annals of the Faculty of Engineering Hunedoara, 2012, vol. 10, no. 3, pp. 115-118.