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# QUALITY QUANTIFICATION MODEL OF BASIC RAW MATERIALS

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Basic raw materials belong to the key input sources in the production of pig iron. The properties of basic raw materials can be evaluated using a variety of criteria. The essential ones include the physical and chemical properties. Current competitive pressures, however, force the producers of iron more and more often to include cost and logistic criteria into the decision-making process. In this area, however, they are facing a problem of how to convert a variety of vastly different parameters into one evaluation indicator in order to compare the available raw materials. This article deals with the analysis of a model created to evaluate the basic raw materials, which was designed as part of the research.

*Key words:* metallurgy, iron, raw materials, basic additives, costs

## INTRODUCTION

Blast-furnace charge consists of metalliferous materials, slag formers and fuel. Blast-furnace charge materials should be characterized by a balance of their properties, low share of fine-grained particles, narrow range of grain sizes and sufficient mechanical strength. The flux materials, which usually have basic character, represent an important input raw material. Their importance is even higher, because metallurgical enterprises in Central Europe mainly use acidic ore raw materials from Ukraine and Russia [1]. This is due to their prices, availability, but also low logistics costs (e.g. compared to ores from Australia and Brazil) [2].

Fluxes facilitate the formation of blast-furnace slag with optimal chemical composition and optimal technological properties. The final slag should have such a chemical composition and physical properties to be capable of desulphurization of iron as much as possible, to ensure a perfect reduction of iron and a high degree of manganese reduction and, last but not least, to have an adequate viscosity. This kind of slag then typically contains between 0,4 % - 0,9 % of FeO [3]. The most commonly used basic additives include compounds based on CaO and MgO. These are usually additives including dolomitic limestone or dolomite. These additives also significantly affect not only the technology of iron production, but especially the cost of the whole process and therefore the final price of metal [4].

The selection of a suitable supplier of materials can fundamentally affect the economic indicators of production. Dolomitic limestone was chosen for the evaluation of the quality of basic raw materials, since it belongs to materials frequently used in the Czech Republic [5, 6].

This article analyzes the developed evaluation model as prepared in the conditions of company Ostrava Mining, Inc., which is among the major suppliers of basic raw materials for Czech metallurgical companies. The created model uses mathematical tools to quantify all the relevant indicators.

## QUALITY EVALUATION OF BASIC RAW MATERIALS

A number of different criteria can be used to evaluate the basic raw material (dolomitic limestone).

The primary ones will always be the criteria having impact on the iron production process itself and its technology. In the last ten years in the production of pig iron, however, the importance of the parameters affecting the final price of the produced metal has been increasing significantly. This is due to high competitive pressure. The decision-making process more and more often takes into account parameters such as the price of raw materials, logistics services, payment terms or the possibility of operational contracts. The former classification of key parameters of basic raw materials has recently seen dramatic changes. In general, the relevant parameters of the evaluation of the basic raw materials can be classified into the following areas [7]:

- Chemical properties (content of free bases, the amount of impurities)
- Physical properties (moisture, lumpiness, strength)
- Logistic aspects, supplier (transport, amount of raw materials in stock)
- Price and payment aspects (price, maturity)

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In terms of the chemical properties, the content of free bases can be considered as dominant. From this perspective, the quality of basic additives can be quantified precisely by the amount of allocated free bases, which can be assessed by means of equation (1).

$$W = W_{CaO} + W_{MgO} - B\left(W_{SiO_2} + W_{Al_2O_3}\right) \qquad (1)$$

Where WCaO, WMgO, $WSiO_2$, $WAl_2O_3$ express the parts by weight of these oxides in fluxes in percentages of weight [8]. B is basicity, and basicity is also a key property of slag, which can be expressed in the form of relations (2), (3).

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

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

In this case, $B_1$ and $B_2$ are the values of slag basicity, and W is the weight fraction of the given component in slag. The alkalinity or basicity can therefore be essentially defined as the ratio of the basic and acidic components of oxides. From the physical properties, lumpiness (granulometry of the raw material) can be regarded as a significant aspect. Optimal lumpiness of fluxes for the blast-furnace process is 20 - 40 mm, and below 3 mm for the sintering process [9]. These parameters will naturally affect the technological side of the process. Apart from the chemical and physical parameters, the evaluation can also incorporate the aspects related to the supply conditions (logistics, price parameters) [9]. These features can significantly affect the cost of the entire process and therefore the final price of the produced metal. For the evaluation of a specific basic raw material, it is advisable to simultaneously evaluate all the monitored parameters. Each raw material poses a problem, because we can monitor only a series of isolated parameters [10]. The issue is how to make a complex evaluation of all the properties which are measured in completely different units (%, mm, t). A synthesis of all vastly different parameters is possible by means of mathematical methods of multi-criteria decision-making. These methods were also applied during the analysis of the basic raw materials quality.

## EXPERIMENTAL PART

The evaluation of the suppliers of basic raw materials can take advantage of a number of criteria. It is very beneficial to use a system based on multi-dimensional evaluation enabling to take into account more relevant properties in order to find a suitable option. A model for the evaluation of the basic raw materials was created within company Ostrava Mining, Inc. during the execution of the research project (2015). This model is based on the evaluation of the following areas: physical - chemical, logistics, cost (Table 1, 2).

Two evaluation criteria have been proposed for each of these areas, based on the conducted research. They can be summarized into the following points:

A. Physical - chemical

Criterion 1 – Basicity / %

Criterion 2 – Lumpiness / %

B. Logistics

Criterion 3 – Quantity offered within the scope of the consignment / t

Criterion 4 – Warehouse replenishment cycle / days

Table 1 **The criteria values of the compared basic raw materials**

| No. | Criteria | Dolomitic limestone suppliers | | |
|---|---|---|---|---|
| | | $S_1$ Czech Republic | $S_2$ Poland | $S_3$ Ukraine |
| $K_1$ | Basicity / % | 3,8 | 3,3 | 4,2 |
| $K_2$ | Lumpiness / % | 94 | 82 | 97 |
| $K_3$ | Consignment / t | 2 000 | 1 500 | 1 800 |
| $K_4$ | Replenishment / days | 30 | 90 | 90 |
| $K_5$ | Price / $ | 19,3 | 20,5 | 22,5 |
| $K_6$ | Maturity / days | 45 | 60 | 30 |

Table 2 **Analysis of the supplied basic raw material (dolomitic limestone)**

| No. | Criteria | $v_i$ | $x_i^*$ | $x_i^0$ | $d_{ij}$ of individual suppliers | | |
|---|---|---|---|---|---|---|---|
| | | | | | $S_1$ Czech republic | $S_2$ Poland | $S_3$ Ukraine |
| $K_1$ | Basicity / % | 0,200 | 4,2 | 3,3 | 0,039 | 0,200 | 0 |
| $K_2$ | Lumpiness / % | 0,200 | 97 | 82 | 0,008 | 0,200 | 0 |
| $K_3$ | Consignment / t | 0,150 | 2 000 | 1 500 | 0 | 0,150 | 0,024 |
| $K_4$ | Replenishment / days | 0,150 | 30 | 90 | 0 | 0,150 | 0,009 |
| $K_5$ | Price / $ | 0,200 | 19,3 | 22,5 | 0 | 0,028 | 0,200 |
| $K_6$ | Maturity / days | 0,100 | 60 | 30 | 0,025 | 0 | 0,100 |
| | | | | Σ | 0,072 | 0,728 | 0,333 |
| | | | | $D_j$ | 0,268 | 0,853 | 0,577 |
| | | | | Sequence | 1. | 3. | 2. |

C. Cost

Criterion 5 - Price / $ / t

Criterion 6 - Maturity / days

From the point of view of the nature of these criteria, it is obvious that the factors are considerably different. From this perspective, it is advisable to use the multi-criteria decision-making methods. If case of basicity, the evaluation will include the ratio of basic and acidic additives (%). In case of lumpiness, the monitored criterion is evaluated as a percentage quantity of the basic raw material, which corresponds to the desired size of 20 - 40 mm (1 - 2 mm if used in case of sinter). The logistics and cost parameters then meet the common standards. In case of the quantity provided within the consignment ($K_3$), this amount expresses the amount (tons) that the supplier is willing to provide to the metallurgical company. This stock is always available and is located in the metallurgical plant. The price of dolomitic limestone was determined as a weighted average of all the fractions offered by each supplier. Metallurgical enterprises use dolomitic limestone of grain size of 1 - 60 mm for various parts of the production process (sintering, blast furnace). The price presented in Table 1 represents the weighted average of all the used types of grain sizes. The evaluation of the quality of basic raw materials used raw materials and their suppliers ($S_1$ - $S_2$) from the following regions: Czech Republic, Poland, and Ukraine.

These are the most frequently used sources of metallurgical companies in the Czech Republic. In case of supplies of basic raw materials from Ukraine, they are often offered together with the imported iron ore. Concrete criteria values of the evaluated basic raw material (dolomitic limestone) are shown in Table 1.

The complex comparison of the individual basic raw materials was performed by means of a method determining the distance from an imaginary option. The method uses the principle of measurement of Euclidean distance in space. The evaluation is based on the quantification of a distance of the individual options from a fixed one. This represents such an alternative, in which the values of all the criteria are ideal. The evaluation of the individual suppliers of basic materials can be performed using equations (4, 5).

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

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

Where:

- $D_j$ distance from an imaginary option
- $v_i$ criterion weight (importance)
- $x_{ij}$ value of each criterion from the point of view of the individual options
- $x^0_i$ the worst value with respect to the i – th criterion
- $x^*_i$ the best value with respect to the i – th criterion.

It is necessary to define the importance (weight) of each monitored criterion. The weights of the individual criteria within the frame of the company have been determined by means of a qualified estimate based on long-term experience and the executed research. The relevant weight for each criterion is presented in Table 2 in column $v_i$. The acquired value of Euclidean distance is, in its essence, the sum of partial deviations of each criterion from the ideal value. The basic raw material, which will have the lowest value, is the best, based on the monitored criteria. A distance from an imaginary option ($D_j$), equation (4), has been determined for all raw materials. This value was used to perform the evaluation (Table 2) of the raw materials. Lower value of distance $D_j$ represents a better option. The individual basic raw materials (suppliers) have been compared using this method. Table 2 presents the determined distances from the imaginary (ideal) options in line $D_j$.

The final ranking has been determined using this value. The value of distance from an imaginary option can be used as a key parameter for determining the complex quality value of the basic raw material.

## RESULTS AND DISCUSSIONS

The evaluated basic raw materials were assessed from the point of view of six criteria, representing three areas (physical and chemical properties, logistics, cost). The applied mathematical methods were used to determine the following order (Table 2):

1. Supplier $S_1$ - Czech Republic (0,268)
2. Supplier $S_3$ - Ukraine (0,577)
3. Supplier $S_2$ - Poland (0,853)

The values in brackets represent the distances from an optimal (imaginary) option. The order determined on the basis of this model is interesting in terms of many aspects. The supplier of dolomitic limestone from Ukraine took the second place, although it had the best values in physical and chemical parameters. If the evaluation had been based solely on similar indicators, it would have been the best solution. The solutions would have been optimal only in terms of the physical and chemical properties. Current demands related to the manufacturing costs, however, require you to take into account additional parameters and criteria as well. The overall top-rated basic raw material was from a supplier in the Czech Republic ($S_1$). This was affected especially by the fact that it achieved the best value in the area of logistics criteria and price. The price conditions were also the reason why the supplier of dolomitic limestone from Ukraine took the second place. The worst evaluation (third place) was recorded in case of basic raw material from Poland ($S_2$). This raw material (supplier) had the best cost parameters of all the entities, but considerably worse physical and chemical and logistics parameters. This aspect clearly shows the benefits of the designed evaluation, which allows you to quantify a number of vastly different criteria. If the evaluation of the basic raw materials had been conducted using only one isolated criterion, it wouldn´t have been possible to find the optimal solution. A synthesis of all partial criteria enables us to provide a global view of the quality of the specified basic raw material. This evaluation system can also be easily transformed into a percentage result form. In this case, the determined distances from an imaginary option will be converted to percentages. The determined values of each basic raw material will be compared and evaluated again.

## CONCLUSINS

Metallurgical enterprises must more and more often use complex methods to analyze a series of demanding problems. The selection of blast-furnace raw materials and thus the basic additives must currently be executed on the basis of a number of relevant criteria. The chemical and physical properties can significantly affect the course of the sintering and blast-furnace processes. Logistics and price attributes affect the cost of the entire process and therefore the price of the metal produced. The actual logistics attributes may also affect the availability of raw materials and their storage in the company. If we evaluate the basic raw materials using only isolated criteria, it will be very difficult to find the best option. The applied evaluation model based on the use of mathematical methods allows us to transform all the criteria into a single indicator.

The final evaluation is then based on a comparison of this value for all monitored raw materials. The results obtained in this way may represent a significant contribution for the decision-making process. The evaluation will not be based solely on the technical parameters, but also on the criteria affecting the cost of the entire process, including the logistics aspects. In the long run, this concept can bring metallurgical organizations many competitive advantages.

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