NEW TECHNOLOGY, NEW REFRACTORIES. 
ENGINEERING-ECONOMIC ANALYSIS

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The heat resistance of refractories, expressed in hours, heats, etc., is determined by the performance characteristics of the refractory lining and the observance of operating conditions of a plant. Currently, the efficiency of using refractories is assessed in terms of production cost per ton of the end product. In determining the production cost of a refractory, it is necessary to take into account not only the net cost but also additional expenditures expressed in roubles (less frequently, in US dollars) per ton of product. Taking, as an example, the use of different refractory materials in the service of the outer lining of the branch inlet of a vacuum degasser, we carried out an engineering-economic analysis of the potential applicability of actual refractories to one or the other technology. Improving the actual technology of using refractory materials provides a way towards improving economical efficiency.

The continuing sophistication of metallurgical processes, the increasingly demanding operational conditions, and the wider use of advanced technologies for rapid production of high-grade metals make refractory materials one of the most important technical and economical priorities. Currently, the expenditure on refractory materials accounts for 10% of the production cost of steel ingots in Europe [1].

In Russia, many manufacturers employ off-furnace metal processing technologies using DH and RH-type vacuum degassers AKOS, VOD, VAD, and other units for treating metal in the ladle to produce high-grade steels with a minimum expenditure of energy. Simultaneously, the purchase of new, often expensive refractory materials for the lining of vacuum degassers and ladles operating under heavy-duty conditions (high temperatures, prolonged exposure to molten slag and metal, etc.) adds to the production cost of the end product. World manufacturers of refractories are expanding production of costly high-resistant materials versus less expensive refractory products. The overall tendency here is that while the production and consumption of refractories in absolute values decreases, the consumption of refractories in terms of cost increases [2].

The customer who uses advanced and costly refractories has an economic advantage owing to the longer service life of production units and economy on repair jobs (including replacement of the linings), and owing to the increased output, energy savings, manufacture of high-quality products in demand on the market, reduction of rejects, etc. With each consumer, the situation is different and requires individual analysis.

Refractories in use must guarantee definite operational stability, that is, failure-free service life under normal conditions of the unit’s performance. The resistance of a refractory, expressed in hours, number of heats, or other appropriate units depends on the quality of refractory lining and on the observance of optimum (standard) production technology. In turn, the optimum technology is determined not only by the quality of refractory used but also the operational characteristics of the lining and a range of other factors, such as the qualification of personnel, reliable operational control, observance of operating conditions, etc.

In general, the specific consumption rate of refractory materials $G$ (kg/ton steel) in the lining of a metallurgical plant (in whole or in part) can be expressed as the ratio of the total of refractories spent on the lining $\sum A$, kg, to the amount of steel $Q$, ton, produced with the use of this lining, with allowance for refractory materials used in repair jobs, etc.:

$$G = \sum \frac{A_i}{Q_i} = \frac{A_1}{Q_1} + \frac{A_2}{Q_2} + \frac{A_3}{Q_3} + \ldots + \frac{A_n}{Q_n},$$

where $A_1, A_2, A_3, \ldots$ are the quantities of refractories of grades of quality 1, 2, 3, ... in the lining; $Q_1, Q_2, Q_3, \ldots$ are...
the quantities of metal melted (processed, teemed) using refractories of grade 1, 2, 3.

On the other hand, the quantity of metal melted (processed, teemed) can be determined as

$$Q = qZ, \quad (2)$$

where $q$ is the mass of the heat (in tons), and $Z$ is the resistance of the lining (in heats).

At present, the refractory rate is considered not only in kilograms per ton of metal, although precisely this index is most commonly used for estimating the efficiency of performance of refractories in one sector of industry or another.

It has been reported that in the ferrous metallurgy of Japan, the refractory rate decreased from 11.5 (1990) to 9.5 kg/ton steel (1999) [3].

Regrettably, no reliable data on the refractory rate for metallurgy in Russia over the last 9 years could be found, despite the usefulness of this index for monitoring production dynamics. Over the world, the analysis in terms of $G$ is commonly carried out by most metallurgical enterprises, in part (for individual units) or in whole. Still, at present this criterion is of secondary importance.

Of primary importance is the index $P$ determined as the cost of refractories per ton of the finished product (for example, US dollars per ton, roubles per ton, etc.). In a similar manner, the cost analysis per ton of melted (processed, teemed) metal is carried out; however, these data are seldom available. For example, the metallurgical company Collac (France) reported a nearly twofold decrease in refractory cost per ton of metal is carried out; however, these data are seldom available. For example, the metallurgical company Collac (France) reported a nearly twofold decrease in refractory cost over a period from 1986 to 1994 [2]. The paper by Sennikov et al. [4] is one of the few domestic publications giving a comparison of production costs for refractories used in the lining of steel-teeming ladles (high-silica, periclase-spinel-carbon, and periclase-carbon components).

For most manufacturers, the $P$ index is expressed in roubles per ton of product, and for those who make wide use of imported refractories, it is expressed in US dollars per ton of product. In a similar manner, production costs are analyzed for individual units (blast furnace, electric furnace, converter, steel-teeming and intermediate ladles, etc.):

$$P = \sum P_j = P_1 + P_2 + \ldots + P_n, \quad (3)$$

where $P_j$ are refractory costs per ton of the finished product for the $j$th unit, for example: 1) electric furnace, 2) vacuum degasser, 3) steel-teeming ladle, etc.

In on-line analysis as an aid in making decisions on the applicability of one of the recommended refractories or another, knowledge of the refractory costs for an actual unit seems more useful, that is

$$P_1 = \frac{1}{10^3} \sum G_j C_j = \frac{1}{10^3} G_1 C_1 + \frac{1}{10^3} G_2 C_2 + \ldots + \frac{1}{10^3} G_n C_n, \quad (4)$$

where $G_1, G_2, \ldots$ are the refractory rates of grade 1, 2, ... for unit No. 1, kg/ton; $C_1, C_2$ is the cost of refractories of grade 1, 2, ... used in the lining of unit No. 1, roubles/ton.

Equation (4) can be rewritten in the following manner:

$$P = \sum \frac{A_j C_j}{Q_j} = \frac{A_1 C_1}{Q_1} + \frac{A_2 C_2}{Q_2} + \ldots + \frac{A_n C_n}{Q_n}, \quad (5)$$

where $Q_1, Q_2, \ldots$ is the quantity of metal melted (processed, teemed) using the corresponding refractories of grade 1, 2, ...; alternatively, the following equation can be used:

$$P_1 = \sum \frac{A_j C_j \alpha_j}{Q} = \frac{A_1 C_1 \alpha_1}{Q} + \frac{A_2 C_2 \alpha_2}{Q} + \ldots + \frac{A_n C_n \alpha_n}{Q}, \quad (6)$$

where $\alpha_j$ is a coefficient parametrizing the service life of a refractory of grade 1, 2, ...; as an example: if the resistance of the reinforcing layer of the lining of a steel ladle is four campaigns, and the resistance of the wall lining is one campaign, and those of the bottom and the slag belt — 1/2 campaign each, then $\alpha_1 = 0.25$, $\alpha_2 = 1$, and $\alpha_3 = 2$, respectively; $Q$ is the quantity of steel (for a steel-teeming ladle) poured out using a standard set of refractory components. For example, the resistance of the lining of a steel-teeming ladle is 80 heats (one campaign); the set of refractory components for the lining of a steel ladle is composed of one lining for the wall and two linings for the slag belt and the bottom; the resistance of the lining for the reinforcing layer is 320 heats, and so on. This approach can also be used in finding a supplier for refractory materials, when the costs analysis is performed based on guaranteed data of the supplier.

In a cost analysis of refractories not net costs alone, but additional costs, should be taken into consideration, also referred to one ton of molten metal. Other items should also be taken into account such as non-returnable tare, transportation charges, and, for imported refractories, custom duty and payment for the declared cargo. It stands to reason that the exchange rate should be taken into account.

Also, labor input and energy costs should not be overlooked. For example, the consumption of power for drying the periclase-carbon lining of a steel ladle is lower than for the castable lining, whereas for labor the exact opposite is true. Production losses associated with the period of use (service life) and repair jobs should also be taken into account.

Occasionally, the effective application of newly developed refractories may require special conditions. For example, replacement of the firebrick lining of intermediate ladles in the continuous casting technology by a new lining composed of a refractory castable and a gun mass has required the arrangement of a production sector equipped with a continuous concrete mixer and a concrete gun as well as facilities for drying the lining under controlled conditions.