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## Methodology for Calculating the Economic Feasibility of Innovative Development of Sponge Ferrotungsten Production in Domestic Metallurgy

*This study presents a comprehensive methodology for assessing the economic feasibility of implementing innovative production of sponge ferrotungsten (SFTG) in the domestic metallurgical industry using powder metallurgy methods. The proposed technology is aimed at fundamentally optimizing the consumption of scarce resources and energy by fully or partially replacing expensive reducing agents, such as silicon and aluminum powders, with dispersed carbon-containing industrial waste. This allows not only to reduce the cost of the product, but also to simplify the hardware design of the melting process.*

*The use of SFTG as an innovative alloying additive in the smelting of high-speed steel (using the example of the P6M5 grade) provides a qualitatively new level of alloying efficiency. Due to the high specific surface area and developed porosity of the "sponge", the time for dissolving tungsten in the melt is reduced, which minimizes the oxidation potential of the bath and reduces irreversible losses of other alloying elements. The paper details a mathematical model of economic calculation based on a cross-sectional analysis: from reducing material consumption at the oxide reduction stage to increasing the productivity of electric arc furnaces DSV-25.*

*Particular attention is paid to the thermodynamic criteria for tungsten absorption, which is 5-7 times higher than that of traditional fused ferrotungsten. The economic effect is confirmed by calculations using current London Metal Exchange (LME) quotes. The results of the study prove that the introduction of FVG production is a strategically important step for import substitution and increasing the competitiveness of domestic special steels on the world market in the context of the energy crisis.*

**Keywords:** sponge ferrotungsten (FVG); powder metallurgy; tungsten alloying; high-speed steel P6M5; resource-efficient metallurgy; reducing agents substitution; carbon-containing waste.

**Introduction.** Existing technologies of carbon and aluminothermic melting for obtaining metals based on molybdenum and tungsten are transformed into domestic methods of powder metallurgy and are receiving their further development [1-3]. The resulting products of the same purpose have qualitatively new, predetermined, technological properties, which confirm advanced scientific developments in domestic and foreign practice [2, 4, 5]. Technological parameters for obtaining sponge alloying materials and their quality characteristics are being improved [6]. Their high economic efficiency

for obtaining and using special steels in steelmaking has been confirmed [7, 8]. This indicates the need to develop this direction in the metallurgy of liquid and refractory alloying materials, which will undoubtedly affect the increase in the efficiency of steelmaking [9].

**Problem statement.** This work sets the task of deepening research in the direction of obtaining a new alloying material based on tungsten by powder metallurgy methods, and the specific tasks of this part of the work are to analyze, calculate and economically evaluate the production and use of sponge ferrotungsten for alloying

special steels.

**Results.** The developed technological regulations for the production of sponge ferrotungsten with predetermined consumer properties, its use as an alloying material revealed a number of factors that were not taken into account when assessing economic efficiency, both in production and in the field of use.

Among such factors that have been developed in the technical solution of resource and energy conservation and that affect its effectiveness, the following should be included:

— exclusion of the use of valuable silicon and aluminum powders as a reducing agent and their replacement with carbon-containing waste;

— elimination of the operation of dividing molten ingots into smaller pieces, etc., which reduces the cost of redistribution of liquid concentrates.

When using spongy tungsten as an alloying material, the time for dissolving tungsten in the melt is sharply reduced, which significantly reduces the selected tungsten and other alloying elements and deoxidizers and significantly increases the productivity of the main metallurgical units, which ultimately reduces the cost of smelting redistribution.

In the current work, an assessment of the end-to-end economic efficiency in obtaining spongy ferrotungsten and its use in smelting high-speed steel P6M5 in an electric arc furnace DSV-25 was performed.

The calculations take into account such factors as a decrease in the cost of obtaining a new material due to a decrease in energy costs for the technology of reducing tungsten concentrate, the use of relatively cheap and common reducing agents in the technology, a decrease in losses due to sublimation of compounds and an increase in the yield of the product. When using a new alloying material as an alloying additive in molten steel, such factors are taken into account as a decrease in the cost coefficients for the re-division of the melt for tungsten, chromium, molybdenum and vanadium due to a decrease in the oxidation potential of the steel melt, the specific consumption of technological energy with an increase in the speed of tungsten diffusion through the steel melt by 5-7 times compared to standard molten ferrotungsten, etc. Thus, this specific technical solution for the use of sponge ferrotungsten as an alloying material to determine its economic feasibility requires the use of not only general recommendations, but also taking into account the original comparison criteria. Such criteria include the calculation of balances for elements introduced and absorbed during steelmaking, and the comparison of the consumption of a given element by the charge with its content in the finished metal (a value inverse to the absorption coefficient).

In these conditions, the calculation using the above-mentioned coefficients is preferable for determining the balance of charge materials for smelting carried out using basic and new technologies. When performing calculations, the methodology described in [7] was used, with the specification of the corresponding coefficients.

According to the results of the implementation of production technologies and the use of sponge

ferrotungsten (FVG), it is recommended to use it instead of fused ferrotungsten of grades FV70, FV75, FV65, etc. According to GOST 17293-82 and tungsten concentrate according to GOST 213-73 of grades KIII, KSH, KMSHI ... KMSHZ.

The economic effect of using FVG is calculated according to the cost of oxide molybdenum (tungsten) concentrate (raw material for FVG production), according to LME (London Metal Exchange) data and the experience of marketing operations at domestic special steel plants. The cost ratio of the stratum KSHI is 1.07-1.09 kg per 1 kg in FEN. The cost price, redistribution of metallization in the production process of sponge ferrotungsten is taken per 1 kg of FRG with a content of 60 % W.

The profit from the production and sale of a new alloying material based on tungsten will be:

$$P = \sum_{i=1}^n (T_1 - C_1) \times Q_1, \quad (1)$$

where:  $T_1$  – the price of 1 kg of tungsten in standard and sponge ferrotungsten at the LME rate;

$C_1$  – full cost of production of sponge ferrotungsten in terms of the basic content of 100 % W;

$Q_1$  – production volume (per 1000 kg).

The generalized indicators of high-speed steel smelting using calcined tungsten concentrate (KSHI), standard fused ferrotungsten FV70 and sponge ferrotungsten (FVG) are taken using 66.3 g of FVG and consumption coefficients before and after the introduction of the new technology.

1. Savings due to reduced consumption of alloying elements per 1 ton of steel P6M5K5 when smelting in an arc furnace DSV-25 are calculated by the formula:

$$E_1 = (\eta_1 - \eta_2)/\beta_1 \cdot y_1 \cdot C_1 + (z_1 - z_2)/\beta_2 \cdot y_2 \cdot C_2 + (l_1 - l_2)/\beta_3 \cdot y_3 \cdot C_3 + (\xi_1 - \xi_2)/\beta_4 \cdot y_4 \cdot C_4 + (m_1 - m_2)/\beta_5 \cdot y_5 \cdot C_5, \quad (2)$$

where:  $\eta_1, z_1, l_1, \xi_1, m_1$  – consumption of chromium, molybdenum and vanadium per ton of liquid steel when smelting from KSHI, kg;

$\eta_2, z_2, l_2, \xi_2, m_2$  – consumption of chromium, molybdenum and vanadium per ton of liquid steel when smelting from FVG, kg;

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$  – share of chromium, molybdenum and vanadium, respectively, in ferroalloys;

$y_1, y_2, y_3, y_4, y_5$  – absorption of chromium, molybdenum, vanadium, tungsten and cobalt from ferroalloys;

$C_1, C_2, C_3, C_4, C_5$  – cost of ferrochrome, ferro-molybdenum, ferrovanadium, ferrotungsten and cobalt, respectively, dollars/kg of metal.

2. Costs of increasing the cost of FVG in relation to the Consumer Price Index (CPI):

$$C = Z_2 \cdot (C_2 - C_2'), \quad (3)$$

where:  $Z_2$  – tungsten consumption, kg/t;  $C_2$  – cost of FVG, \$/kg W;  $C_2'$  – cost of KISI, \$/kg W.

3. Costs of increasing the cost of FVG in relation to

ferrotungsten:

$$C_2 = (Z_2'' - Z_2')(C_2 - C_2'), \quad (4)$$

where:  $Z_2''$  – FVG costs, kg/t;  $Z_2'$  – costs of KMI, kg/t;  $C_2$ ,  $C_2'$  – cost of FVG and FV60, \$/kg W.

4. The total efficiency when using FVG in combination with KSI in F870 is:

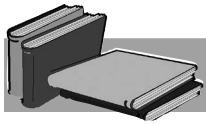
$$E_2 = E_1 - C_2 - C_1 \text{ dollars/t of steel.} \quad (5)$$

5. The economic effect of using 1 t of sponge ferrotungsten is:

$$E_3 = (E_2 \cdot 1000) - E_1. \quad (6)$$

## Conclusions

A technology for obtaining and using sponge ferrotungsten by powder metallurgy has been developed, which differs from traditional ferroalloys based on tungsten by metal thermal melting in flexibility and economy. The method is designed to use relatively cheap and common reducing agents and obtain a product with qualitatively new technological properties: the speed of tungsten absorption in molten steel is 5-7 times higher than from a standard analogue. This allows reducing the burnout of other elements from molten steel by 4-7 % (molybdenum, chromium, vanadium). The method for calculating the economic efficiency of using a new alloying material makes it possible to make a calculation at any time with the availability of data from the LME exchange. Sponge ferrotungsten as an alloying additive of tungsten in the smelting of high-speed steels in an arc furnace at the prices of the London Stock Exchange, confirm the high efficiency and prospects of expanding the scope of implementation.



## REFERENCES

- Ostryk, P. N., Gasik, M. M., & Pyrog, V. D. (1992). Metallurgiya gubchastykh i poroshkovykh ligatur [Metallurgy of Sponge and Powder Alloys]. Tekhnika [in Russian].
- Grigor'ev, S. M., Akimenko, V. B., Popov, A. N et al. (1983). Izvlechenie metallizirovannogo molibdenovogo kontsentrata iz briketirovanoy shikhty i yego regeneratsiya pri vuplavke stali [Obtaining molybdenum metallized concentrate from briquetted charge and its use in steel smelting]. *Steel*, (8), 79-81 [in Russian].
- Grigoriev, S. M., Ostryk, P. N., Popov, A. N. et al. (1982). A. S. 977510 USSR, MKI C22C 34/34. Avtorskoe svidetelstvo. Sposob polycheniya metallizirovanukh molibdenosoderzhashchikh i/ili volframsoederzhashchikh kontsentratoov [Copyright certificate. Method for obtaining metallized molybdenum and/or tungsten-containing concentrates]. (USSR) No. 3312571/22-02. Appl. 30.11.82. Bull. No. 49, p. 102 [in Russian].
- Grigoriev, S. M., Karpunina, M. S., Moskalenko, A. S. et al. (1999). Termodinamicheskii analiz i matematicheskoe modelirovanie tekhnologii proizvodstva gybchastogo volframa [Thermodynamic analysis and mathematical modeling in relation to the technology of obtaining sponge tungsten]. *Steel*, (11), 33-36 [in Russian].
- Grigoriev, S. M., Karpunina, M. S., Moskalenko, A. S. et al. (1999). Matematicheskaya model termodinamicheskogo ravnovesiya v sisteme W-O-C v svyazi s tekhnologiyey polucheniya gubchastogo volframa [Mathematical model of thermodynamic equilibrium in the W-O- C system in relation to the technology of obtaining sponge tungsten]. *Steel*, (12), 31-34 [in Russian].
- Grigoriev, S. M., & Grigoriev, D. S. (2002). Snizhenie sodержaniya primisey v metallizirovanom volframovom kontsentratoe [Reduction of impurities in metallized tungsten concentrate]. *Steel*, (10), 43-46 [in Russian].
- Pyven, A. N., & Grigoriev, S. M. (1992). Effektivnost ekonomii resursov pri ispolzovanii molibdenosoderzhashchikh materialov [Efficiency of resource saving when using molybdenum-containing materials]. *Non-ferrous metals*. Nell. 10-12 [in Russian].
- Grigoriev, S. M. (2005). Tekhniko-ekonomicheskie pokazateli razvitiya metallurgii gubchastykh i poroshkovykh splavov na primere metallizirovannogo molibdenovogo kontsentrata [Technical and economic indicators of the development of metallurgy of sponge and powder alloys using the example of metallized molybdenum concentrate]. *Ferrous metals*, (3), 26-29 [in Russian].
- Grigoriev, S. M. (1988). Ekonomicheskaya strategiya i taktika resurso- i energoberezhniya v metallurgii ognepurnukh materialov [Economic strategy and tactics of resource and energy saving in metallurgy of refractory materials]. *Sb. "Metallurgiya"*, (1), 17-23 [in Russian].

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## Методологія розрахунку економічної доцільності інноваційного розвитку виробництва губчастого ферровольфраму у вітчизняній металургії

У цьому дослідженні представлено комплексну методологію оцінки економічної доцільності впровадження інноваційного виробництва губчастого ферровольфраму (ГФВ) у вітчизняній металургійній промисловості з використанням методів порошкової металургії. Запропонована технологія спрямована на принципову оптимізацію споживання дефіцитних ресурсів та енергії шляхом повної або часткової заміни дорогих відновників, таких як порошки кремнію та алюмінію, диспергованими вуглецевмісними промисловими відходами. Це дозволяє не тільки знизити собівартість продукції, але й спростити апаратне проектування процесу плавлення.

Використання ГФВ як інноваційної легуючої добавки при виплавці швидкорізальної сталі (на прикладі марки Р6М5) забезпечує якісно новий рівень ефективності легування. Завдяки високій питомій поверхні та розвиненій пористості «губки» скорочується час розчинення вольфраму в розплаві, що мінімізує окислювальний потенціал ванни та зменшує незворотні втрати інших легуючих елементів. У статті детально описано математичну модель економічного розрахунку на основі перехресного аналізу: від зменшення матеріаломісткості на стадії відновлення оксидів до підвищення продуктивності електродугових печей ДСВ-25.

Особлива увага приділяється термодинамічним критеріям поглинання вольфраму, яке в 5–7 разів вище, ніж у традиційного плавленого ферровольфраму. Економічний ефект підтверджено розрахунками з використанням поточних котирувань Лондонської біржі металів (LME). Результати дослідження доводять, що впровадження виробництва FVG є стратегічно важливим кроком для імпортозаміщення та підвищення конкурентоспроможності вітчизняних спеціальних сталей на світовому ринку в умовах енергетичної кризи.

## Ключові слова

Губчастий ферровольфрам (FVG); порошкова металургія; легування вольфраму; швидкорізальна сталь Р6М5; ресурсоефективна металургія; заміна відновників; відходи, що містять вуглець.