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# Main indicators of energy intensity of copper production

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**ABSTRACT**: The main indicators of the energy intensity of the production of blister copper by aggregate, consisting of melting and converter-anodic redistribution, as part of a reflective furnace, oxygen-torch melting, a furnace for a liquid bath for the production of matte and converters for the production of blister copper are considered. Based on theoretical and practical results, the main energy leaving sources are taken into account: natural gas, electric energy, technical oxygen, compressed air, taking into account the degree of loading of the aggregates with raw materials, which significantly affects the indicators of energy consumption rates. Taking into account the main indicators of energy carriers, the structure of technological standards has been compiled and on this basis the generalized energy intensity of copper production has been determined.

**KEYWORDS**: energy intensity, energy carriers, blister copper, reflective furnace, oxygen-torch melting, liquid bath furnace, converter redistribution, technological norm, generalized energy intensity.

## I.INTRODUCTION

In the modern world, one of the main indicators of production is its specific energy intensity, which largely determines the cost and competitiveness of products. This applies to industries such as metallurgy, in particular in the production of copper. In this case, the energy intensity of the production of copper produced by various enterprises may be different. The high level of energy consumption is largely due to the low energy efficiency in technology, the load factor of technological equipment units, the use of obsolete and physically obsolete equipment. A number of publications are devoted to this issue: [1-3, 9-17] and our research in the field of energy efficiency of copper production: [4-8].

In [1-2, 18-19, 24] a comparative analysis of the energy efficiency of the production of copper products of the Ural Mining and Metallurgical Company was made in detail. The conformity of Russian industrial complexes with international standards of energy efficiency of production is shown. The article [3, 11-12, 21, 24] notes that all over the world, high-quality ore resources are rapidly reduced, which leads to an increase in energy consumption for the extraction of poor ore and its enrichment. According to [9-10, 21] are provided for obtaining one ton of copper 835 kg fuel equivalent (not including mining and processing costs). In another case, the energy intensity of one ton of copper, according to various estimates, is 2.8 - 6.5 tons of fuel equivalent. In [22-25] great attention is paid to reducing the energy intensity of technological processes and improving the energy efficiency of production. At the same time, for the implementation of energy saving, tactical and strategic paths are distinguished. The strategic approach includes the reconstruction of production, the introduction of new energy-saving technological processes. Based on the literature data, a characteristic of the technology for producing blister copper has been compiled. Copper ores extracted from quarries undergo mechanical enrichment by separating valuable materials from the waste material [4-8].

Comparison of the actual specific consumption of fuel and energy resources (FER) with regulatory and component analysis of standards for all technological stages of production allows us to estimate the energy efficiency of production and determine the source of overspending, as well as to develop effective measures to eliminate it.

ISSN: 2350-0328
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## II. RESEARCH PROBLEM AND METHOD

The development of scientifically based standards is quite time-consuming, skilled and hard work, requiring special methodological approaches, taking into account all aspects of copper production. The main methods of developing standards for fuel consumption, heat and electricity are the computational, analytical, experimental, and their combination. The experimental-instrumental (experimental) method of developing individual norms consists in determining the unit costs of fuel, thermal and electrical energy according to the data obtained as a result of tests (experiments). Each enterprise has its own technology for the production of copper and it is not possible to provide a uniform method for determining energy intensity.
This article discusses the indicators of energy intensity of the production of blister copper based on which anodic and granulated copper is produced, according to the existing technological scheme presented in Figure 1.

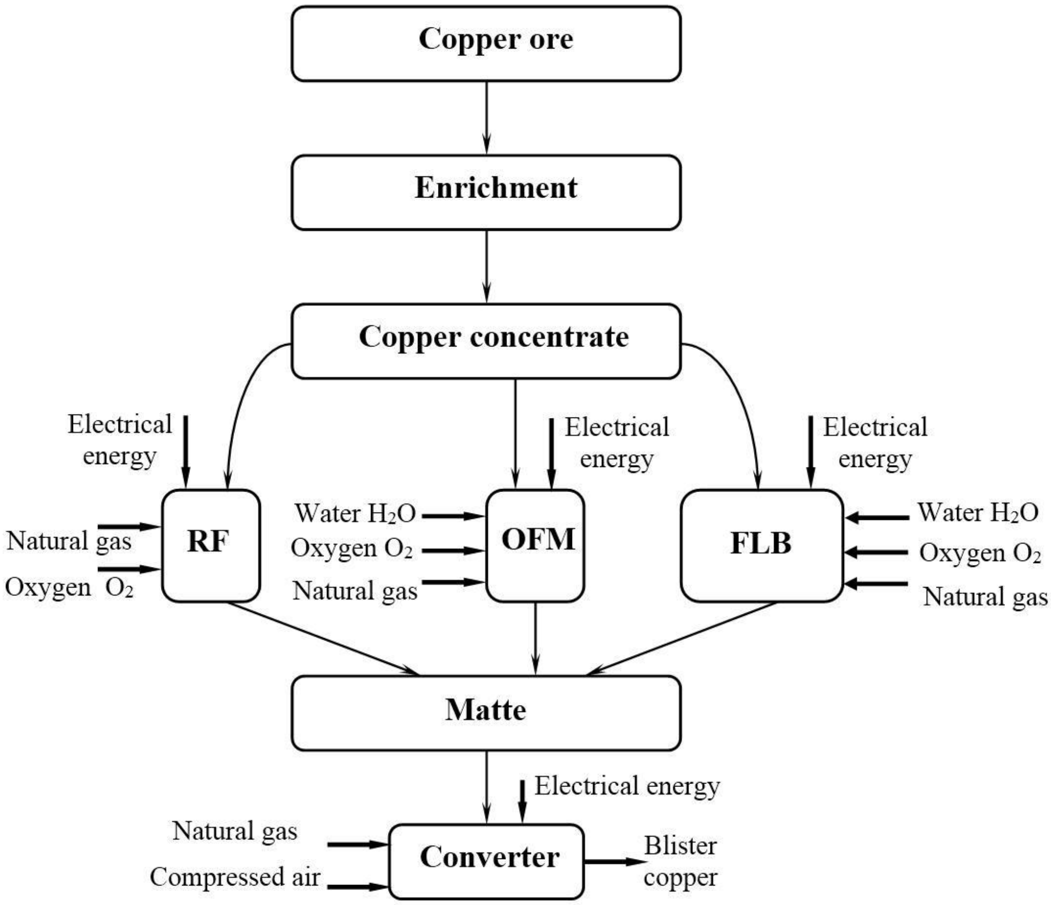


**Fig. 1. Structure of energy consumption by aggregates and feedstock**

## III. ENERGY CONSUMPTION IN THE PRODUCTION SYSTEM BLISTER COPPER

The main producer of blister copper is a copper smelter, which includes a smelting division and an anodic conversion zone. The melting stage includes a reflective furnace (RF), a furnace for oxygen-flare melting (OFM) and a furnace in a liquid bath (FLB). The converter-anodic redistribution includes: a converter, anode furnaces and a copper granulation furnace. We have taken into account the main components of energy carriers necessary for the full cycle of the technological process to assess the energy intensity of the production of each redistribution based on theoretical and practical results.

In the typical structure of the norms of energy consumption for the production of blister copper for technological needs, the consumption of electrical energy is given, for example, for drying concentrates, casting machines, and other

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Vol. 6, Issue 3, March 2019

mechanisms. At the same time, in order to assess the energy intensity of the production of each redistribution, it is necessary to take into account all the components of energy carriers necessary for the full cycle of the technological process. For example, process oxygen, compressed air, natural gas, and process water are used in large volumes for the production of blister copper. In some cases, from the main components of energy carriers, technological oxygen and air are referred to plant-wide standards, although it is noted that their consumption should be distributed in proportion to the technological process. With this approach, in some cases, indicators of energy intensity of production are distorted. So the specific consumption of electricity for the production of rough copper is indicated without taking into account the consumption of electricity for the production of process oxygen, air, process water and other energy sources and also very significantly, the volume of raw materials entering the unit.

Based on the theoretical and practical results, when developing the energy intensity indicators of each technological redistribution, it is necessary to identify and keep records of the impact on the energy intensity indicators of changes in individual elements of the technological process, the volume of incoming raw materials and their quality. At the same time, in order to assess the volume of energy intensity of each unit, all indicators of energy carriers should be reduced to a single system, that is, to a ton of oil equivalent (TOE).

The main components of the consumption of energy for the operation of the process of each unit in the general case, according to the regulations are determined in the function [6].

$$G = \varphi(V, W, O_2, Z) \tag{1}$$

where the accepted notation: $W$ – electric power consumption, kWh; $O_2$ – technical oxygen consumption, m$^3$; $V$ – natural gas consumption, m$^3$; $Z$ – compressed air consumption, m$^3$.

For the normal functioning of the technological process of a reflective furnace according to Figure 1, the main energy sources are natural gas, oxygen and electrical energy, i.e.

$$G_{RF} = \varphi(V, O_2, W) \tag{2}$$

where $G_{RF}$ – the total value of energy carriers for RF.

The energy intensity for processing 1 ton of charge for the reflection furnace $G_{RF}$ is

$$G_{RF} = \frac{\sum(V + O_2 + W)}{Q} \tag{3}$$

For the normal functioning of the process of oxygen-flare smelting according to Figure 1, the main energy sources are natural gas, oxygen and electrical energy, that is

$$G_{OFM} = \varphi(W, O_2, V) \tag{4}$$

where $G_{OFM}$ – the total value of energy carriers for OFM.

Electrical energy is mainly consumed by fans, smoke exhausters, feed pumps, feed pumps for waste heat boilers.
Energy intensity for processing 1 ton of charge for OFM is

$$G_{OFM} = \frac{\sum(W + O_2 + V)}{Q} \tag{5}$$

For the normal functioning of the technological process of the furnace in a liquid bath according to Figure 1, the following energy sources are necessary, i.e.

$$G_{FLB} = \varphi(O_2, W, V) \tag{6}$$

where $G_{FLB}$ – the total value of energy carriers for FLB.

The energy intensity for processing 1 ton of the charge for FLB is

$$G_{FLB} = \frac{\sum(O_2 + W + V)}{Q} \tag{7}$$

For the normal functioning of the technological process of the converter redistribution (CR) according to Figure 1, the following energy sources are necessary, i.e.

ISSN: 2350-0328
# International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 3, March 2019

$$G_{KП} = \varphi(Z, W, V) \tag{8}$$

where $G_{CR}$ – the total value of energy carriers for CR.

The energy intensity for the processing of 1 ton of matte by the converter redistribution is determined

$$G_{CR} = \frac{\sum(Z + W + V)}{Q} \tag{9}$$

Electricity is spent on circulating pumps of waste heat boilers, smoke exhausters and electrostatic precipitators.
In this case, gas, technical oxygen, compressed air and electrical energy are energy carriers for all furnaces and converter processing, but their consumption as a percentage of each of them is different. One of the main energy sources involved in the process in the production of blister copper is technical oxygen and compressed air. The units of the melting plant consume technical oxygen: a reflective furnace (RF), a furnace for oxygen-flare melting (OFM) and a furnace in a liquid bath (FLB). Compressed air is used in the converter redistribution (CR).

As a percentage, the consumption of the total volume of technical oxygen by aggregates is given in Table 1 [6].

Table 1.

| The volume of consumption of technical oxygen in% | RF | OFM | FLB |
|---|---|---|---|
| | 14.7 | 28.5 | 56.8 |

The equipment for the production of technical oxygen and compressed air consists of compressors.
The entire volume of oxygen produced is distributed among the aggregates RF, OFM, and FLB:

$$\sum Q_{oxy} = Q_{RF} + Q_{OFM} + Q_{FLB} \tag{10}$$

where $\Sigma Q_{oxy}$ – total oxygen produced; $Q_{RF}$ – oxygen consumption by the aggregate RF; $Q_{OFM}$ – oxygen consumption by the aggregate OFM; $Q_{FLB}$ – oxygen consumption by the aggregate FLB.

We accept the consumption of electrical energy in proportion to the production of oxygen and therefore the consumption of electrical energy in aggregates RF, OFM and FLB is

$$\sum W_{oxy} = W_{RF} + W_{OFM} + W_{FLB} \tag{11}$$

In this case, the energy intensity of oxygen production is defined as

$$N_{KИС} = \frac{\sum W_{oxy}}{\sum Q_{oxy}} = \frac{W_{RF} + W_{OFM} + W_{FLB}}{Q_{RF} + Q_{OFM} + Q_{FLB}}, \ [\text{kWh / thousand m}^3] \tag{12}$$

In the diagram in Figure 2 shows the total consumption of electrical energy per aggregates in percent.

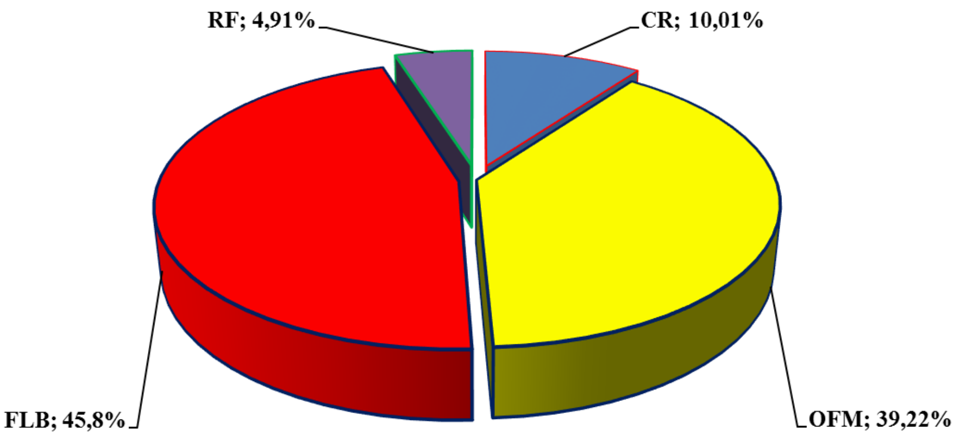


**Fig.2. Total consumption of electrical energy per unit in percent**

ISSN: 2350-0328
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Vol. 6, Issue 3, March 2019

The diagram in Figure 3 shows the total consumption of natural gas by aggregate as a percentage.

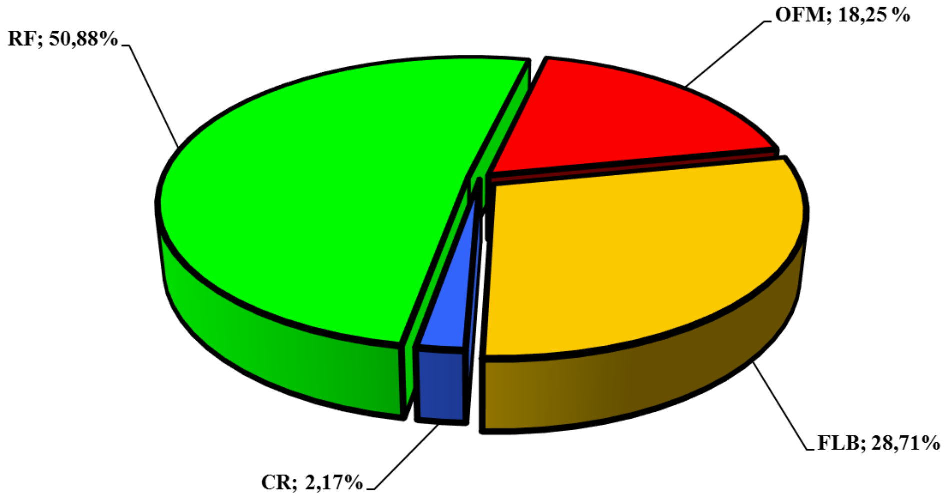


**Fig. 3. Total consumption of natural gas by percentage**

The diagram in figure 4 shows the total consumption of technical oxygen by aggregate as a percentage.

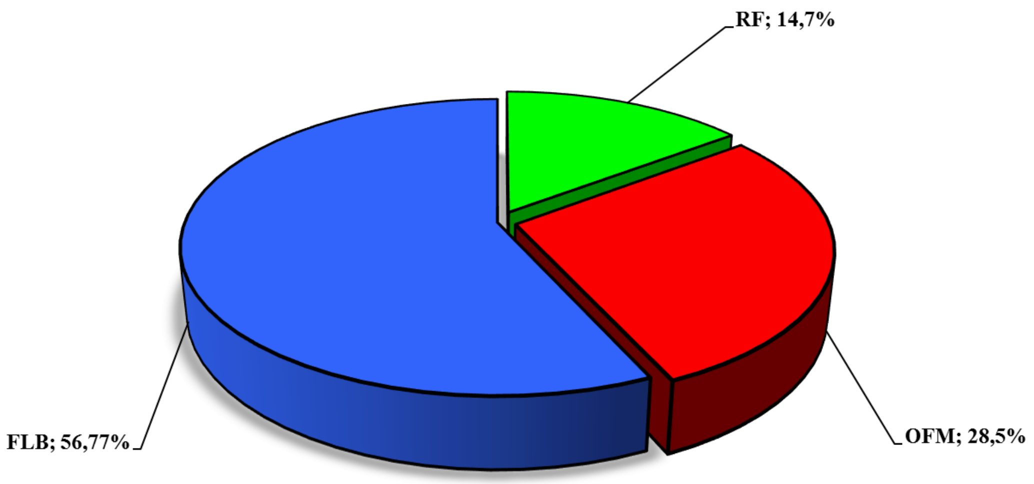


**Fig.4. Total consumption of technical oxygen by aggregates in percent**

The entire volume of compressed air is used only for converter processing.

## IV. RESULTS

Analysis of energy consumption by aggregate is [5]:
for a reflective furnace, the largest volume of energy consumption is natural gas - 83.7%, then oxygen is 15.22% and electricity is 1%;
for oxygen-flare melting - natural gas 44.06% oxygen 43.27%, and consumption of electric energy 12.65%;
for the furnace of the liquid bath - oxygen 50.61%, natural gas 40.69% and electrical energy 8.7%;
for the converter unit - air 57.71%, natural gas 26.13%, electrical energy 16.15%.

ISSN: 2350-0328
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Vol. 6, Issue 3, March 2019

To determine the dependence of the influence of the volume of loading with raw materials for each unit, the indicators of changes in the specific norms of electrical energy consumption 100% of the load ranging from 80-100%; 65% of loading ranging from 50-80%.

The composition of the norms of energy consumption for the production of blister copper is a list of its consumption items considered in the norms. The structure of the technological norms of energy consumption for the production of blister copper is shown in Table 2.

Table 2.

| The name of the item energy consumption | Consumption of energy carriers, TOE | Production volume, ton | The norm of consumption of energy carriers, TOE / ton |
|---|---|---|---|
| Smelting of the charge – reflective furnace:<br>Natural gas;<br>Oxygen;<br>Electrical energy. | $G_{RF}$:<br>$G-1$<br>$G-1{,}1$<br>$G-1{,}2$<br>$G-1{,}3$ | $Q_1$ | $N_1=\frac{\sum G_1}{\alpha_1 Q_1}$ |
| Smelting of the charge – oxygen-flare furnace:<br>Natural gas;<br>Oxygen;<br>Electrical energy. | $G_{OFM}$<br>$G-2$<br>$G-2{,}1$<br>$G-2{,}2$<br>$G-2{,}3$ | $Q_2$ | $N_2=\frac{\sum G_2}{\alpha_2 Q_2}$ |
| Smelting of the charge – furnace liquid bath:<br>Oxygen;<br>Natural gas;<br>Electrical energy. | $G_{FLB}$<br>$G-3$<br>$G-3{,}1$<br>$G-3{,}2$<br>$G-3{,}3$ | $Q_3$ | $N_3=\frac{\sum G_3}{\alpha_3 Q_3}$ |
| Converting the matte –converter redistribution:<br>Air;<br>Natural gas;<br>Electrical energy. | $G_{CR}$<br>$G-4$<br>$G-4{,}1$<br>$G-4{,}2$<br>$G-4{,}3$ | $Q_4$ | $N_4=\frac{\sum G_4}{\alpha_4 Q_4}$ |

where $G$–$1$; $G$–$2$; $G$–$3$; $G$–$4$ – total volume of energy carriers, respectively to the RF, OFM, FLB and CR;
$Q_1$, $Q_2$, $Q_3$ – the volume of production of matte, respectively to the RF, OFM and FLB;
$Q_4$ – volume production of blister copper by CR;
$\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$ – the coefficient of loading with raw materials, respectively for RF, OFM, FLB and CR;
$N_1$, $N_2$, $N_3$, $N_4$ – energy intensity (norm) of energy resources consumption per unit of production.

The energy intensity of each (norm) of production (excluding the preparation of the charge for smelting) is determined accordingly,
For a reflective furnace:

$$N_1=\frac{\sum G_1(G_{1-1}+G_{1-2}+G_{1-3})}{\alpha_1 Q_1} \qquad (13)$$

For oxygen – flare melt:

$$N_2=\frac{\sum G_2(G_{2-1}+G_{2-2}+G_{2-3})}{\alpha_2 Q_2} \qquad (14)$$

For the furnace in a liquid bath:

$$N_3=\frac{\sum G_3(G_{3-1}+G_{3-2}+G_{3-3})}{\alpha_3 Q_3} \qquad (15)$$

For converter redistribution:

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Vol. 6, Issue 3, March 2019

$$N_4 = \frac{\sum G_4 (G_{4-1} + G_{4-2} + G_{4-3})}{\alpha_4 Q_4} \quad (16)$$

The overall technological rate for the production of blister copper will be

$$N_{copper} = \sum (N_1 + N_2 + N_3 + N_4) \quad (17)$$

## V. CONCLUSION

The generalized energy intensity of the production of blister copper, consisting of a melting stage and a converter-anodic redistribution, was determined, consisting of a reflective furnace, an oxygen-flare melt, a furnace for a liquid bath for the production of matte and a converter for the production of blister copper which allows us to evaluate the energy efficiency of production and determine the source of overspending, as well as to develop effective measures to eliminate it.

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International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 6, Issue 3, March 2019

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