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THE LATEST TECHNOLOGY TRENDS FOR SLAG PROCESSING IN STEEL INDUSTRY

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НОВІ НАПРЯМКИ РОЗВИТКУ ТЕХНОЛОГІЙ ПЕРЕРОБКИ ШЛАКІВ В МЕТАЛУРГІЇ

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НОВЫЕ НАПРАВЛЕНИЯ РАЗВИТИЯ ТЕХНОЛОГИЙ ПЕРЕРАБОТКИ ШЛАКОВ В МЕТАЛЛУРГИИ

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Annotation. Accumulation of metallurgical slag caused a number of heavy environmental problems, which led to a significant withdrawal of valuable land from use. The objective of this work was to identify the main directions for the development of new technological processes for the complete and waste-free processing and recycling of melted slags, gravel slags, dump slags and to outline the main directions for the research. To this end, works of the Ukrainian and foreign scientists in the field of metallurgical slag processing were analyzed, and the conclusion was made about the environmental and economic efficiency of metallurgical slag processing. The modern principle is formulated for the metallurgical industry, according to which slag should not be considered as waste. On the contrary, slag, like metal, should be considered as one more product of the blast furnace. This principle requires to develop a set of new technological approaches for the melted slag and solid (granular) slag processing into the cheap and valuable materials for industry. This approach will significantly reduce cost of the iron output. The thematic focus of research and technological developments for solving the designated modern principle in metallurgy are determined. For solving the problem of reducing negative impact of metallurgical enterprises on the environment and increasing profitability of their production, the following issues were researched and solved:

1. Determination of the heat content of fire-liquid slag (the melts). Calculation of generating capacity of the equipment, which uses the utilized heat of the melted slags. The calculations were carried out for the conditions of the Ilyich Iron And Steel Plant, Mariupol. Temperature of the melted slag discharged from the blast furnace of the plant is 1400-1450ºC.

2. Usage of dump waste for producing binder materials and micro-fillers for additives into the high-strength concrete. The technological scheme for processing and technological line for obtaining Portland cement clinker are presented.

Implementation of these developments allows to reduce energy consumption at the enterprise, to use slag for obtaining valuable raw materials, and to solve the environmental problem.

Keywords: recycling, metallurgical slug processing, clinker, melted slug, environmental protection.

Introduction. It is well known that our global world, developing in an anthropogenic direction, has achieved significant success in various industries due to the use of the results of scientific and technical research, discoveries, and technological developments.

But the technogenic direction of the development of mankind has a negative side: the harmful effects on the environment of industrial waste, which mainly characterizes industrialized countries, whose economy is based on the extraction and processing of natural resources and their wasteful use.

One of the significant technogenic (man-made) environmental pollutants are metallurgical enterprises: emissions of sulfur-containing and carbon dioxide gases into the atmosphere, pollution of large areas with industrial waste – slag, which also pollute water sources.

Among metallurgical slag, blast furnace slag prevail, which is a by-product and a waste product of pig iron production in blast furnaces. The increase in pig iron production causes an inevitable increase in the production of blast furnace slag, in comparison with 45-60% of the pig iron production. Blast furnace slag accounts for more than 70% of the total amount of slag obtained in the metallurgical industry.

The accumulation of metallurgical slag in recent years (for example there are more than 2 billion tons of slag dumps in Ukraine) has caused a number of complex environmental problems, which led to a significant withdrawal of valuable land from use and increased damage to the state economy.

All these facts dramatically increase the urgency of the problem of the complete processing of metallurgical slag, the rational use of the obtained products and the transition to waste-free technological schemes for metallurgical production

In the last century, the practice of metallurgical slag using was based mainly on the classical studies of Langen, Michaelis, Passov, Grun, Guttman and others. The begining of the 21st century, can be characterized as a stage of intensive scientific research, experimental and design studies, the results of which represent a solid theoretical basis for the development of modern technological processes for the processing of slag melts, granulated slag and dump slag slag and practical use of products of their processing.

The processing and use of slag of one of the most voluminous wastes of metallurgical production ranges from 50 to 100%.

In the developed countries with the metallurgical industry, all blast furnace slag and a significant portion of steelmaking slag are processed. The developed countries of the world take the problem of secondary resources recycling extremely seriously; European states, members of the European Union, as well as the USA and Japan are especially concerned.

For example, in Germany the laws were passed according to which metallurgical slags from the waste category were transferred to the category of by-products of production. In many developed countries, special institutions and organizations have been created that deal with the use of metallurgical slag in construction, sometimes on the basis of metallurgical plants: the National Slag Association in the USA, the Technical Association for the Study and Use of Blast Furnace Slags in France, the National Slag Association in Canada, the British Slag Association in England. The organization of slag processing in different countries is not the same, due to the specific conditions of each country.

In England and Germany, slag products are obtained directly at metallurgical plants; in other countries, slag in liquid state or partially processed (granulated) is transferred to companies or special firms for the production of building materials. The US National Slag Association has created an entire slag processing industry.

Currently, in the UK, the Building Research Establishment has proposed a system for assessing the environmental properties of building materials, according to which these properties are evaluated in points: the higher the score, the lower the environmental properties of the evaluated material. According to the proposed system, the environmental properties of ground blast furnace slag are rated at 0.47, Portland cement - at a score of 4.6, i.e. the use of slag is about 10 times more environmentally friendly than Portland cement. Annually in the UK more than 2 million tons of ground blast furnace slags are used to replace Portland cement in concrete. At the same time, carbon dioxide emissions are reduced by almost 2 million tons, which is equivalent to the total emissions of 500 thousand cars per year. Electricity consumption is reduced by 2,000 GW per year. The annual saving of natural raw materials for concrete preparation is 2.5 million tons. A potential reduction in burial volumes is 2 million tons per year. All this experience of the developed industrial countries of the world testifies to the positive results of the processing of metallurgical slag, both in environmental and economic aspects.

The objective of this work is to identify the main directions for the development of new technological processes for the complete and waste-free processing and recycling of slag melts, gravel slags, dump slags and outline the main directions for research.

Methods. The classification of wastes of a significant technogenic environmental pollutant, metallurgical industry is shown schematically in Fig. 1.

The main waste products are primary and secondary slags. The share of blast furnace (primary) slag accounts for more than 70% of the amount of slag obtained in the metallurgical industry. It is well known that in order to eliminate or significantly reduce the harmful effects on the environment, it is necessary to develop and implement advanced technological processes that ensure the use of low-waste and non-waste technologies that exclude any type of waste by using them as secondary raw materials.

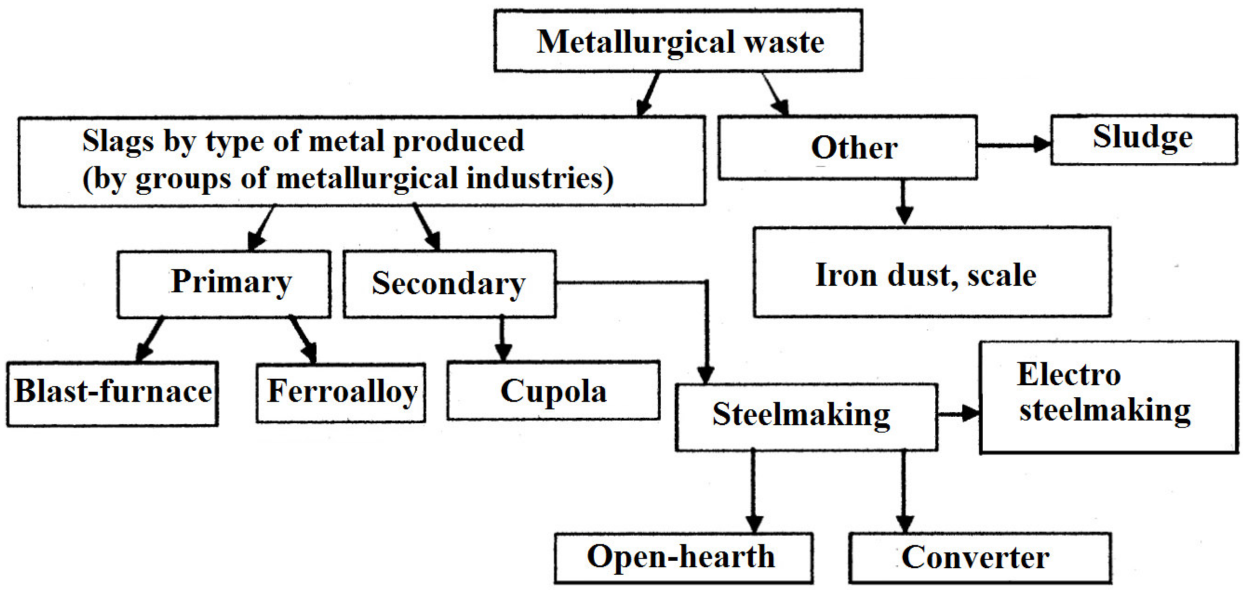

Figure 1 – Classification of metallurgical waste

To solve the task of developing and implementing new technologies for the complete processing and use of metallurgical slag, it is necessary to fully perform the modern principle in metallurgy: a blast furnace should be considered as a complex unit for the production of two main types of products - cast iron and slag. With this approach, when slag is considered as one of the main or secondary types of product, it is necessary to solve a set of measures for the processing of slag melts in a blast furnace to produce high-quality and valuable materials that will significantly reduce the cost of the current output of pig iron. As well as the inclusion in the processing of granulated slag and dump slag to obtain, for example cheap binders which will positively affect the profitability of production.

The need to consider slag as one of the main types of blast furnace production is justified by the fact that metallurgical slag is not only is inferior in physical and mechanical properties, but also in some cases surpass the natural materials replaced by them. Since slag is formed from waste rock of iron ore materials, fluxes, ash, fuel, as well as metal oxidation products and impurities, the total content of calcium, iron and silicon oxides in the slag reaches 75%. This determines the broad prospects for the use of metallurgical slag.

Previously, the task was to organize the processing of slag to a certain level. Currently, taking into account modern requirements for environmental protection on a global scale, the task is to develop technological processes for the complete processing of waste, as well as the elimination of harmful emissions into the atmosphere. This was became possible thanks to comprehensive studies of the properties of liquid and solid slag, the processes of hydrodynamic interaction of slag melt with water and air, the porosity and crystallization of slag, the study of the characteristics of sulfur dioxide emissions from slag and their neutralization.

To solve the problems, the following directions (research and development) were worked out.

1. Determination of the heat content of fire-liquid slag (melts). Calculation of the energy capacity of a plant using the utilized heat of slag melts.

2. The development of a technological scheme for processing dump slag and a technological line for the production of PC clinker.

Under the first item on the heat content in slag melts, the total amount of heat contained in the fire-liquid slag discharged from the blast furnace and the amount of heat that can be utilized by wet granulation of slag were calculated. The calculation of the capacity of a power plant operating on utilized heat, which is an important element of the technological process of processing slag melts, is performed.

The calculations were carried out for the conditions of the metallurgical plant named after Ilyich, Mariupol. The temperature of the slag melt discharged from the blast furnace of the plant is 1400-1450ºC. Calculation of the heat content of the slag melt going to granulation was carried out for a temperature of 1400 ° C, which is optimal for producing granulated slag with high hydraulic activity.

When calculating the amount of heat that can be utilized during granulation, it must be taken into account that only part of the heat of slag melts is directly used in granulation. Due to rapid cooling, the slag hardens in a glassy state, the latent heat of crystallization about 300-400 kJ per kg is not released and is realized in the form of chemical energy, giving the slag a valuable quality - hydraulic activity. The rest of the heat (70-80% of the total) with the existing granulation methods is spent mainly on the evaporation of water and is irretrievably lost.

The annual production of pig iron at the plant according to production capacities is 5.5 million tons. The output of slag per 1 ton of pig iron is 0.42 tons. On an annualized basis, slag production is 0.42 · 5.5 million tons = 2.31 million tons. The heat content in the fire-liquid slag is 350 kcal per 1 kg.

The amount of heat contained in 1 kg of liquid slag at t = 1400ºC is determined by the formula:

$$Q = m \cdot c \cdot \Delta t,$$

where c = 0.288 kcal / (g · deg) – specific heat of slag melt at t = 1400 ºC; m = 2.31 million tons – annual production of blast furnace slag at the Ilyich metallurgical plant; Δt = 1400 – 20 = 1380 ºC – temperature difference between the slag melt and the environment.

The total amount of heat contained in the blast furnace slag of annual production will be $253 \cdot 10^9$ kcal per year.

The amount of heat in 1 kg of slag melt with a temperature of 1400ºC will be:

$$Q = 1 \cdot 0.288 \cdot 1380 = 397.44 \text{ kcal} = 397.44 \cdot 4.184 = 1662.89 \text{ kJ},$$

where 1 kJ = 0.239 kcal or 1 kcal = 1 / 0.239 = 4.184 kJ.

Since granulation takes 300 to 400 kJ per kg to crystallize slag, the heat of 1 kg of slag melt that can be disposed of will be 1662.89 – 400 = 1262.89 kJ.

The total amount of heat, with an annual slag production of 2.31 million tons, possible for utilization will be $Q = 1262.89 \cdot 2.31 \cdot 10^9 = 2917 \cdot 10^9$ kJ.

We determine the power of the power plant in kW. The amount of kW·h due to the utilization of heat of slag melts per year:

$$N = 2917 \cdot 10^9 / 3600 = 810 \cdot 10^6 \text{ kW·h / year},$$

where 3600 = 1 kW·h.

The theoretical capacity of the power plant will be:

$$Nm = 810 \cdot 10^6 / 8760 = 92465 \text{ kW}.$$

If we take the efficiency of steam power plant η = 0.6, then

$$N = Nm \cdot \eta = 94265 \cdot 0{,}6 = 55480 \text{ kW}.$$

Such power is not utilized but is carried away into the atmosphere in the form of combined-cycle emissions.

As follows from the calculation, when using the heat of slag melt (minus heat losses due to crystallization of granulated slag) in a "slag-steam" boiler with efficiency equal to 60%, from each kilogram of slag melt, 300 kcal can be obtained. With one ton of slag solution, you can get the same amount of heat as from a steam boiler with efficiency 0.8 heated 70 kg steam coal. Which in terms of the year: 70 ·

$2.31 \cdot 10^6$ = 161700 tons of coal per year.

This direction of development of heat use during granulation of slag melts by water is promising in economic and environmental aspects.

The second item is dump slag and technology for their processing.

In the study of dump metallurgical slag, the task was set of obtaining a binder material and micro-aggregates for additives in the production of high-strength concrete.

The solution to the problem is presented in the diagram (Fig. 2).

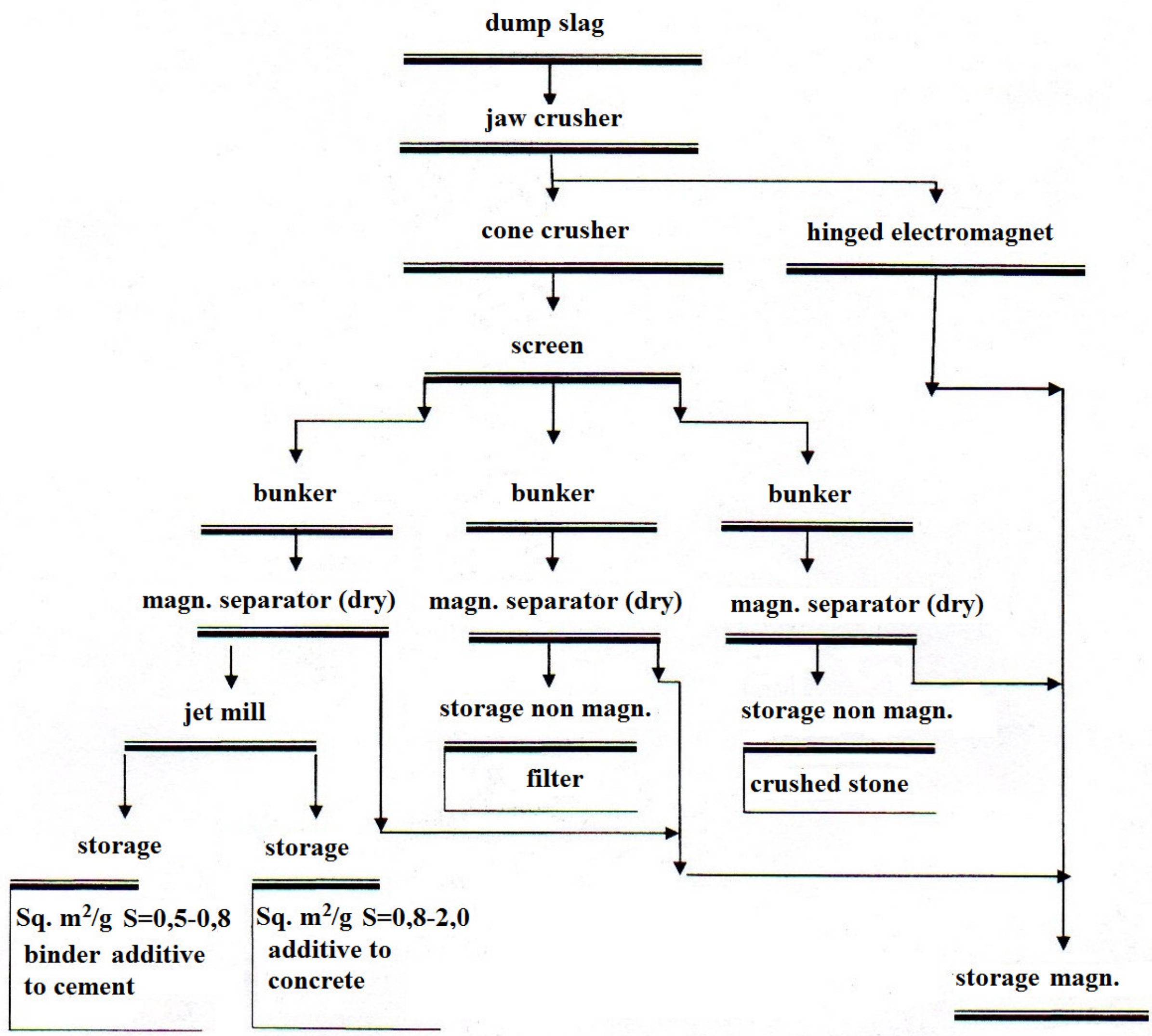

Figure 2 – The technological scheme of processing dump metallurgical slag

In the technological chain of slag processing, grinding of a non-magnetic fraction of 0-3 mm was made in a crusher with a screen. Then we get two fractions. The first is in a cyclone with a specific grain surface of 0.5-0.8 m^2/g. The second in the filter is with a specific grain surface of 0.8-2.0 m^2/g. The fraction of 0.5-0.8 m^2/g is used as a binder, and the fraction of 0.8-2.0 m^2/g is used as micro-aggregates in concrete, which increase the strength of concrete, as well as resistance to abrasion, chlorine and sulfate aggression, in addition reduces water permeability, which makes concrete able to carry heavy loads and withstand the effects of adverse environmental conditions.

A description of the method of processing dump metallurgical slag is presented in the source [2].

In addition, the following experiments were carried out. By firing at different temperature conditions of a two-component raw material mixture consisting of dump blast furnace slag and limestone tailings (sinter industry waste - fraction 10 mm) taken in a 2 : 3 ratio respectively, clinker samples were obtained. Chemical analysis of the samples showed that their composition corresponded to the chemical composition of standard clinker (see Table 1).

Table 1 - Chemical compositions of clinker

№	Clinker type		CaO	SiO_2	Al_2O_3	Fe_2O_3	Other
1	Estimated		64.74	22.32	4.15	0.68	6.47
2	Experimental	A	64.0	27.0	4.0	0.66	4.34
3		B	65.6	26.3	5.2	0.41	2.49
4		C	67.0	26.6	4.0	0.72	1.69
5	Standard		63-67	21-24	4-7	2-4	-

Laboratory tests showed high strength indicators of all samples of an experimental clinker (Table 2).

Table 2 - The results of strength tests of samples from the experimental clinker

№	Sample name	Specific surface, m^2/g	Water-cement ratio	Strength after 28 days, kg/cm^2
1	Clinker A	0.58	0.4	500
2	Clinker B	0.58	0.4	572
3	Clinker C	0.58	0.4	651

The high strength characteristics of all samples of the experimental clinker, crushed before placing the clinker samples into the FRITSCH mill, can be explained by a high degree of dispersity ($S = 0.58\ m^2/g$). This increased the reactivity of the experimental clinker. The difference in strength characteristics of samples can be explained by different temperature regimes of firing the raw clinker mixture. The Clinker B, which showed the highest strength (651 kg/cm^2, see Table 2) after heating to t = 1650 ºC, unlike samples A and B, was exposed at this temperature for 20 minutes.

This contributed to a more complete occurrence of mineral formation reactions, which is completely correlated with chemical analyses of samples of experimental clinker (Table 2). In clinker B, the highest content of the main mineral-forming oxide

CaO is 67% (Table 1), which mainly determines the strength of the clinker. This is published in the source [3].

The positive results of the experiments served as the basis for the development of a technological line for producing clinker (cement) from metallurgical waste. It provides the production of PC clinker with a high hydraulic module *m* = 2.37 (for a standard PC clinker *m* = 1.7 - 2.4) from a two-component raw material mixture: 40% dump slag and 60% limestone tailings. The general scheme of the technological line is shown in Fig. 3.

The developed way for the production of clinker cement from metallurgical production waste has a significant environmental and economic effect and it is advisable for using.

In conclusion, it should be noted that the civilization of any state is determined by its attitude to the problem of rational and safe handling of production waste, secondary material and energy resources, preservation of the environment and public health. We can say that recycling is not only an important component of the sustainable development of the state's economy but also a sign of its civilization.

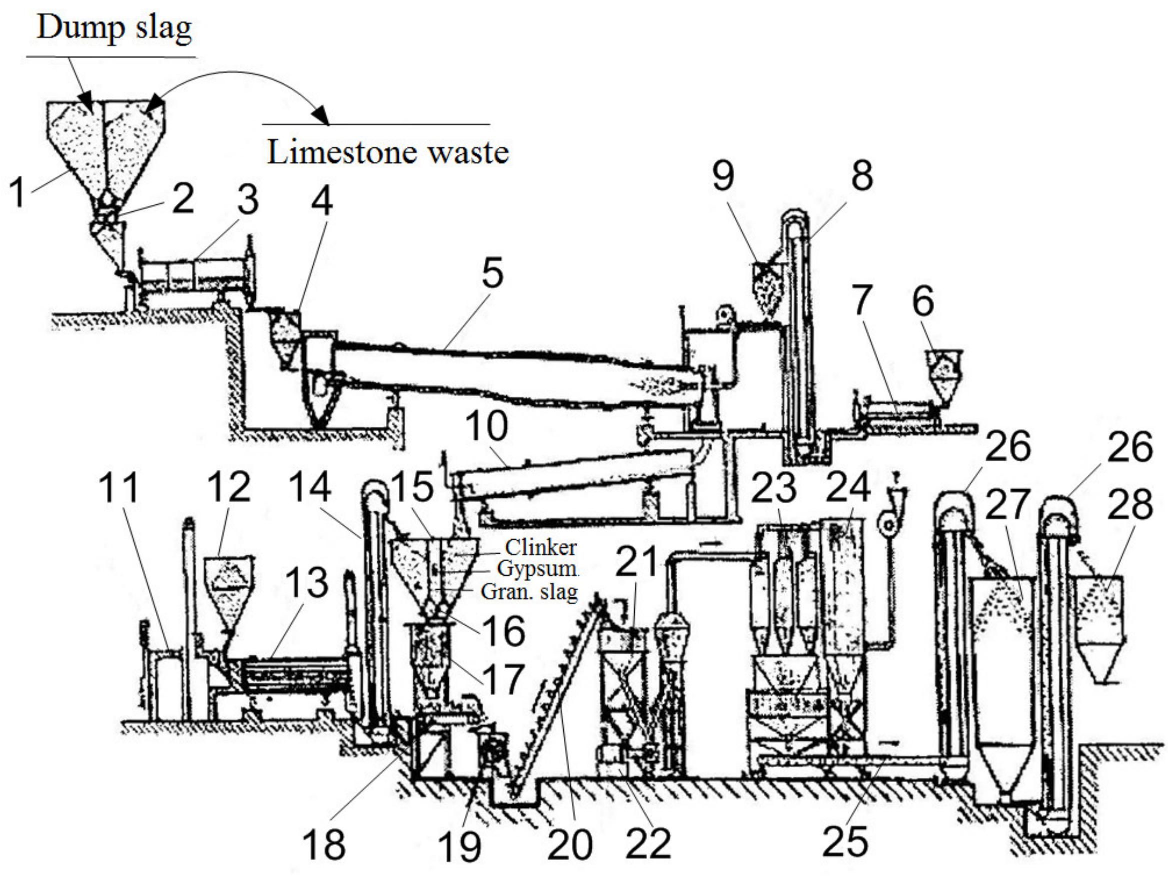

Figure 3 – Clinker (cement) production line

At the clinker production site, the following are installed: 1 - hopper for the initial components; 2 - dispenser; 3 - mill for raw materials; 4 - filling hopper; 5 - rotary kiln; 6 - bunker of fine coal; 7 - mill for coal grinding ; 8 - elevator; 9 - a hopper for crushed coal; 10 - cooler.

On the cement grinding site are located: 11 - coal furnace for heat generation for granulated slag drying; 12 - granulated slag hopper; 13 - a drying drum; 14 - elevator; 15 - receiving hopper; 16 - dispenser of cement components; 17 - storage hopper; 18 - tape feeder; 19 - crusher; 20 - bucket elevator; 21 - mill fine grinding; 22 - compressor; 23 - a cyclone; 24 - bag filter; 25 - screw feeder; 26 - elevator; 27 - cement hopper (storage); 28 - cement loading hopper.

Results and discussion. To change the attitude towards production wastes, it is necessary to give the status of environmental activity objects to a wide range of resource-useful materials and their maximum involvement in market and economic relations with the deregulation of such relations by the state, i.e. to stimulate economic activity in the field of handling secondary material resources and by-products of production.

It is necessary not only to prescribe at the legislative level but also to popularize such definitions as by-products from the production and processing of ferrous and non-ferrous metals and their alloys, secondary material and energy resources.

Based on the modern principle in metallurgy, by-products (recyclables) may include materials that are an integral component of production processes. Slag should be considered as a by-product of metallurgical cycles, together with waste slag representing valuable secondary raw materials. An integrated approach is required involving the best foreign and domestic technologies for their processing.

In the EU and the USA, the level of waste and SMR (secondary material resources) utilization is 65-80%. Moreover, about 20% of all aluminium, 33% of iron, up to 50% of lead and zinc, 44% of copper and other useful components are obtained from them. The processing and use of SMR in these countries indicate that this is a profitable segment of resource use, which is 5-15 times cheaper than the development of natural deposits. Enterprises and entrepreneurs in this area have preferences from the state in the form of tax breaks, soft loans, and tariffs. Active commercial activities in this area contribute to the growth of employment.

Significant success in the rational use of resources and the conservation of natural resources have been achieved by states that profess the principles of a social market economy and modern metallurgy principles. These are, first of all, the Scandinavian countries, Canada, Germany. The economic models adopted in them create the best opportunity for the development of civil society, which, in turn, acts as a generator of environmental and economic transformations, stimulates the state to pursue a resource-saving policy, and creates an atmosphere of "greening" of public consciousness. We believe that the set of technological solutions for the processing of metallurgical slag presented in this article will also contribute to this.

Currently, work is underway to expand and supplement with new technologies of a comprehensive scheme for the processing of metallurgical slag according to the intended thematic focus of research and technological development.

Conclusions

1. The analysis of the status of metallurgical slag processing indicates the environmental and economic effectiveness of such technologies.

2. The modern principle in metallurgy, designated by the authors is: slag as pig iron should be considered as the main product of blast furnace production. This

requires the development of a set of technological processes for processing melt and solid (granular and dump) slag, providing valuable materials that will significantly reduce the cost of metal.

3. The solution to the problem of integrated slag processing is possible through the organization of slag associations or companies (firms) working with metallurgical enterprises.

4. To implement the modern principle in metallurgy, it is necessary to develop and adopt at the level of legislative state acts the scientific and technical programs on environmental and resource conservation and the use of secondary material as well as energy resources as alternative sources of natural raw materials and energy.

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Анотація. Накопичення металургійних шлаків викликало ряд складних екологічних проблем, призвело до значного вилучення цінних земель. Метою роботи є визначення основних напрямків для дослідження і розробки нових технологічних процесів щодо повної та безвідходної переробки та рециклінгу шлакових розплавів, граншлаків, відвальних шлаків. Проаналізовано дослідження українських і зарубіжних вчених в області переробки металургійних шлаків. Зроблено висновок щодо еколого-економічної ефективності переробки металургійних шлаків. Позначено сучасний принцип в металургії, згідно з яким шлаки повинні розглядатися не як відходи. Аналогічно металу шлак слід розглядати як ще один продукт доменного виробництва. Такий підхід вимагає розробки комплексу нових технологічних процесів з переробки шлакового розплаву і твердого (гранульованого) шлаку, що забезпечують отримання цінних матеріалів для промисловості. Це також значно знизить вартість випуску заліза. Для вирішення завдання зниження негативного впливу металургійних підприємств на навколишнє середовище і підвищення рентабельності виробництва проведені дослідження і розробки за наступними пунктами.

1. Визначення тепловмісту вогнянорідких шлаків (розплавів). Розрахунок енергетичної потужності установки, що використовує утилізоване тепло шлакових розплавів. Розрахунки проводилися для умов металургійного комбінату імені Ілліча, м Маріуполь. Температура шлакового розплаву, що випускається з доменної печі комбінату, становить 1400-1450 С.

2. Використання відвальних шлаків для одержання в'яжучого матеріалу та мікрозаповнювачів для добавок в високоміцний бетон. Представлено технологічну схему переробки та технологічну лінію отримання портландцементу клінкеру.

Впровадження даних розробок дозволяє знизити енерговитрати на підприємстві, використовувати шлак для отримання цінної сировини, вирішити екологічну проблему.

Ключові слова: переробка металургійних шлаків, клінкер, розплав, захист навколишнього середовища.

Аннотация. Накопление металлургических шлаков вызвало ряд сложных экологических проблем, привело к значительному изъятию ценных земель. Целью работы является определение основных направлений для исследования и разработки новых технологических процессов по полной и безотходной переработке и рециклинга шлаковых расплавов, граншлаков, отвальных шлаков. Проанализированы исследования украинских и зарубежных ученых в области переработки металлургических шлаков. Сделан вывод об эколого-экономической эффективности переработки металлургических шлаков. Обозначен современный принцип в металлургии, согласно которому шлаки должны рассматриваться не как отходы. Аналогично металлу, шлак следует рассматривать как еще один продукт доменного производства. Такой подход требует разработки комплекса новых технологических процессов по переработке шлакового расплава и твердого (гранулированного) шлака, обеспечивающих получение ценных материалов для промышленности. Это также значительно снизит стоимость выпуска железа. Для решения задачи снижения негативного влияния металлургических предприятий на окружающую среду и повышения рентабельности производства проведены исследования и разработки по следующим пунктам.

1. Определение теплосодержания огненножидких шлаков (расплавов). Расчет энергетической мощности установки, использующей утилизированное тепло шлаковых расплавов. Расчеты проводились для условий металлургического комбината имени Ильича, г. Мариуполь. Температура шлакового расплава, выпускаемого из доменной печи комбината, составляет 1400-1450 С.

2. Использование отвальных шлаков для получения вяжущего материала и микрозаполнителей для добавок в высокопрочный бетон. Представлена технологическая схема переработки и технологическая линия получения портландцемента клинкера.

Внедрение этих разработок позволяет снизить энергопотребление на предприятии, использовать шлак для получения ценного сырья и решить многие экологические проблемы.

Ключевые слова: переработка металлургического шлака, клинкер, расплавы, охрана окружающей среды.

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