

Article

Development of Technology of Release of Iron and Its Oxidic Connections from Dump Steel-Smelting Slag

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Abstract: In article questions of development low-waste technologies of processing of steel-smelting slag are considered, gland allowing by extraction and its connections from steel-smelting slag to receive additional raw materials for production became, and the remains to use in building industry. Studying of gravitational methods of enrichment of steel-smelting slag and heat treatment the ore-fuel of pellets is the basis for work. Proceeding from it, in work modern physic-mechanical, chemical and physical and chemical methods of researches (UV-spectroscopy, electronic microscopy, the granulometric analysis) are used.

Keywords: slag; metallurgical dust; rolling scale; tails of dressing-works; iron; magnetite; fusion mixture, melting; arc steel-smelting furnace; production efficiency

1. Introduction

The main problem of modern steel-smelting production in the world is complex processing of slag, utilization of valuable components and increase in complexity of use of raw materials. Over time the given problem will increase since every possible exhaustion of the rich and easily opened ore fields, increase in requirements to environmental protection, growth of needs for ferrous metals is observed. Production of ferrous metals is followed by formation of slag and other types of technogenic waste. Their quantity, in connection with rapid growth of smelting of cast iron and steel, continuously increases and now is hundreds of millions tons. It is easy to present what huge areas can be busy with slag dumps. And it when the deficiency of the fertile land plots occupied by the industrial enterprises sharply increases and becomes aggravated situation with protection of natural resources. But it is only one sides of the problem, the second consists in potential opportunities of use of slag in the national economy.

Complex processing of steel-smelting slag as the main way of engineering-ecological development of society, were offered in the mid-sixties the past century, generally by scientists from the CIS countries. On the basis of their application it was supposed not only it is most useful to use the consumed raw material resources, but also to try to process completely formed waste.

The 21st century is century of high technologies. Further scientific and technical progress, reaching world level on quality and ensuring high rates of industrial production force to operate intensively natural resources among which more than 70% fall to the share of mineral raw materials.

For the last 25 years from subsoil of Earth of mineral raw materials it is extracted about the same as for all last 100 years. In connection with general drop of maintenance of useful components in mineral raw materials, maintenance of the reached level of industrial production demands the increasing volume of the processed raw materials. At current situation doubling of physical volume of extraction of mineral raw materials happens each 30 years, and fossil fuel - each 15 years.

In the CIS the reserves of slag which are saved up for years of work of the metallurgical enterprises exceed 500 million tons. They occupy the huge spaces and are sources of pollution of water and air basins. Problem of processing of dump slag and extraction from them metal component with complex use of production wastes is one of relevant tasks. This problem has several aspects. First, metal, extracted from slag, as a rule, is cheaper than the metal received in result of processing of ore. Secondly, waste of processing of slag can use for various purposes and, thirdly, processing of slag dumps will allow to free the territory.

There is no uniform direction in processing and use of slag abroad that is explained by specifics of work of the metallurgical enterprises of the each country.

Processing of steel-smelting slag abroad does not differ variety. Their consumption increases every year. Raises degree of their processing in Japan, Germany, the Czech Republic and other countries.

So, slag exhaust in ladles or holes at furnaces, at some plants liquid slag transport by trucks.

In the martin furnace of the Spermous Poynt plant (USA) slag on the course of melting is downloaded through average charging window in pit. After cooling it is taken out by rail. At melting release slag is merged through sock of steel casting ladle in slag bowl. The filled ladles take out on the slag yard.

For crushing simplification slag is merged in holes layer-by-layer. On the some plants apply thermo - crushing of slag, processing them water jets or in pools. The method of fast cooling and crushing by mixing of hot slag with the cooled-down slag crushed stone is developed [1].

When choosing effective ways of processing of slag seek for possibly fuller extraction of metal, increase in degree of purity of metal-products and their wider use. A metal-product, comprising 60 - 85% of iron, use in steel-smelting production, 50 — 60% of iron — in domain furnace charge and 30 - 50% of iron - in an agglomerative charge. The mineral component of slag is also used in metallurgical production as a iron-flux and also processed in breakstone, applied in concrete, a road and railway construction.

The growing demand for construction materials, especially at deficiency of some of them, led to successful developments and practical application of steel-smelting slag in construction and in other countries. For example, in Great Britain for these purposes slag overwork at the plants "British Steel", "Tarmak Roadstoun" in Tisport.

Use of mix of domain and steel-smelting slag as railway ballast, for the road bases, in the bitumen and asphalt coverings is widespread in the USA. Long researches of curing of concrete in Germany showed that additives to domain slag in steel-smelting production noticeably increase durability of a slag-concrete.

In Germany, Great Britain, France, Japan a considerable part the steel-smelting slag is crushed in the flour used as agriculture fertilizer. An indispensable condition of use of slag in a rural farm — minimum content of metal in them.

Therefore at the plant of Tib of Kawasaki to Seyteets (Japan) process all converter slag into ballast materials and agricultural fertilizers.

At the plant of Xing Nippon to Seyteets where the most part of steel-smelting slag is processed, granulation of converter slag was experienced. Slag from a ladle is merged on the drum rotating with a speed of 200 - 300 rpm. Slag breaks into the granules with a diameter about 2 mm which are flying away in the container with flowing water. Granulate is exposed to magnetic separation; iron-content particles come to furnace charge of metallurgical furnaces; easy granules can be applied as warm and sound-proof material and to a getting fertilizers. Small capital investments and operational costs provide high profitability of this way.

Besides processing of metallurgical slag of the current exit, in the USA, Great Britain, Germany, the Czech Republic and other countries a considerable part of slag and the metals accompanying them is extracted from slag dumps.

One of shops of Hekkert Endzhiniring for processing of marten slag from dumps is put into operation at the United Steel Corporation plant in Geneva (USA). For loading of slag and its delivery to the shop on dumps the excavator six cranes on tracks to the course, five dump trucks work with a

ladle with a capacity of 3.4 m³. Slag from the reception bunker arrives on vibrator. The top product fineness more than 305 mm is split up by one of crane equipped with an electromagnet with a diameter of 1650 mm which lifts and dumps the monkey weighing 11.8 t. Metal is collected by an electromagnet, cleaned and sorted. Slag comes to the jaw-crusher and then to the conical crushers working in the closed cycle with four crash. Metal is selected by ten magnetic separators. Crushed stone is applied as ballast for the rail ways or filler in asphalt concrete.

From the analysis fortunes of processing of slag abroad can be made conclusion that processing of steel-smelting slag quickly increases and they are used as a reverse product in metallurgy, road construction and agriculture.

2. Research of processes of release of iron and its oxidic connection by method of gravitational enrichment

For effective application of gravitational methods for division of components of steel-smelting slag, it is necessary to have preliminary data on the chemical composition, physical and physic-mechanical properties of the processed slag. Also, at gravitational enrichment such indicators as density, fractional and particle size distribution of the minerals which are a part of slag [2] are of great importance. Taking into account it we will consider in more detail influence of these parameters on indicators of gravitational enrichment.

Density of minerals – the relation of mass of grain in m monolith to its volume W:

$$\delta = \frac{m}{W'} \tag{1}$$

where δ – density of mineral, kg/m³;
m – mass of grain, kg;
W' – the volume of grain, m³.
Fineness of separate grain is designated by its linear size.

For simplification of calculations exclude influence of a form of particles and then use the concept "equivalent diameter", i.e. diameter of spherical de grain which volume is equal to the volume of grain of irregular shape:

$$W = \frac{\pi d_s^3}{6} \tag{2}$$

$$d_s^3 = \sqrt[3]{\frac{6W}{\pi}} = \sqrt[3]{\frac{6m}{\pi\delta}} = 1,24\sqrt[3]{\frac{m}{\delta}} \tag{3}$$

The form of grains depends by nature minerals. The form of grains is characterized by the form coefficient representing the relation of a surface of an equal sphere (equivalent diameter of grain) to the surface of grain of irregular shape (the size of grain of irregular shape):

$$\varphi = \frac{S_s}{S} = \frac{4,87W^{2/3}}{S} \tag{4}$$

where φ – form coefficient;
S_s is a sphere surface;
S – surface of grain of irregular shape.
Values of coefficient of a form of particles φ are given below:
spherical..... 1.0
rounded, rounded..... 0.8-0.9
angular..... 0.6-0.7
lamellar..... 0.6-0.7

2.1. Fractional analysis of steel-smelting slag

Division of components of steel-smelting slag into fractions of various density for definition of characteristics of their concentrating was the purpose of carrying out the fractional analysis.

Subject to the fractional analysis various classes of a size. As dividing environments are used: water solution of mineral salts, organic liquids, suspensions.

The analysis of minerals banding by fineness up to 1 mm in static conditions of division with application the middle of capacities with environments of various density, and fineness less than 1 mm - in dynamic conditions of division with use of centrifuges.

For stratification of tests of ores, and in our case - steel-smelting slag - it is possible to use heavy liquids and suspensions with a density of 2400, 2700, 3000, 3300, 3500, 3700, 4000, 4200 kg/m³.

No more than 10 kg consistently immerse test in portions in the prepared liquids or suspensions by means of a reticular tank, removing every time and separating a mesh scoop easy fractions, floating on a surface. The number of fractions form n 1 where n — amount of liquids or suspensions. The received fractions wash with water, dry up, weigh, subject to cutting then direct to a chemical analyze.

On the basis of data on weight and quality of fractions tables are formed, and then curve enrichments are under construction.

The fractional analysis of three tests of steel-smelting slag of JSC “Uzbeksteel” (Uzbekistan) was in vitro made. The chemical composition of tests is given in tab. 1.

Table 1. Chemical composition of steel-smelting slag.

# tests	Connections, %									
	Fe	FeO	Fe ₂ O ₃	CaO	SiO ₂	Al ₂ O ₃	MnO	MgO	P ₂ O ₅	Other
Test of #1	3,7	2,0	15,2	25,6	21,6	5,8	5,3	13,8	1,7	5,3
Test of #2	4,1	2,3	14,7	24,3	23,0	5,2	5,4	13,9	1,2	5,9
Test of #3	3,6	1,7	14,5	25,7	22,5	5,7	5,5	13,4	1,3	6,1
Average structure	3,8	2,0	14,8	25,2	22,4	5,6	5,4	13,7	1,4	5,8

Results of the fractional analysis showed that density of the components which are a part of slag fluctuates from 2.5 to 5.2 g/cm³. Depending on density of components they can be divided into the following fractions: heavy, average and easy fractions.

To heavy fraction components of slag with a density more than 4.0 g/cm³, belong to average fraction from 2.7 to 4.0 g/cm³ and to easy - with a density less than 2.7 g/cm³.

The fractional analysis of slag of JSC “Uzbeksteel” (Uzbekistan) showed the following distribution of components on fractions:

- heavy fraction MnO-4.7-5.0 of g/cm³, FeO Fe₂O₃ - 5.0-5.2 g/cm³;
- average fraction Al₂O₃ - 3.9-4.0 g/cm³; MgO – 3.2-3.7 g/cm³; CaO – 3.0-3.5 g/cm³.
- easy fraction SiO₂ - 2.5-2.7 g/cm³.

The received results of the fractional analysis are reduced in Figure 1.

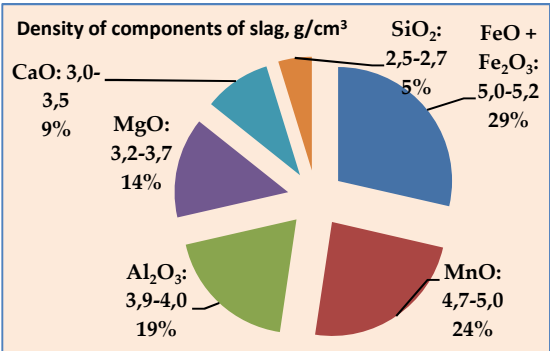


Figure 1. Fractional analysis of steel-smelting slag of JSC “Uzbeksteel” (Uzbekistan).

2.2. Determination of particle size distribution of steel-smelting slag.

Particle size distribution of steel-smelting slag of a define in the way of a dry sieving. Applied set to determination of particle size distribution sit, the device for stirring sit, doing 140-150 courses a minute.

For determination of particle size distribution mm were used a sieve with a size of cells: 3.0; 2.5; 2.0; 1.5; 1.2 mm. Previous weighed hinge plate of steel-smelting slag was located on the top sieve of set. Duration of stirring was 5-10 min. the Device stopped, from it was taken out a sieve, and weighing of the rest on each sieve was made. The hinge plate of slag weighing 5.0 kg was exposed to the graduation analysis.

Results of the graduation analysis are given in tab. 2.

Table 2. Particle size distribution of initial steel-smelting slag

Class, mm	The weight, kg	The exit on classes, %	The total exit on "+", %
+3,0	0,859	17,18	17,18
-3,0+2,5	0,280	5,6	22,78
-2,5+2,0	0,320	6,4	29,18
-2,0+1,5	0,470	9,4	38,58
-1,5+1,2	0,243	4,86	43,44
-1,2	2,828	56,56	56,56
	5,0	100	100

For the maximum division of grains when using gravitational methods of enrichment, one of necessary conditions is, division of particles from the dead containing rock, for achievement of this condition researches on crushing of steel-smelting slag with determination of particle size distribution of the crushed slag were conducted.

2.3. Definition of the key process parameters of allocation of valuable components using differences in their physic-mechanical properties.

Results of the carried-out analyses allowed to choose the enrichment methods based on the difference of density of minerals. Researches on enrichment of slag by methods of hydraulic classification, a jigging, the screw separator and enrichments on a concentration table were conducted. These methods found broad practical application and give rather objective information about technical and economic indicators of process [4].

Laboratory researches of hydraulic classification were conducted on the one-spiral qualifier with a length of trough of 1.6 m, 0.28 m wide and with a diameter of spiral of 0.28 m.

For carrying out experiments the pulp with T was prepared: = 1:10 till 1:20 which was given to a trough of the spiral qualifier. Studied efficiency of division of particles depending on duration of stay of material in the device and sitovy composition of initial material. Results of pilot studies are presented in Figure 2.

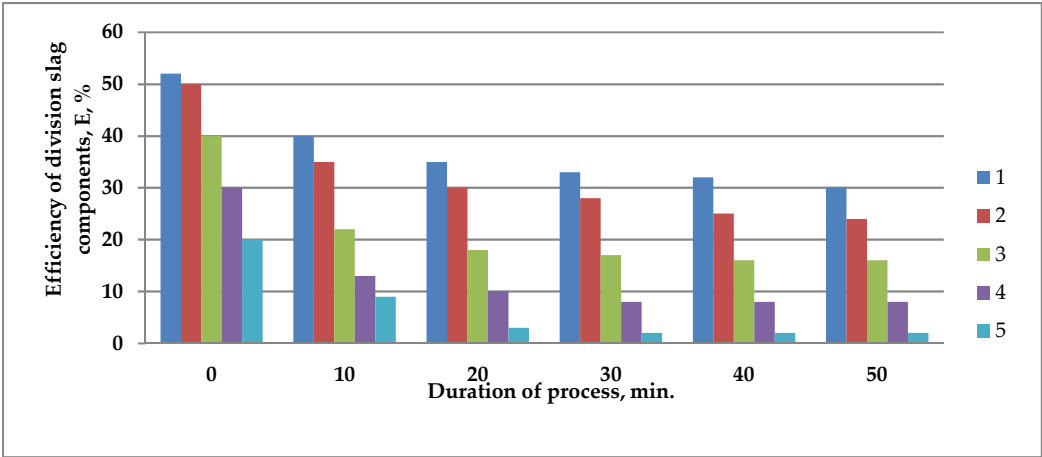


Figure 2. Dependence of efficiency of division of components of the processed steel-smelting slag on process duration: 1) $d_{max} = 4$ mm; 2) $d_{max} = 3$ mm; 3) $d_{max} = 2$ mm; 4) $d_{max} = 1$ mm; 5) $d_{max} \leq 0.5$ mm

Apparently from data in Figure 2. division of grains on the hydraulic spiral qualifier proceeds in 15-20 minutes, at the same time the efficiency of division is not high, and the initial size of grains has no great influence. It means that this method is ineffective for the solution of tasks of release of iron and its oxidic connections in an independent product. However the method of hydraulic classification can be used at preparatory processes, for example, for washing and desludging of initial material.

Researches on an enrichment of the processed steel-smelting slag by method of a jigging were conducted in the laboratory two-chamber diaphragm jigger MOD-2 vehicle. Average values of results of 5-6 pilot studies are presented in tab. 3. In experiments tails of the first jigging loaded again therefore received two concentrates.

Table 3. Qualitative quantitative indices of division of valuable components of steel-smelting slag at a jigging

Products	Exit		Contents, %			Extraction, %		
	kg	%	FeO+Fe ₂ O ₃	Fe	MnO	FeO+Fe ₂ O ₃	Fe	MnO
Initial slag	10,0	100	17,6	3,8	5,4	100	100	100
Concentrate 1	4,9	49	15,2	2,8	4,7	42,0	36,8	43,1
Concentrate 2	2,1	21	31,5	6,2	9,4	37,5	34,2	36,5
Tails	3,0	30	12,08	3,7	3,7	20,5	29,0	20,4

These tables 3. show that extraction of valuable components in a concentrate low though an exit of a concentrate made 49-50%. The maintenance of useful components rather big (up to 29%) that will lead to irrevocable losses of metal. Probably, physic-mechanical properties of slag-forming components do not differ at so big size that it is effective to divide them by a jigging method. Use of this technique does not give effective technical and economic indicators and it cannot be recommended for industrial introduction [5].

One of possible methods of division of components of the processed steel-smelting slag is use of the screw separator. Results of the conducted researches are presented in tab. 4.

Table 4. Qualitative quantitative indices of division of valuable components of steel-smelting slag on the screw separator

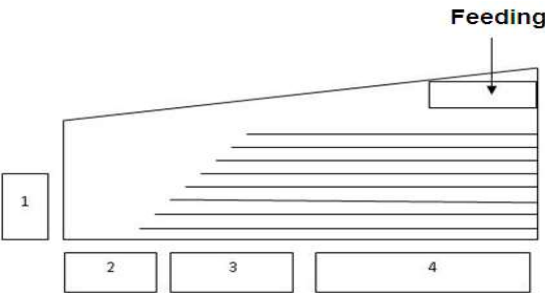
Products	Exit		Contents, %			Extraction, %		
	kg	%	FeO+Fe ₂ O ₃	Fe	MnO	FeO+Fe ₂ O ₃	Fe	MnO
Initial slag	10,0	100	17,6	3,8	5,4	100	100	100
Concentrate 1	4,2	42	17,85	4,5	5,5	42,6	50,0	42,1
Concentrate 2	3,5	35	14,75	4,2	4,3	29,6	39,5	27,8
Tails	2,3	23	21,3	1,8	6,7	27,8	10,5	29,6

Analysis of data of table 4. shows that extraction of valuable components when using the screw separator is slightly higher, than at the previous series of experiments. At the same time total extraction made, %: FeO Fe₂O₃ – 72.2; Fe – 89.5; MnO – 70.4. However losses with tails are considerable size that significantly reduces technical and economic indicators of process and can hardly be an effective method of processing of the fulfilled steel-smelting slag.

One more method of processing of steel-smelting slag is enrichment on a concentration table. Pilot studies were conducted on a laboratory single-tier concentration table of LKS – 1Ya. The table is intended for material enrichment by fineness – 3 mm, productivity of a table of 15-20 kg/h; the size of the course of a sound board is regulated in repartitions of 8 - 16 mm; number of the courses in a minute 275-325; inclination of a sound board from 0 to 100; consumption of water of 0.5 m³/h.

After establishment of technical indicators of a table began performance of a pilot study. At first water in the quantity sufficient for a covering was pumped by a thin layer of all surface of a table. Steel-smelting slag moved in a loading box of a table in the form of the pulp received after crushing with the relation: T = 2:1. The quantity firm in a pulp was 1 kg. Watching formation of a fan on a table, regulated an inclination and an amount of water in a middle and trailer part of a table. The inclination was regulated so that the border of coarse-grained fraction of tails got to the first tail receiver. Having passed all material, reduced an inclination of a table a little and a brush washed away the material which accumulated on a sound board, without stopping a table. Having washed away all material, the table was stopped, each of the received fractions was dehydrated, dried.

The schematic image of enrichment of the crushed steel-smelting slag is shown in Figure 3.



1,2,3 – cups for collecting concentrates; 4 – a cup for collecting tails of enrichment
Figure 3. - The layout chart of cups at gravitational enrichment of the crushed steel-smelting slag

Results of experiments on enrichment of steel-smelting slag on a concentration table are given in tab. 5. (numbering of tests in the table corresponds to numbering of the tests given in the test sheets fulfilled by the Central laboratory JSC “Uzbeksteel” (Uzbekistan). In numbering of tests the first digit number of experience, the second the product number according to Figure 3.

Table 5. Results of researches on gravitational enrichment of steel-smelting slag on a concentration table

# tests	The weight of test, gr	Product yield, %
1.1	248,6	24,9
1.2	222,0	22,2
1.3	123,0	12,3
1.4	406,4	40,6
Total	1000,0	100
2.1	283,2	28,3
2.2	97,0	9,7
2.3	112,0	11,2
2.4	507,8	50,8
Total	1000,0	100
3.1	341,4	34,1
3.2	104,4	10,4
3.3	77,2	7,7
3.4	477,0	47,8
Total	1000,0	100
4.1	308,6	30,9
4.2	153,6	15,3
4.3	71,8	7,2
4.4	466,0	46,6
Total	1000,0	100

In the Central laboratory JSC "Uzbeksteel" (Uzbekistan) the analysis of the chemical composition of products was made and the maintenance of Femet, FeO, Fe₂O₃ is defined and also, carried out microscopic and UV analysis. Which results are given in tab. 6., Figure 4.

Qualitative quantitative indices of enrichment of the crushed steel-smelting slag on a concentration table are given in tab. 6.

Table 6. Average values qualitatively - quantitative indices of division of valuable components of steel-smelting slag on a concentration table

Products	Exit, %		Contents, %		Extraction, %	
	kg	%	FeO+Fe ₂ O ₃	Fe	FeO+Fe ₂ O ₃	Fe
Initial slag	5,0	100	17,6	3,8	100	100
Concentrate of I	1,46	29,3	37,9	10,2	63,0	78,2
Concentrate of II	1,2	24,0	16,8	1,73	22,8	11,2
Tails	2,34	46,7	5,3	0,9	14,2	10,6

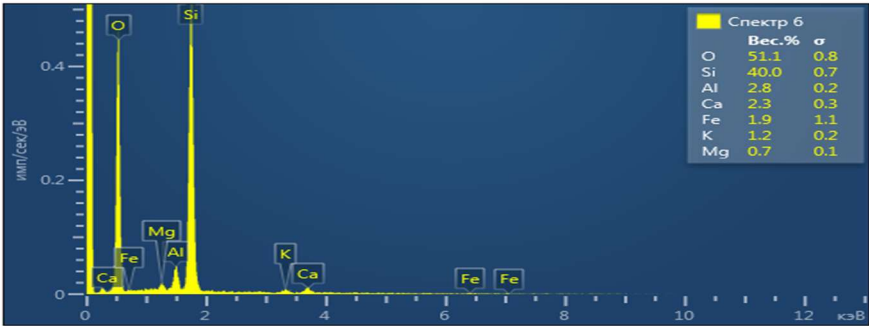


Figure 4. The electronic and microscopic picture of a concentrate after enrichment on a concentration table

The comparative analysis of indicators of extraction of FeO, Fe₂O₃ was made for the choice of an optimum way of gravitational enrichment of steel-smelting slag, Fe results of which are given in tab. 7.

Table 7. The comparative analysis of extraction of useful components from steel-smelting slag by method of gravitational enrichment

Enrichment methods	Extraction valuable components	Extraction, %		
		Concentrate-1	Concentrate-2	Tails
Jigging	FeO+Fe ₂ O ₃	42,3	20,0	37,7
	Fe	28,6	12,8	58,6
Screw	FeO+Fe ₂ O ₃	38,6	18,6	42,8
	Fe	32,7	21,4	45,9
Concentration table	FeO+Fe ₂ O ₃	63,0	22,8	14,2
	Fe	78,2	11,2	10,6

Comparing the received results to results of a jigging it is possible to tell that enrichment on a concentration table is more preferable than other methods of enrichment.

By results of the conducted researches it is visible that at enrichment of steel-smelting slag on a concentration table extraction of valuable components makes, %: a concentrate 1 – FeO - Fe₂O₃ - 63.0; Fe – 78.2; concentrate 2 – FeO - Fe₂O₃ - 22.8; Fe – 11.2. Content of iron, its oxides and MnO is in the limits quite available to their subsequent use in furnace charge of metallurgical furnaces. They can be used as oxidizers when smelting became, or the ore-fuel of pellets, their metallization and loadings in ars-smelting furnaces can be applied to preparation [6].

3. A research of processes of heat treatment of gravitational concentrates in the recovery environment

The technology of receiving crude ore and coal pellets from the thin-milling of the materials supporting not less than 70-90% of fraction of-0.074 mm practically remains the same, as well as for ore granules, and can be realized on the granulators used now that will be coordinated with results of work [7]. In view of high capillary moisture capacity of thin-milling fuel in comparison with a concentrate, the humidity of furnace charge for receiving the ore-fuel of granules needs to be maintained 2-4% above, than by production the ore-fuel of pellets. Crude the ore-fuel pellets from 20% of fuel (powder of the Angren coal) with a diameter of 10 mm maintained before destruction of loading 0.8 kg, and after drying of 1.0-1.2 kg / a pellet.

We conducted researches on definition of influence of temperature of roasting on some technological indicators of process of enrichment of iron ore pellets. Results of researches are given

in Figure 1 – 3. Experiments were made under following conditions: roasting time – 60 minutes, diameter of a pellet – 10 mm, composition of furnace charge of 80% poor ore and 20% of fuel.

In Figure 5. changes of content of iron in a concentrate depending on roasting temperature are presented.

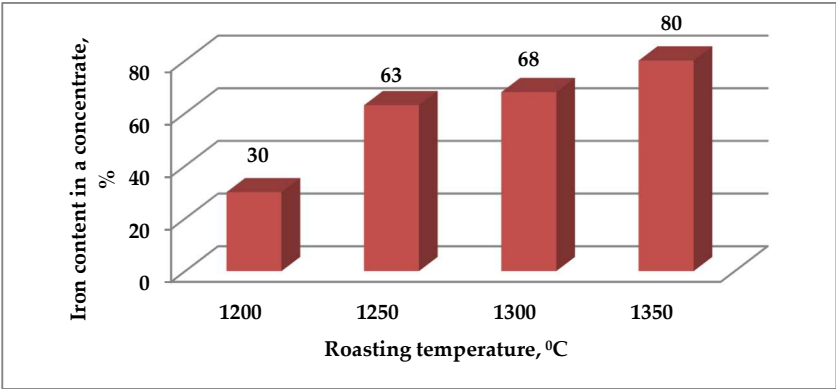


Figure 5. Influence of temperature of roasting on iron content in a concentrate

From Figure 7. it is visible that with increase in temperature of roasting iron content grows in a concentrate. This phenomenon can be explained as follows. For course of chemical or structural changes in a firm phase there has to be a movement of atoms. Various mechanisms of this phenomenon are possible. Transition of atoms from normal knots of a lattice in a nearby vacancy [8] can be one of them. Vacancies exist in each crystal at all temperatures other than absolute zero. Speed with which diffusion of atoms in this case proceeds depends on ease of movement of atoms from normal knot in vacant and on concentration of vacancies. Movement of atoms in any direction is equivalent to wandering of vacancies in an opposite direction. Therefore in a similar case it is possible to speak about diffusion of vacancies.

One of options of this process is the so-called "relay" mechanism at which the atom which is in an interstice passes into normal knot, pushing out the atom which was earlier there in a new interstice.

The valid mechanism of process in this system is defined by the relative size of the energy which is required for course of this process. Diffusive processes, as a rule, in many respects determine the speed of chemical reactions and agglomeration.

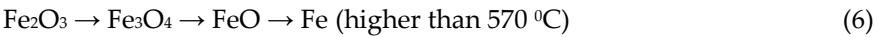
The size of energy necessary for this purpose is called energy of activation of process, and the temperature dependence can be presented by expression:

$$D = D_0 \exp(-E / RT) \tag{5}$$

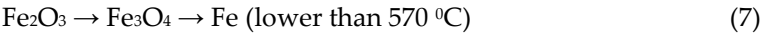
where E is the seeming energy of activation of diffusion.

The size of coefficient of diffusion and its change with growth of temperature increases also that, most reactions of restoration of oxides of iron accelerate.

Process of restoration of iron of oxides, according to Baykov's principle about the sequence of transformations, proceeds in steps by transition from the highest oxides to the lowest in schemes



or



At the same time according to the chart Fe – O in a system arise not only the lowest oxides and metal, but also solid solutions.

Restoration of oxides of iron solid carbon perhaps on the following reactions:



For the last reaction:

$$\lg K_p = - 7730/T + 7,84 \tag{11}$$

Total negative thermal effect 4240 kJ/kg of iron.

Carbon oxide reversible reaction is the cornerstone of processes of restoration of oxides of metals:



This reaction proceeds from left to right when ΔG reactions – size negative i.e. when the thermodynamic potential of a system decreases upon transition from an initial state to equilibrium.

If to express a constant of balance through partial pressure of gases and vapors of participants of reaction:

$$Kp = \frac{P_{me} \cdot P_{CO_2}}{P_{meo} \cdot P_{CO}} \quad (13)$$

where to R_{me} , R_{meo} , R_{co} , – vapor pressure and gases of participants of reaction at balance and to express an initial state through

$$Kp^1 = \frac{P_{me}^1 \cdot P_{CO_2}^1}{P_{meo}^1 \cdot P_{CO}^1} \quad (14)$$

$$\text{That} \quad \Delta G = RT \ln Kp1 - RT \ln Kp \quad \text{or} \quad \Delta G = RT \ln \frac{P_{me} \cdot P_{CO_2}}{P_{meo} \cdot P_{CO}} \quad (15)$$

Reaction goes from left to right when $Kr1 < Kr$, and ΔG reactions – size negative. The size of a constant of balance can be determined on the equation:

$$\ln Kp = -\frac{\Delta G}{RT} \quad \text{or} \quad Kp = -\frac{\Delta G^o}{4,57T} \quad (16)$$

where ΔG^o – standard izobarno – the isothermal potential of the reaction determined by a difference:

$$\Delta G^o = \Delta G^o_{CO_2} - \Delta G^o_{CO} - \Delta G^o_{MeO} \quad (17)$$

from sizes of standard thermodynamic potentials of formation of the CO_2 , CO and MeO connections from elements.

Values $\Delta G^o_{CO_2}$, ΔG^o_{CO} and ΔG^o_{MeO} it is possible to find in reference books and also according to charts of dependence ΔG^o_{MeO} from temperature (the chart of energy of Gibbs).

In some cases MeO and Me are in the condensed firm or liquid phases, then $R_m = \text{const}$ and $R_{meo} = \text{const}$,

$$Kp = \frac{P_{CO_2}}{P_{CO}} \quad (18)$$

The thermal effect of reaction (18) can be calculated on warmth of education of participants of reaction from elements:

$$Q = (Q_{CO_2} - Q_{CO}) - Q_{MeO} \quad (19)$$

$$\text{At } 298 \text{ To } Q_{CO_2} = 94.05 \text{ kcal (398.13 kJ)}$$

$$Q_{CO} = 26.5 \text{ kcal (110.77 kJ)}$$

$$\text{then } Q_{298} = 67.65 \text{ (282.78) -}$$

Reactions of restoration of oxides of metals carbon oxide can be exothermic or endothermic depending on warmth of formation of oxide from elements [9]. Thermal effects of reaction of restoration of some oxides by carbon oxide, kcal are given below (h4.18 kJ):

$\text{Cu}_2\text{O} + \text{CO} = 2\text{Cu} + \text{CO}_2$	27,8
$\text{PbO} + \text{CO} = \text{Pb} + \text{CO}_2$	16,6
$\text{NiO} + \text{CO} = \text{Ni} + \text{CO}_2$	10,0
$\frac{1}{2} \text{Ge}_2 + \text{CO} = \frac{1}{2} \text{G} + \text{CO}_2$	61,1
$\text{FeO} + \text{CO} = \text{Fe} + \text{CO}_2$	3,2
$\text{ZnO} + \text{CO} = \text{Zn} + \text{CO}_2$	-15,0

$\frac{1}{2} \text{SiO}_2 + \text{CO} = \frac{1}{2} \text{Si} + \text{CO}_2$	-37,2
$\text{NbO} + \text{CO} = \text{Nb} + \text{CO}_2$	-29,0
$\text{UO}_2 + \text{CO} = \frac{1}{2} \text{U} + \text{CO}_2$	-61,1
$\text{MgO} + \text{CO} = \text{Mg} + \text{CO}_2$	-75,5
$\frac{1}{2} \text{TiO}_2 + \text{CO} = \frac{1}{2} \text{Ti} + \text{CO}_2$	-59,7

If > 67.6 kcal (282.78 kJ), then thermal effect of reaction of restoration - negative size that is observed at metals with big affinity to oxygen (Zn, Ti, Nb, V and others).

If > 67.6 kcal (282.78 kJ), then thermal effect of reaction of restoration of oxide of metal - the positive size, and reaction is followed by allocation of heat. Thus, than the affinity of metal to oxygen is more, especially the thermal effect of reaction of restoration of its oxide is negative [10].

It is possible to calculate a constant of balance of restoration of oxides of metals carbon oxide and to graphically represent dependence of a logarithm of a constant equilibrium reactions of restoration from temperature (Figure 8).

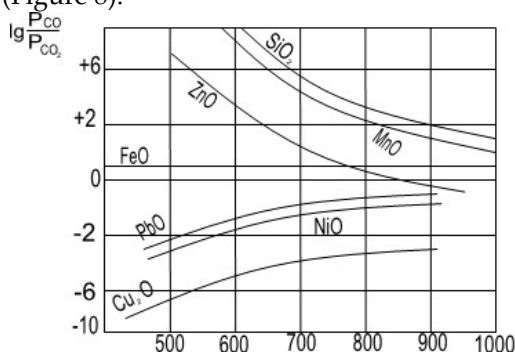


Figure 8. Dependence of a logarithm of a constant of balance of reactions of restoration of various oxides carbon oxide from temperature

Knowing a balance constant at this temperature, it is possible to calculate it on equilibrium structure of a gas phase for reaction under conditions

$$\frac{1}{Kp} = \frac{P_{CO}}{P_{CO_2}}; P_{CO} + P_{CO_2} = P; \% CO + \% CO_2 = 100\%$$

$$\text{Then } P_{CO} = \frac{\% CO \cdot P}{100}; P_{CO_2} = \frac{\% CO_2 \cdot P}{100} = \frac{(100 - \% CO) P}{100} \quad (20)$$

$$\frac{1}{Kp} = \frac{P_{CO}}{P_{CO_2}} = \frac{\% CO}{\% CO_2} = \frac{\% CO}{100 - \% CO} \quad (21)$$

$$\text{From where } CO_2 = \frac{Kp \cdot 100}{1 + Kp} \% \text{ and } CO = \frac{100}{1 + Kp} \% \quad (22)$$

In Figure 9 equilibrium structures of a gas phase for reactions of restoration of oxides of metals in dependence – from temperature are represented.

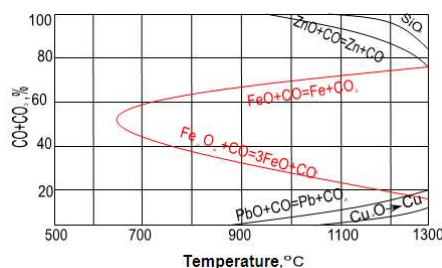


Figure 9. Dependence of equilibrium concentration CO in mix with CO₂ for reactions of restoration of oxides of metals carbon oxide from temperature

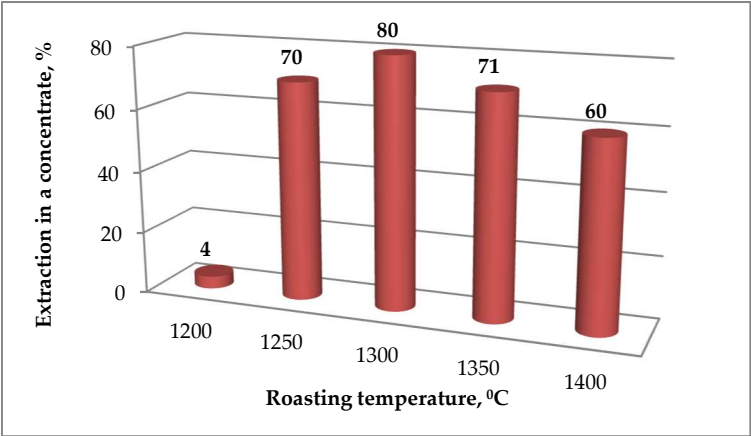
In the lower part of this chart the metals with small affinity to oxygen (Cu, Pb, Ni) demanding for the restoration of insignificant concentration CO in a gas phase with the size $K_p > 1$ are located. In the top part of the chart metals with big affinity to oxygen (Zn, Si, Mn) are located for which $K_p < 1$ demanding for recovery of the considerable contents CO in a gas phase.

From charts (Figure 8 and 9) it is visible that constants of balance of reaction of restoration of oxides for from them metals with temperature increase increase (FeO, Cu₂O, NiO) for others decrease (ZnO, SiO₂, Fe₃O₄).

At negative thermal effect of chemical reaction, according to Le-Chatelie's principle, increase in temperature shifts balance of reaction of restoration of iron from left to right, i.e. towards formation of metal.

Important indicator of concentrating process is extraction of a valuable component in a concentrate.

In Figure 10. results of researches on definition of this indicator depending on roasting temperature are presented.



Roasting time – 15 min. in air current; d pellets = 10 mm; structure of 80% ore, 20% coke.

Figure 10. Influence of temperature of roasting on extraction of iron in a concentrate

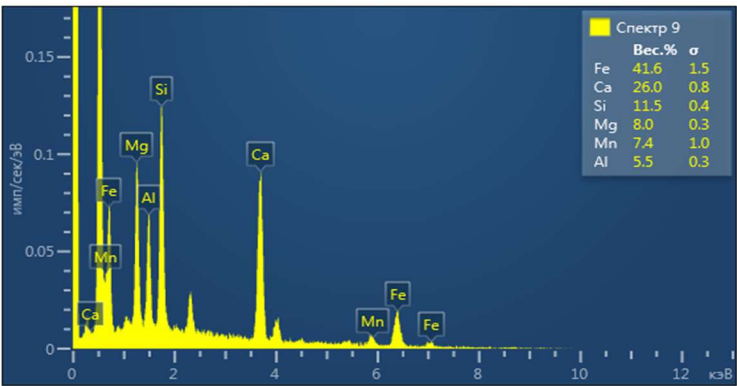


Figure 11. The electronic and microscopic picture of a concentrate after recovery

From data in Figure 10. and 11. it is visible that with temperature increase extent of extraction of iron in a concentrate increases. It is a consequence of the fact that at high temperatures recovery processes proceed more intensively. However, extent of extraction remains quite low and it leads to the fact that at heat treatment of the crushed iron ore materials the agglomeration phenomenon is observed. It especially becomes more active if the porous pressed body is exposed to processing. Thus, agglomeration is shown at heat treatment as separate dispersion particles (for example, at recovery or roasting of concentrates in the boiling layer), and granules (crude pellets, briquettes) [11].

The initial porous body is the system remote from a status of thermodynamic equilibrium at the same time in many parameters. It is caused by a big free surface of separate particles, existence of microdistortions of type of shift of atoms from regular provisions in a grid, nonequilibrium defects

of type of dislocations, excess vacancies, etc. At complexity of structure of dispersion medium non-equilibrium of a system is caused also by a field of a gradient of concentration. At agglomeration, reduction of surface energy of particles, and "curing" of separate defects, alignment of concentration [12] happens the being irreversible process, both.

Solid-phase agglomeration influences process of recovery when processing ore and coal pellets. At recovery them in the mine furnace this process is of great importance because the upper limit of temperatures of recovery is limited to temperature of agglomeration of pellets in clusters with violation of the modes of process.

Processing of iron ore materials during thermal recovery has, in comparison with the clean phenomenon, some features from which first of all it is necessary to select:

- a) existence of a large number of components (oxides of iron, silicon, aluminum, calcium, magnesium and so forth);
- b) noticeable amount of the gases which are formed during process;
- c) course of oxidation-reduction processes;
- d) course of solid-phase reactions (between magnetite and silicon dioxide, lime and hematite and other);
- e) possibility of formation of a quantity of a liquid phase of variable structure and properties.

These features do not give the chance to use without changes of pattern of agglomeration, found mainly for metal powders. For example, iron ore material is the system remote from thermodynamic potential in many parameters. As recovery processing is followed by chemical reactions, reduction of free energy of a system as a result of course of reactions can be characterized by more powerful flows of substance, than other processes. In other words, approach of a system to balance in one parameter, can be energetically justified in that case when it is followed by temporary removal from balance in other parameters. Practically it can be expressed in other process of change of porosity of granules, the size of grains, etc.

Generally the pellet can be considered as a porous polycrystal with an extensive network of interpartial borders. The more the area the interpartial of borders, the is more dense and stronger a pellet. Proceeding from it, objective criterion of behavior of iron ore particles when heating is the total area of interpartial contacts or an inverse value – the total area of contacts of a particle – a time which is expressed by a total or specific surface of a time.

We conducted researches on determination of strength properties in a cold condition of pellets from a specific surface of a time. The specific surface of a time was determined by a widespread bottle method [13-20]. Results of researches are presented in Figure 12.

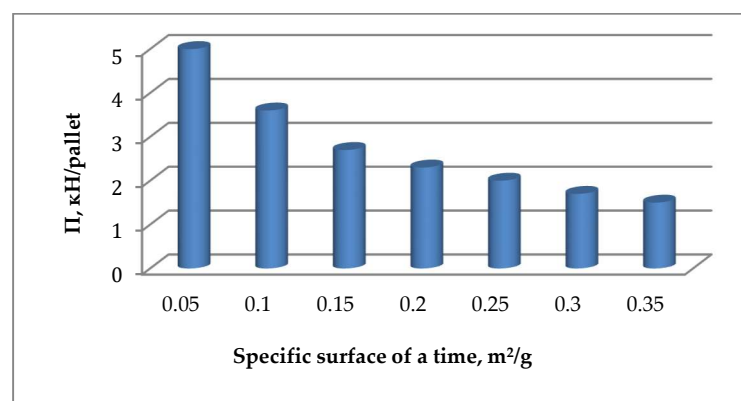


Figure 12. Dependence of cold durability on a specific surface of a time in pellets

From data in Figure 12. it is visible that with increase in a specific surface of a time durability of pellets significantly falls. Especially it is important to consider it when loading material in the mine furnace, since at the same time pellets can collapse that reduces gas permeability of furnace charge, increases dust remove and the recoverability of oxides owing to change of aerodynamic conditions in the furnace decreases.

Also furnace charge agglomeration since will significantly be at a loss recoverability owing to decrease in a reactionary surface and formation of hardly reparable connections has an adverse effect.

From previously enriched materials metallized furnace charge for domain melting can be received by various methods: restoration by gas in the mine furnace, restoration by the solid reducer on the conveyor indurating machine combined by restoration firm and gas reducers in the tubular furnace. At the same time it is necessary to pay attention to the following circumstances:

1) it is possible to metallized any iron ore material – ore, agglomerate, pellets and also to combine processes of an agglomeration with metallization, creating the recovery atmosphere in a furnace charge layer;

2) for metallization it is possible to use both solid, and gaseous reducer and also their combination;

3) as reducer it is economically expedient to use not scarce and inexpensive types of fuel;

4) the efficiency of metallization grows with reduction of amount of dead rock in iron ore material.

We concretize these provisions.

It is in our opinion more preferable to carry out an agglomeration of the enriched small concentrates with metallization, than to receive the oxidized materials, and then to restore them and the reason is that two processes are combined in one. Restoration received before agglomerate and pellets is connected with certain diffusive resistance as rather dense final structure of agglomerate and pellets significantly slows down process of restoration and increases a reducer consumption.

The analysis of work of the advanced enterprises allowed us to establish that receiving and pro-melting the metallized of pellets has some advantages before production and use of metallized agglomerate. First by production of metallized agglomerate the consumption of solid fuel is much more. This results from the fact that when receiving metallized agglomerate solid fuel performs two functions: heat source for carrying out agglomeration and reducer.

The consumption of solid fuel (coke trifle) for usual conditions of agglomeration (i.e. without metallization of a product) fluctuates within 4-8% (carried to an agglomeration charge). At metallization of oxides of iron, for example, on reaction of $\text{Fe}_3\text{O}_4 + 4\text{C} = 3\text{Fe} + 4\text{CO} - 645.29 \text{ Mj}$ for restoration of 1 kg of iron are required to 48: 168 = 0.286 kg of carbon.

At iron content in an agglomeration charge of 60%, the set extent of metallization of 40% and the content of carbon in solid fuel of 85% the reducer consumption on process will make:

$$60 \cdot 0,286 \cdot 0,4 : 0,85 = 11,3\%.$$

On 1 kg of the restored iron 1016 KJ are required heat of 4.2 Mj, or on 1 kg of agglomerate (60% of iron, extent of metallization of 40%). At the general expense of heat, equal 3.36 Mj, an additional expense of heat and, therefore, fuels will make 30%.

By production the metallized of pellets solid reducer is used only for metallization, and a source of heat is gas. Therefore on production the metallized of pellets is spent for 10-12% of solid fuel less.

Besides, by production of metallized agglomerate the most scarce and expensive type of fuel – a coke trifle is generally used. When using the metallized of pellets it is possible to use more wide choice of solid fuels, including coal and products of their processing.

Thirdly, when receiving the metallized of pellets can be reached significant increase in density and, therefore, bulk weight that has to provide additional gain of capacity of blast furnaces. At agglomerate metallization density of pieces changes a little. The metallized of products in blast furnaces is the most important result of use decrease in specific weight of coke. This circumstance is very important for Uzbekistan since all required coke is imported with expense of currency [21-25].

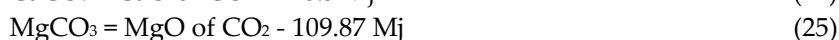
Smelting of metal in any metallurgical units it is impossible without calcium oxide presence. This connection is used for formation of fusible eutectics like $2\text{MeO} \cdot \text{CaO}$ which melting at rather low temperatures (1150 - 1200 °C) dissolve in themselves other refractory connections and promote, thereby, the normal course of metallurgical processes. Besides, oxide of calcium normalizes physical and chemical characteristics of slag (basicity, density, a superficial tension, viscosity, etc.) and does possible to operate the course of technological processes.

Calcium oxide for removal of such harmful component for steel smelting as sulfur is irreplaceable. This element is removed on reaction:



Sulfide of calcium slag and removed from the furnace.

Calcium oxide together with other carbonates can come to the furnace together with iron ores. However a share of these materials in domain furnace charge it is small. Thereof the fluxing additives to furnace charge - limestone or dolomite are of great importance (CaCO_3 , $\text{CaCO}_3\text{-MgCO}_3$). In the blast furnace decomposition of carbonates proceeds on reactions:



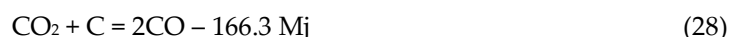
Reaction of decomposition of a carbonate of calcium most is important for blast-furnace process. The dependence of elasticity of dissociation of a carbonate of calcium on temperature is expressed by the equation:

$$P_{\text{CO}_2} = - (8920/T) + 7,54$$

Decomposition of CaCO_3 in the metallurgical furnace can begin at equality of elasticity of dissociation of limestone and partial pressure of carbonic acid in the atmosphere of the furnace. Calculations show that 98 kPa at $T = 1183 \text{ K}$, i.e. at this temperature decomposition of CaCO_3 begins P_{CO_2} .

In the blast furnace from tuyere to top throat there is a powerful heat flux formed by burning of solid fuel and inflation of hot air (over 1000°C). In process of warming up of a piece from inside layers of limestone carbonic acid which removal is limited by diffusion of gas in a time is emitted. At the same time the speed of diffusion is influenced by the general pressure of gas in the furnace which slows down transition of CO_2 on gas Wednesday. Limestone dissociation freely proceeds provided that the elasticity of CO_2 vapors exceeds the general pressure of gas in the furnace [26-30]. By our calculations such conditions are created at a temperature about of 1000°C .

Decomposition of limestone goes without change of average temperature of a piece as all heat brought to a piece is spent for a covering of endothermic effect of reaction of dissociation. Therefore by analogy with water boiling process process of decomposition is called "chemical boiling". The emitted carbon dioxide at a temperature over 1000°C reacts with coke carbon



with considerable endothermic effect and expenditure of scarce expensive coke.

The endothermic effect of reaction of decomposition of limestone, interaction of the emitted carbon dioxide with carbon of coke and decrease in recovery potential of gas in the furnace because of dilution by its carbon dioxide worsens indicators of domain melting and especially strongly influence a coke consumption.

At reaction of decomposition of limestone to 1 kg of the allocated CO_2 to be spent:

$$178.4 : 44 = 4.075 \text{ Mj.}$$

Besides, at reaction of $\text{CO}_2 + \text{C} = 2\text{CO}$ is spent for 1 kg of CO_2 in addition:

$$166.32 : 44 = 3.78 \text{ Mj.}$$

It is difficult to establish extent of participation of CaCO_3 of carbon dioxide formed at decomposition in this reaction. Having accepted that a half of CO_2 allocated from limestone participates in this reaction, we receive an additional expense of heat:

$$3.78 \cdot 0.5 = 1.89 \text{ Mj}$$

Thus, to be spent for 1 kg of CO_2 of limestone

$$4.075 + 1.89 = 5.947 \text{ Mj}$$

In terms of 1 kg of the limestone containing 43% of CO_2 it will make

$$5.947 \cdot 0.43 = 2.557 \text{ Mj.}$$

Each 1 kg of carbon at combustion at tuyere on reaction $\text{C} + 1/2\text{O}_2 = \text{CO} + 117.94 \text{ Mj}$ allocates:

$$117,94 : 12 = 9,828 \text{ Mj.}$$

If to consider what in coke of 85% C and to tuyere reaches 80% of all coke, then 1 kg of coke at tuyere allocates

$$9.828 \cdot 0.85 \cdot 0.8 = 6.883 \text{ MJ.}$$

Then the additional consumption of coke on 1 kg of limestone will make

$$2.557: 6.883 = 0.37 \text{ kg/kg.}$$

Economy of coke at a limestone conclusion makes 0.20 - 0.40 kg/kg of limestone of domain furnace charge.

Calcium oxide absolutely necessary component for metal smelting. The direction connected with addition of lime in furnace charge during its preparation for metallurgical conversion is very perspective i.e. at agglomeration or an agglomeration. In this case there is a possibility of loading in the furnace not simple, and the fluxing of burdening materials. In this case negative impact of addition of lime in blast furnaces will be eliminated during preparation of initial materials for melting.

On the basis of the analysis of possible ways of involvement the ore-fuel of pellets in the industry it is possible to draw a conclusion that such basic opportunity is available. The choice of an optimal variant will depend on technological and technical and economic indicators by preparation of raw materials for metallurgical conversion.

3.1. The analysis of the physical and chemical processes proceeding at heat treatment the ore-fuel of pellets

For definition of optimum reducer and its expense, experiments with use as reducers oil coke of the Fergana oil refinery plant (FORP) and brown coal the Angren section were made.

Based on industrial experience of process of a Wealz of zinc cake and information obtained in the analysis of references the decision amount of the FORP coke loaded into furnace charge was made to accept equal 40% of the mass of a gravitational concentrate (the average content of carbon in coke of 95%).

When using as reducer of brown coal of the Angren section, lower content of carbon in it (73.44%) in comparison with coke, proceeding from it amount of coal of the gravitational concentrate added to furnace charge too up to 40% of weight was considered.

The hinge plate of a gravitational concentrate for preparation of furnace charge with oil coke and to brown coals made 20 g, and amount of the added reducer of 8 g.



Figure 13. Ore-fuel pellet

The prepared furnace charge (Figure 13.) it was loaded into a fireclay crucible and was established in previously heated to 1100 °C electric furnaces with cilit heaters and burned within 60 min. After the set time, crucibles with hinge plates were taken out from the furnace and cooled to room temperature.

Process of restoration of iron of oxides proceeds in steps, according to the chart Fe-O in a system there are not only lowest oxides, but also solid solutions. On the basis of the principle of the sequence of transformations of A.A. Baykov transition to the lowest comes from the highest oxides according to the following schemes: at temperatures over 560°C $\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4 \rightarrow \text{FeO} \rightarrow \text{Fe}$, lower than 560°C magnetite is restored to metal iron, passing wustite $\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4 \rightarrow \text{Fe}$ [31].

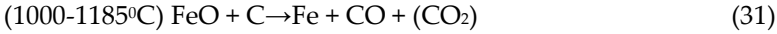
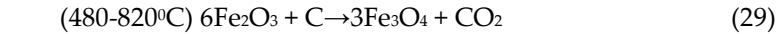
Extent of metallization in scientific and technical sources strongly differ that is caused by a different type of oxides and reducers, both techniques of carrying out experiments and methods of definition of extent of metallization differ.

Oxide decomposition has a great influence on speed reactionary ability of reducer. The recovery ability of carbon materials is defined by the content of volatiles and ashes, porous structure and a specific surface. The FORP oil coke has the greatest porosity which in tens times more, than at other carbonaceous materials. The FORP oil coke reacts already at 500°C.

We investigated kinetics of restoration of oxides of iron oil FORP coke and the Angren coal. Experiments were made at 1100 °C. It is revealed that cement carbide in significant amounts it is formed at low extents of restoration, with growth of volumes of a metal phase the amount of carbides of iron decreases.

Process of carburizing begins before complete recovery of iron from oxides, it should be considered in the context of formation of solid solutions of carbon in α - and γ -iron. As a result $\gamma \rightarrow \alpha$ there is a α -iron saturated up to 0.03% C, excess carbon is emitted in the form of carbide. The analysis of structure shows that as a result of uneven distribution of carbon structural heterogeneity and zonality of course not only processes of restoration, but also carburizing takes place. With growth of temperature the speed and extent of carburizing increase, and increase in hold time leads to increase in amount of the connected carbon in the restored iron.

The results of pilot studies presented to work [36] where quality of reducer used MPG6 graphite showed that restoration of Fe_2O_3 is followed by three stages:



Temperatures of achievement of the maximum speed of restoration are 780-980 and 1010°C.

Under our conditions carbon heat treatment restoration of gravitational concentrates a significant amount of metal iron appears only at higher than 1000°C. The maximum extent of metallization of 87% (60 min. roasting) was reached at 1100°C. At 1200°C extent of metallization structure of 31.1%.

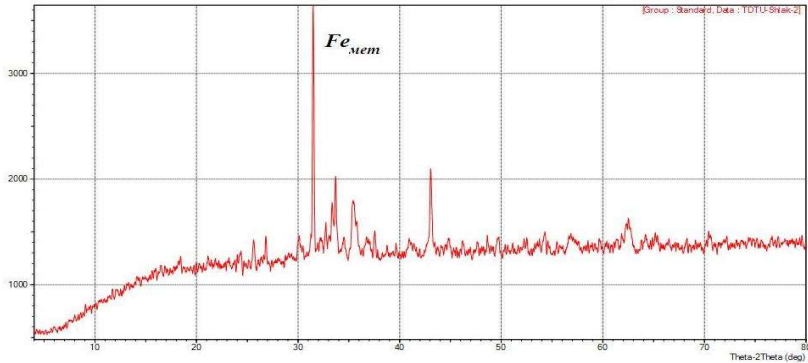


Figure 14. Diffractogram of steel-smelting slag after restoration with coal

Diffractogram recorded (Figure 14) magnetite – 2.541; 1.612; Å, and metal iron at peak 2.7 Å.

At temperatures below 900 °C extent of metallization did not exceed 7%. Optimum temperature for ore-fuel restoration of a gravitational concentrate brown to coals is 1100 °C at which extent of restoration and metallization of briquettes reached respectively 87 and 80%.

Processes solid-phase restoration of iron from gravitational concentrates with use as reducer of coals, have no unambiguous assessment that is connected with different physical and chemical properties of coals, complexity of a system and simultaneous development of recovery reactions with participation of solid carbon and gaseous products.

The purpose test was the technology of heat treatment the ore-fuel of pellets in the recovery environment. Technology carrying out high-temperature experiments, studying of properties of the initial and received after metallization materials included thermodynamic modeling of processes of solid-phase restoration of iron from the ore-fuel of pellets.

Definition of phase-10 of millimetric steelmaking slag and the samples of slag containing slag were subjected to researches of Diffraction of X-rays and mineralogical investigation under optical a microscope with to define the phases existing in their structures. The structure of diffraction of X-rays from-10 millimetric slag fraction is illustrated in Figure 3.15. When carrying out researches as ferriferous raw materials used the gravitational concentrate received by enrichment of steel-smelting slag. The phase structure initial a concentrate is presented by hematite (Fe_2O_3) - much; is present magnetite (Fe_2O_3), wustite (FeO), ferrite of calcium ($\text{CaO} \cdot \text{Fe}_2\text{O}_3$); meets also silicates iron aluminates.

When studying kinetics of heat treatment ore-fuel pellets applied a gravimetric method of continuous weighing of a sample at isothermal endurance.

For studying of processes of metallization were made the ore-fuel of pellets, consisting of a gravitational concentrate and reducer (see the above-stated data). Components in the set ratios mixed and bricketed. The mass ratio between oxides of iron and carbon in pellets corresponded above told by a ratio [32].

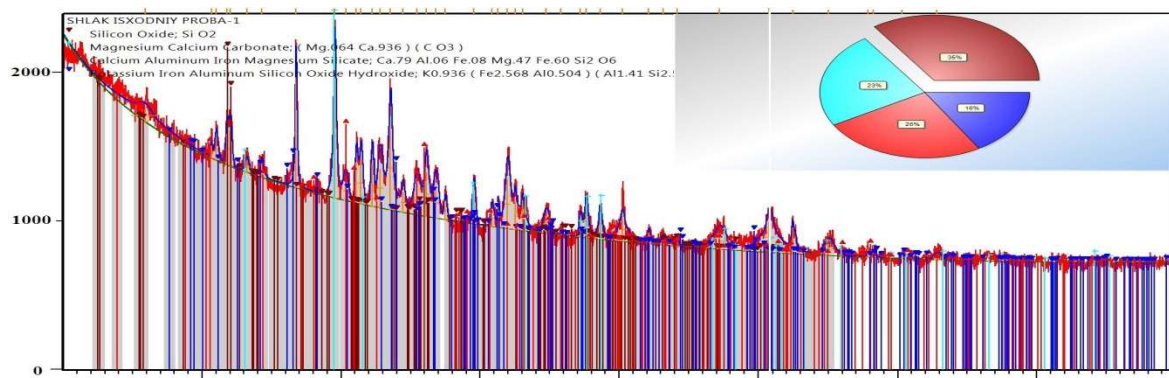


Figure 15. Diffractogram of a gravitational concentrate receipt in recovery process

Pellets weighing 50 g placed in a graphite crucible in a hot zone of the furnace of resistance heated to experiment temperature and carried out isothermal endurance. In the materials received the metallic determined by methods of the chemical analysis the maintenance of Fe_{total} and Fe_{met} . Degree and speed of restoration estimated on change of weight and speed of change of mass of a pellet. Extent of restoration was calculated by a formula

$$\alpha = \frac{m_{\text{O}_2}^{\text{del}}}{m_{\text{O}_2}} \quad (32)$$

where m_{O_2} amount of oxygen in oxides of iron, the contained pellets;

$m_{\text{O}_2}^{\text{del}}$ - the mass of the oxygen removed from a pellet;

The mass of remote oxygen was determined by a formula

$$m_{\text{O}_2}^{\text{del}} = m_{\text{CO}} \frac{M_{\text{O}}}{M_{\text{CO}}} = (\Delta m^{\text{del}} - m^{\text{V}}) \frac{16}{28} \quad (33)$$

here M_{O} и M_{CO} - the molar mass of oxygen and monoxide of carbon, g/mol;

Δm^{del} - decrease of mass of a pellet, %;

m^{V} - loss of mass of a briquette due to removal flying, contained in reducer, and waste of a graphite crucible.

Speed of restoration was calculated by a formula

$$V_{\alpha} = \frac{\Delta \alpha}{\Delta \tau} \quad (34)$$

where $\Delta \alpha$ - change of extent of restoration, %;

$\Delta \tau$ - change of time, min.

Extent of metallization of the received materials was counted according to a formula [33]:

$$\varphi_{met} = \frac{Fe_{met}}{Fe_{total}} \cdot 100 \tag{35}$$

in which φ_{met} - extent of metallization, %;
 Fe_{met} - content of iron metal, %;
 Fe_{total} - the content of iron of the general (the sum of the oxidized and metal iron), %.
Extent of metallization of oxides of iron it was carried out on the atomic and absorbing analyzer to Physical and Chemical Methods of a Research laboratories of GC "Institute of mineral resources" (Uzbekistan).
Results of analyses are given in tab. 8.

Table 8. Content of metal iron in initial test and after roasting

Name of test	Average content of Femet, %
Initial hinge plate of a gravitational concentrate	4,78
Pellet (furnace charge: gravitational concentrate of 20 g oil coke 8 g)	44,5
Pellet (furnace charge: gravitational concentrate of 20 g coal 8 g)	36,4

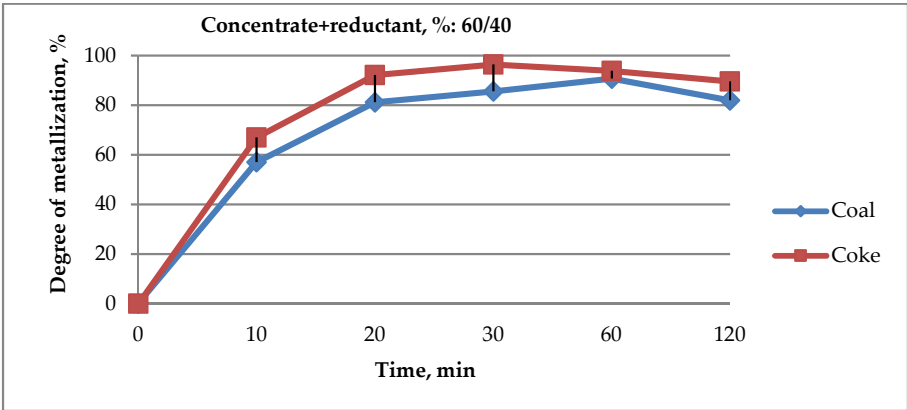


Figure 16. Extent of restoration of oxides of iron at a temperature of 11000C

From the data provided in tab. 8. and Figure 16. it is visible that when using as coal reducer, extent of metallization is lower, than when using oil coke. Proceeding from the received results and also considering the cost of the oil coke (about 4.4 million bags for ton) exceeding coal cost (about 0.5 million bags for ton) and the high content of the sulfur in coke which is harmful impurity for steel the decision as reducer to use brown Angren coal [34-37] was made.
For determination of optimum quantity reducers the decision to increase and reduce expense reducers was made. Four hinge plates with the content of coal and coke in furnace charge 10, 20, 30 and 50 of % of the mass of a gravitational concentrate were prepared. All four hinge plates burned in identical conditions (1100 °C, 60 min.).



Figure 17. Process burning ore-fuel of pellets

Results of roasting are given in table 9 and in Figure 18.

Table 9. The maintenance of Femet from amount of reducer in furnace charge

Amount of reducer in furnace charge in % of the mass of a gravitational concentrate	The maintenance of Fe _{met} , %
10	31,8
20	61,56
30	52,98
50	49,98

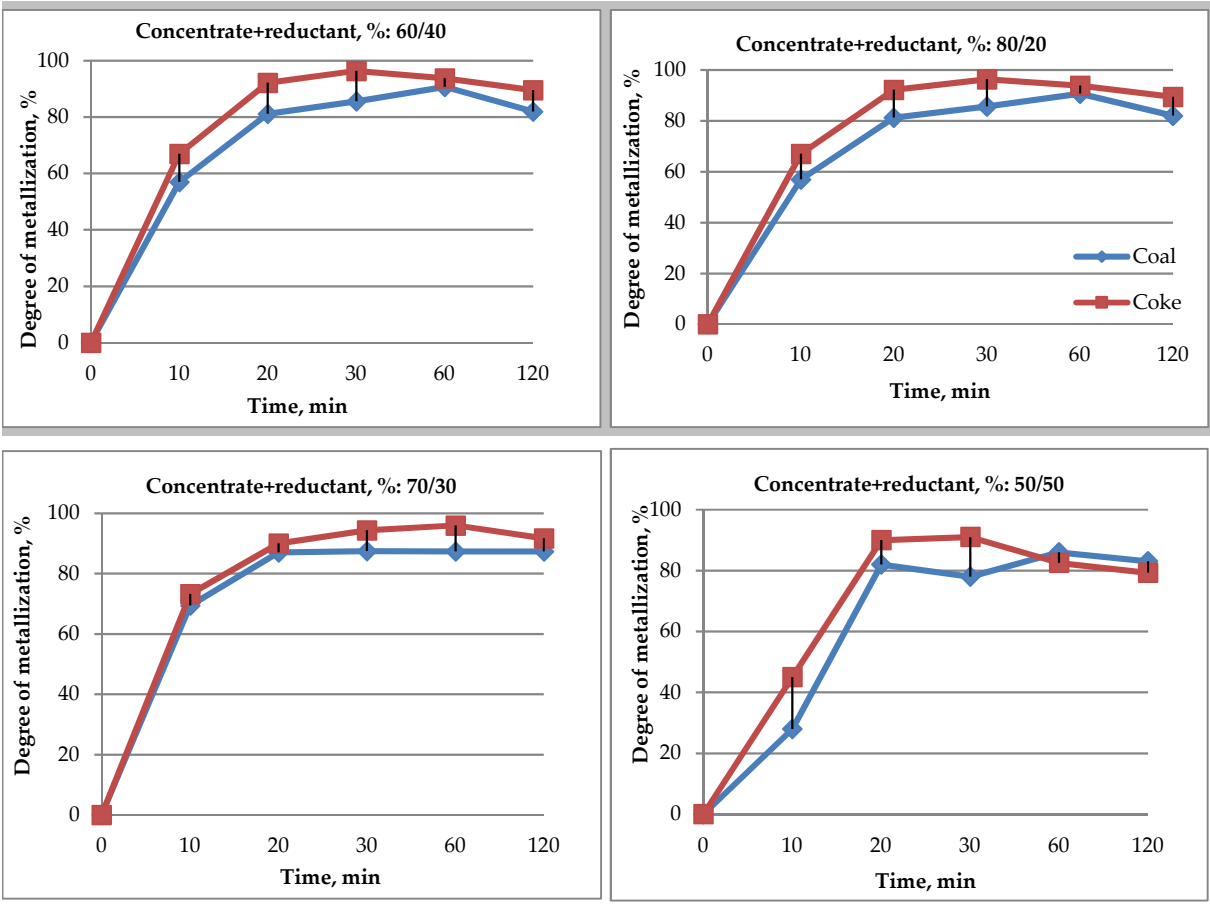


Figure 18. Extent of restoration of oxides of iron at a temperature of 11000C

From results of the researches given in tab. 9 and Figure 18 it is visible that optimum structure for iron oxide restoration at a ratio of 80% gravitational a concentrate for 20% a corner.

4. Conclusion.

By results of the conducted researches it is possible to draw conclusions:

- the fractional analysis of tests of steel-smelting slag is made and the following result is received: components of steel-smelting slag are distributed on fraction as follows: heavy fraction MnO -4.7-5.0 of g/cm^3 , FeO - Fe_2O_3 - 5.0-5.2 g/cm^3 ; average fraction Al_2O_3 - 3.9-4.0 g/cm^3 ; MgO - 3.2-3.7 g/cm^3 ; CaO - 3.0-3.5 g/cm^3 ; easy fraction SiO_2 - 2.5-2.7 g/cm^3 ;
- the particle size distribution of the initial (processed) steel-smelting slag is defined: 3 mm - 17.18%; 3,0 2,5 mm - 5.6%; 2,5 2,0 mm - 6.4%; 2,0 1,5 mm - 9.4%; 1,5 1,2 mm - 4.86%; 1.2 mm - 56.56%;
- as a result of the carried-out comparison of results of enrichment of steel-smelting slag, it is established that an optimum method at which the maximum extraction of FeO , Fe_2O_3 , Fe is reached is enrichment of steel-smelting slag on a concentration table;
- it is established that at enrichment of steel-smelting slag on a concentration table extraction of valuable components makes, %: a concentrate 1 - FeO - Fe_2O_3 - 63.0; Fe - 78.2; a concentrate 2 - FeO - Fe_2O_3 - 22.8; Fe - 11.2;
- it is established that as reducers of oxides of iron oil coke and the Angren brown coal can be used;
- it is defined that when using as coal reducer, the content of metal iron in pellets is lower, than when using oil coke. Proceeding from the received results and also considering the cost of the oil coke (about 4.4 million bags for ton) exceeding coal cost (about 0.5 million bags for ton) and the high content of the sulfur in coke which is harmful impurity for steel the decision as reducer to use brown Angren coal was made;
- the optimum amount of the coal added to furnace charge of the roasting making 20% of the mass of a gravitational concentrate is defined;
- it is established that the optimum temperature of recovery roasting is 1100 °C;
- it is defined that process of restoration of iron of oxides proceeds in steps according to the following scheme: at temperatures above 560 °C of $\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4 \rightarrow \text{FeO} \rightarrow \text{Fe}$, below 560 °C magnetite is restored to metal iron, passing wustite $\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4 \rightarrow \text{Fe}$

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