RESEARCH OF PROCESSES AND DEVELOPMENT OF SEPARATORS FOR METAL RECOVERY FROM METALLURGICAL SLAGS

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Abstract

This article relates to the analysis of formation and the metal content of slag, generalised data from enterprises on yield and treatment of slags. Test results of the metal content determination in slag dumps, slag granulometric composition, its physical and chemical properties, as well as results of experimental investigation of metal recovery process from slags are presented. Dependences of metal recovery on slagging, granulometric composition and magnetic field parameters of separators were obtained. Electromagnetic separators were developed. Results of technological research carried out under industrial conditions of metal removal from slags, metal scrap cleaning from mineral component are examined in this article.

INTRODUCTION

In connection with the rise in ferrous metal production, the yield of metallurgical slag increases. Considerable quantity of metal is lost in the slag. These losses reduce, to a considerable extent, the yield of high-quality metal and complicate essentially the processing of liquid and solid slags. In particular, presence of metal in the slag creates danger of explosion during the slag granulation, as well as makes worse conditions of crushing and milling of solid slags.

It should, therefore, consider the processing of slags not only from the point of view of the utilisation of its mineral component, but also from the point of view of

metal removal, as much as possible, with its subsequent utilisation in metallurgy. It applies especially to steel-smelting slags in which the metal content in comparison with blast furnace slags is several times higher.

The practice shows that as a result of insufficient attention to problems of processing of solid steel-smelting slags and of absence of special equipment for their processing and metal removal in slag yards or slag dumps, more than 1.5 million tonnes of metal remains unrecovered annually, while the total yield of steel-making slags in CIS is 22.7 to 22.8 million tonnes. Considerable portion of metal remains in slag and is used for road building with broken stone. Recovery of metal from slags and its utilisation in metallurgy is one of the most important reserves of raw material.

ANALYSIS OF FORMATION AND METAL CONTENT OF SLAG

All data obtained from enterprises in the Ukraine on yield and treatment of blast furnace and steel-making slags have been collected and generalised. The yield of blast furnace slags averages about 20.373 million tonnes per annum, and of steel-smelting slags 4.2395 million tonnes. Data were collected and generalised according to the production level (up to 1991).

From physical and chemical properties of slag, of the greatest importance is the fractional composition which is defined by the relationship of different size pieces in a slag, and in the first place by the presence of fine fractions. Of equal importance are the hardness and strength of the slag; these parameters determine its resistance to mechanical action.

Analysis of physical and chemical properties has shown that a solid slag is a hard material of high abrasiveness and strength. These properties have an influence on operation of the production equipment. Specific gravity of slag ranges from 3 to 3.65 g/cm³, impact resistance PM 75 kg/s/cm², compression strength 1300 kg/s/cm, abrasiveness index over 500. Physical and chemical properties of the converter slags obtained from two plants are shown in Table 1.

Representative samples of slags were selected at some plants in order to determine the metal content of the slag. The sampling was performed from 1 m length of the

Table 1 Physical properties of selected slags

Property	Novolipetsk Met. Plant	Ilyich Met. Plant
Specific gravity [g/cm ³]	3.560	3.500
Bulk mass [t/m ³]	1.570	1.560
Porosity [%]	10.350	10.350
Water absorption [%]	1.280	1.840
Degree of abrasion in drum [%]	20.200	49.000
Crushability in cylinder [%]	9.850	8.000
Compression strength [kg/cm ²]	400-1400	400-1400
Weight loss [%]	4.700	3.800

conveyor at its several points under different operating conditions and during several days. All selected samples were weighed and then they were subjected to graded crushing and milling. After each stage of crushing, the slag was subjected to magnetic separation. Test results of the metal content determination in the slag dumps are summarised in Table 2.

This it is determined that the slag fed for the secondary treatment contains, on average, 3.03% of metal from the slag mass.

Slag removed during the secondary treatment of steel-smelting slags has a considerable slag content of mineral component. Slag content of scrap in each fraction is determined by the apparent density method based on density difference of metal shot and slag particles.

In this way, first of all, the sample volume is calculated by volume of water displaced by this sample from the measuring vessel. Then, proceeding from from the sample weight, the prescribed iron weight by volume (7.8 g/cm³) and the slag weight by volume (2.7 g/cm³), one can determine the shot volume in this sample.

$$V_{\text{Fe}} = \frac{P_{\text{np}} - 2.7V_{\text{b}}}{7.8 - 2.7}$$

and after that, the iron content of the sample:

$$Fe = \frac{7.8V_{Fe}}{P_{np}} \times 100\%$$

where P_{np} is the sample weight (kg), V_b is the volume of displaced water (dm³) and V_{Fe} is the volume of iron in the sample (dm³).

Table 2 Metal content in assorted slag samples

Sample mass [kg]	Metal removed before crushing		Metal removed after crushing and milling		Metal content of the milled slag		Metal content of slag	
	10 ⁻³ kg	%	10 ⁻³ kg	%	10 ⁻³ kg	%	10 ⁻³ kg	%
402.000	4,710.50	0.470	2,839.20	0.280	3,862.80	0.380	11,412.5	1.110
14.775			50.300	0.005	136.450	0.020	186.750	0.020
13.260			36.700	0.005	230.780	0.023	267.480	0.030
20.220			226.150	0.020	567.080	0.060	793.230	0.080
13.275			186.230	0.020	286.520	0.030	472.750	0.050
14.625			153.980	0.015	245.470	0.020	399.450	0.040
38.760			165.580	0.020	762.190	0.080	927.770	0.090
39.560			381.800	0.040	457.180	0.050	838.980	0.080
40.780			551.150	0.060	673.550	0.070	1,224.70	0.120
39.035			497.300	0.050	438.920	0.040	936.220	0.090
69.200	1,075.00	0.110	703.200	0.070	1,038.00	0.100	4,698.08	0.480
60.050			878.380	0.090	900.750	0.090	1279.13	0.130
55.300			693.550	0.070	553.000	0.050	746.550	0.080
79.500			1,806.30	0.180	1,113.00	0.110	2,019.30	0.200
62.650	1,040.00	0.100	1,145.30	0.110	814.400	0.080	3,499.70	0.360
40.000			612.000	0.060	600.000	0.060	712.000	0.070
Total 1003.460	6,825.50	0.680	10,927.1	1.090	12,680.0	1.260	30,414.6	3.030

The generalised data of the slag content of scrap are presented in Table 3. The slag content of scrap, taking into account the specific yield, averages 57.5%.

Table 3 Concentration of slag in scrap (in %)

Sample number	Fraction of scrap [mm]					
	+ 70.00	40-70	20-40	10-20	5-10	-5.00
1.00	69.10	62.00	69.09	80.50	89.10	75.40
2.00	49.71	59.10	67.87	74.24	72.39	84.40
3.00	64.20	52.71	64.31	50.49	48.78	86.90
4.00	54.50	58.70	68.50	83.78	81.01	89.30
5.00	49.80	54.50	71.70	79.50	86.10	
6.00	46.00	48.20	46.46	44.04	83.10	
7.00	48.50	36.88	38.87	77.90	56.12	
Average	54.50	53.20	60.90	70.06	78.80	84.00

INVESTIGATION OF THE PROCESS OF METAL REMOVAL FROM SLAG

In existing technological circuits of treatment of metallurgical slags (Novolipetsk Metallurgical Plant, Mariupol Ilyich Metallurgical Plant) standard separators produced for mining and coal industries are used for the metal removal from fractionated crushed stone. During the processing of the slag material these separators do not ensure the maximum removal of metal contained in the slag. To create special electromagnetic separators intended for treatment of metallurgical slag, tests of optimum regimes of the magnetic separation process were carried out with experimental magnetic separation equipment.

Samples used for investigation:

slag sand fractions — 5 mm

scrap and slag crushed stone fractions: +5–10 mm, +10–20, +20–40, +40–70, +70–150 and +150–300 mm.

The objective of the tests was to formulate preliminary requirements for special separators. During the course of this work the scrap removal was studied as a function of:

- magnetic field strength
- granulometric composition of scrap
- thickness of layer of scrap to be separated
- suspension height of a separator
- slag content of scrap.

For all scrap fractions, in order to determine the dependence of the efficiency of removal on magnetic field strength, separation was carried out under the following conditions: the samples of the available scrap of a certain mass and of a certain slag content (for fractions of 5–10, 10–20, and 20–40 mm the average slag content of samples was 40 to 45%) were placed on a conveyor belt. Scrap samples were disposed at some distance after each other. Scrap samples were fed into the magnetic field of the separator at a slow speed corresponding to the speed of belt movement of production-scale conveyors.

Samples were removed from the zone of the magnet action by a discharging device. The percentage of the scrap removal was determined. Value of the electric current supplying electromagnetic coils was varied in an interval: beginning of the scrap recovery: 100% of the scrap removal. Suspension height of the electromagnet was 120 mm.

Test results show that the initial magnetic field strength ensuring the beginning of the scrap removal of the above-mentioned fractions is 120 Oersted. 100% guaranteed scrap recovery of the above mentioned fractions is achieved in magnetic fields with strength that is not less than 400 Oe, and for +5–10 mm fraction not less than 500 Oe.

Based on the results of the tests, optimum regimes of the magnetic separation process were determined for fractionated crushed stone and sand slag. Taking into account the layer thickness of the separated material which is determined by capacity of the system for treatment of slags and by actual measurements on a conveyor, the suspension height of magnetic separators is calculated on the basis of a double dimension of the slag layer on a conveyor. The best conditions of the separation process are listed in Table 4.

Table 4 The optimum condition of separation of slag

Fraction [mm]	Thickness of layer [mm]	Height of suspension [mm]	Magnetic field strength in separation zone [Oe]
-5	40	80	1,000
5-10	40	80	800
10-20	60	120	620
20-40	60	120	520
40-70	100	200	600

Determination of the optimum parameters of magnetic induction in the working zone of separator for scrap removal, with maximum particle size of 40 mm, 150 mm and 300 mm was performed under production conditions at the Novolipetsk Metallurgical Plant.

To this end, three experimental separators were manufactured in which the magnetic induction was varied over a wide range. As a result of the tests the following values of magnetic induction in the working zone were fixed when the guaranteed scrap recovery took place.

1. Separator for removal of scrap with size 40 mm:
magnetic induction in the working zone: 0.2 T
power consumption: not more than 2.5 kW
2. Separator for removal of scrap with size 150 mm:
magnetic induction on the edge of the working zone: 0.29 T
magnetic induction in the middle of the working zone: 0.17 T
3. Separator for removal of scrap with size up to 300 mm:
magnetic induction in the edge of magnetic poles: 0.11 T
magnetic induction on the surface of the working zone: 0.22 T.

Power consumption of these two separators under thermal steady-state conditions did not exceed 13.6 kW.

The SPSH (СШШШ)–04/80 electromagnetic separator presented in Fig. 1 is intended for removing magnetic scrap from metallurgical slags with particle size of 40 mm transported by a belt conveyor.

Fig. 1 The SPSH–04/80 electromagnetic separator

The SPSH–04/80 electromagnetic separator consists of an electromagnetic system (4) and a device for discharge of the magnetic product (3). The electromagnetic system (4) comprises a magnetic yoke, excitation coils and pole-pieces of special profile. The device for the discharge of the magnetic product (3) is fixed on the electromagnetic system by means of arms (2). The separator is suspended on frame (5) over the belt conveyor (1) 800 mm wide for transportation of slag with particle size of 40 mm.

Magnetic product is fed into a zone of the magnet action and is attracted by the magnetic field to the belt of the device for the discharge of the magnetic product and is removed from the zone of the magnetic field action by means of scrapers fixed on the conveyor belt. It is then discharged into the receiving chute (6).

The SKSh–15/100 electromagnetic separator shown in Fig. 2 is intended for removing magnetic scrap from metallurgical slags with particle size of 150 mm transported by a conveyor belt. SKSh–15/100 electromagnetic separator consists of a frame (5), electromagnetic pulley (1), electromagnetic system (3), drive (2) and discharge device (4) in the form of an endless conveyor belt.

Fig. 2 Schematic diagram of the SKSh-15/100 electromagnetic separator.

The SKSh-115/100 electromagnetic separator is mounted on frame (7) over the conveyor belt (6) 1000 mm wide, for transportation of slag with particle size of 150 mm. The separator is mounted over the conveyor belt with a small gap between the top edge of the transported slag and the belt surface of the discharging device, as can be seen in Fig. 3. Linear velocities of the conveyor belt and of the discharging device should be equal.

Fig. 3 Position of the conveyor belt with respect to the discharge device.

During the motion on the conveyor belt (6), a raw slag is fed into the action zone of the magnetic field established by the electromagnetic system (3). Due to its action, magnetic scrap is attracted to the belt (4) of the discharge device. Then, by means of the conveyor belt of the discharge device, the scrap moves into the action zone of the magnetic field of the pulley, is attracted to it, moves upwards and is further transported by the belt conveyor into the discharge chute.

Schematic diagram of the SPSH-30/140 electromagnetic separator is shown in Fig. 4. This separator is intended for removal of metallurgical scrap with particle size of 300 mm. The separator consists of electromagnet (1), frame (2), discharging device (3) and drive (4). The discharging device (3) consists of a belt on which scrapers are fixed, as well as a driving drum and a tension drum. The separator is mounted over the driving (discharging) drum (5) of the belt conveyor 1400 mm wide, for transportation of raw slag. In order to avoid the shunting of the magnetic field of the separator, the driving drum (5) is made of non-magnetic steel.

Fig. 4 Schematic diagram of SPSH-30/140 magnetic separator

Magnetic scrap of large size (300 mm) and weight (up to 100 kg) is not attracted to the discharging device, and under the action of the magnetic field of the separator it changes its fall trajectory and reaches a scrap chute. The separator operates both in continuous mode and in a mode with metal detector.

RESEARCH OF TECHNOLOGY FOR METALLIC SCRAP CLEANING

It was established that during the secondary processing of steel-smelting slags by means of a system for treatment of slags, the metal is removed with the slag

content of about 40 to 50 %. For technical and economical reasons it is much more sensible to use steel scrap in steel-making units providing compliance of quality indices of scrap with requirements of regulations which control its use. (The slag content is 10 to 15%). Technology of scrap cleaning from a mineral component will raise its metallurgical value.

The efficiency of the scrap cleaning process from mineral components depends on technical specifications of a concrete cleaning mechanism. Tests were carried out under conditions of a production process at Novolipetsk Metallurgical Plant by Niipivtorchermet and Gipromashugleobogashcheniye Institutes. Representative samples of the converter slag removed from a slag were used. In each test samples with the most characteristic slag content for all mass of scrap were selected. The scrap cleaning was performed by using an experimental drum having the following specification:

Internal diameter:	1200 mm
Length of cylindrical part	4800 mm
Diameter of the the feed opening	800 mm
Rotational speed	7 rpm
Diameter of discharge opening	80 mm
Capacity	3 t/h

The test results are presented in Table 5. Comparison of the initial and resulting data shows that the scrap cleaning in a drum under the conditions of the tests results in reduction of the slag content to 15 %.

On the grounds of the research carried out so far, specifications for systems of equipment for slag treatment were formulated as a whole and for its individual parts.

DEVELOPMENT OF SYSTEMS FOR TREATMENT OF SLAG

Based on investigations carried out by the Gipromashugleobogashcheniye Institute, systems of equipment KSh-1000 and KSh-75 have been developed for treatment of metallurgical slags (blats-furnace, process, steel works) in slag dumps and from current production.

Table 5 Results of scrap cleaning tests

Sample number	Sample mass [kg]	Slag content in scrap [%]	
		Before cleaning	After cleaning
1	2.48	59.6	16.8
2	6.15	54.8	11.2
3	2.78	28.2	11.7
4	16.42	35.8	14.9
5	19.25	41.6	10.8
6	5.15	32.5	9.9
7	4.23	45.8	13.2
8	11.32	38.5	14.1
9	8.25	41.6	11.9
10	9.25	37.1	10.8

The principle of operation of these systems is based on successive slag screening after crushing with subsequent removal of metallurgical scrap and its slag inclusions in a magnetic field of electromagnetic separators, and on cleaning of the removed scrap from mineral components. The main parameters and overall dimensions of these systems are listed in Table 6.

Table 6 Specifications of systems for slag treatment

Specification	Unit of measurement	Value	
		KSh-1000	KSh-75
Capacity	t/year	1,000	75
Slag content of the removed scrap	%	40	40
Maximum size of scrap	mm	300	250
Slag content of cleaned metal scrap	%	10	10

Each of these systems comprises the following special equipment: receiving hopper with a feeder, tube screen, unbalanced—throw screen, three electromagnetic separators and assembly for scrap cleaning.

The systems should be operated with standard equipment completed and selected by the Institute depending on concrete conditions of the equipment installation. The systems are manufactured by the Lugansk Parkhomenko Machine—building Plant in co—operation with the Gipromashugleobogashcheniye Institute.

Vladimir Nikolaevich Vlasov was born in 1950 and graduated from the Lugansk Machine—Building Institute. Dr. Vlasov's main interest is the design of magnetic separators and devices for separation of non—magnetic metals and ores and concentration of diamond—bearing raw materials in magnetic liquids. He is the author of 42 inventions and patents and of 15 papers.

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