

Article

Research on the Production of Pigments Based on Composite Pellets in the Recycling of Industrial Waste

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Abstract: This article presents the complex processing of low-grade and substandard chromium ores, as well as sludge tailings, with the production of composite chromium-containing materials and pigments, while improving environmental performance in the Republic of Kazakhstan through the utilization and processing of technogenic raw materials. In this work, to study the physicochemical properties of the starting materials, modern analytical, thermodynamic, chemical, granulometric, as well as computational, mathematical, laboratory, and experimental methods were used. In particular, studies of a method for producing composite pellets for chromite pigments based on industrial technogenic waste of the Republic of Kazakhstan are presented. Based on the results of the experimental studies, composite pellets were obtained, having a compressive strength of 150–220 kg/pellet and containing 49.7% of chromium oxide and 0.5–1.0% of carbon in its composition. The resulting chromite pigment based on the composite pellets is a modification of chromium oxohydroxide with the formula $\gamma\text{-CrOOH}$. The density of the resulting pigment is 3.4 kg/m³. The chromite pigment based on the composite pellets is recommended for use in various coloring compositions, including using it for printing on cotton and mixed fabrics intended for sewing outerwear.

Keywords: industrial waste; environment protection; environment engineering; composite pellets; chromite ores; printing; pigments



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1. Introduction

Currently, the issues of environmental protection and solution of environmental problems of industrial regions, with the aim of complex utilization of industrial waste and mineral raw materials, as well as improving the welfare of the population and preserving the fauna and flora of the Republic of Kazakhstan, are an urgent task [1,2].

Integrated processing of low-grade and substandard chromium ores, as well as sludge tailings, while improving environmental performance, dramatically increases the value of using non-traditional raw materials in factories for the production of composite chromium-containing products and pigments [3,4].

Currently, in the world practice for the production of pigments for the textile industry, there are many ways to obtain them based on chromium compounds, but the use of composite industrial waste in the form of internal overburden of coal mining, substandard chromite ores, and dust from aspiration systems has not been sufficiently studied. A systematic approach to chromite waste has not been developed as a raw material for the production of composite pigments containing surface-active modifiers and used for printing on cotton and mixed fabrics [5,6].

There is a known method for producing iron-containing inorganic pigments from technogenic waste [7–11]. Among the most demanded iron-containing pigments are iron oxide pigments, the color of which is mainly determined by the features of their composition and structure. The basis of yellow pigments is Fe(III) oxide hydrates: red—Fe (III) oxides and black—Fe₂O₃. Corresponding pigments can be successfully obtained from iron-containing industrial wastes [12–14]. Iron oxides can be included not only in the composition of iron oxide pigments themselves but also in the composition of mixed pigments obtained from industrial sludge, which have increased resistance to corrosion. The increase in anticorrosion properties is due to the presence of Zn, Cr, Ni, and Cu compounds in industrial wastes, which, to one degree or another, pass into the composition of the obtained pigments [15]. The development of the technology of mixed pigments allows one to rationally dispose of technogenic wastes of complex composition [16,17].

Pronounced anticorrosion properties are exhibited by pigments containing calcium ferrite. The ratio of iron oxide to calcium oxide in the sludge mixture intended for processing should be 1:2–1:4. Calcination of the mixture at 900 °C allows obtaining calcium ferrite suitable for use as an anticorrosive pigment [18,19].

In the Republic of Kazakhstan, the chromite ore deposits of the Kempirsay massif are located in Aktobe region, the southern tip of the Ural range—in Northern Mugodzhary.

The chromite ore of the Kempir say massif is a fine-grained rock with a massive texture. Porphyritic crystals of amphibole and laths of plagioclase stand out against the fine-grained background of the main ore mass [20,21].

Chromite ores are from light gray to gray with various inclusions, and internal overburden rocks are from light brown to dark brown, depending on the content of iron-manganese and chromium impurities in them [22–24].

Internal overburden rocks are wastes of brown coals of the coal mining industry [25–33]. The use of internal overburden rocks in coal mining also seems to be appropriate due to the fact that, when producing pellets, they play the role of a fuel component and a quartz-containing material.

Aspiration dust is a waste of the Aktobe ferroalloy plant. The dust is a finely dispersed fine of a fraction of 0.01–1 mm with a content of metal chromium of 65–70%. Due to the fineness of the dust, it is practically a substandard material [34–38].

Thus, the presence of a large amount of coal-mining waste, aspiration dust, and substandard chromite ores; their poor study; and the lack of available technological solutions for practical use in the industry create conditions for the need to conduct research on methods of utilization and conditions for the thermal processing of starting raw materials and semi-finished products, with the creation of a technology for obtaining composite chromite pigments from industrial waste for printing on cotton and mixed fabrics [39–41].

The aim of this scientific work is to study the method of obtaining pigments based on composite pellets in the recycling of the industrial waste.

2. Materials and Methods

Substandard industrial wastes, such as chromite ores, internal overburden rocks, and aspiration dust, were used as starting raw materials. The bulk density of the analyzed samples is as follows:

- Chromite ores of class 0–10 mm—1.8–1.9 g/cm³;
- Internal overburden rocks—1.2–1.3 g/cm³;
- Aspiration dust (from Aktobe ferroalloy plant)—1.1–1.2 g/cm³.

To study the physicochemical properties of the starting materials, modern analytical (quantitative and qualitative), thermodynamic, chemical, granulometric, as well as computational, mathematical, laboratory, and experimental methods were used.

2.1. Instrumental Research Methods

Research work was carried out using a scanning electron microscope (SEM)(JSM-6490IV, Jeol, Tokyo, Japan), a multi-parameter portable cyberscanner (PCD 650 Eutech),

an IR-Fourier spectrometer (Zhimadzu IR Prestige-21), a differential thermal analyzer (DTA), granule strength meter IPG-1M, and an X-ray energy-dispersive microanalyzer INCAEnergy (High Wycombe, UK).

The morphology of internal overburden rocks and substandard chromite ores was studied using a scanning electron microscope (SEM) brand Jeol JSM-6490I V (Tokyo, Japan). The results are presented in Figures 1 and 2a–e.

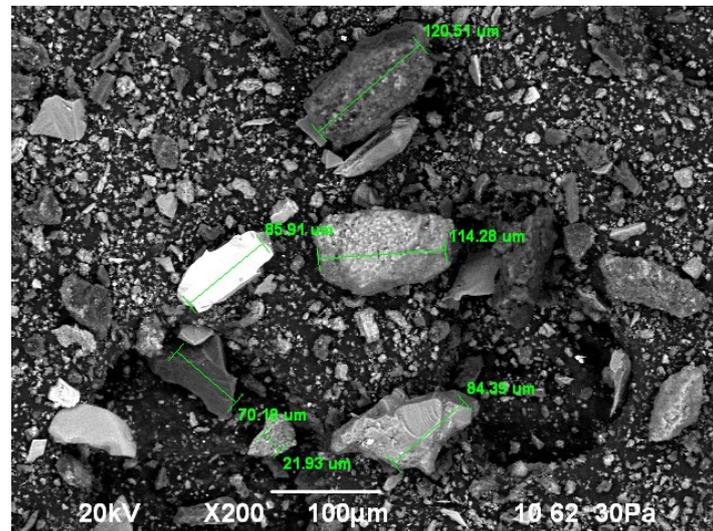


Figure 1. Morphology of internal overburden rocks on reflected electron probe (magnification $\times 200$).

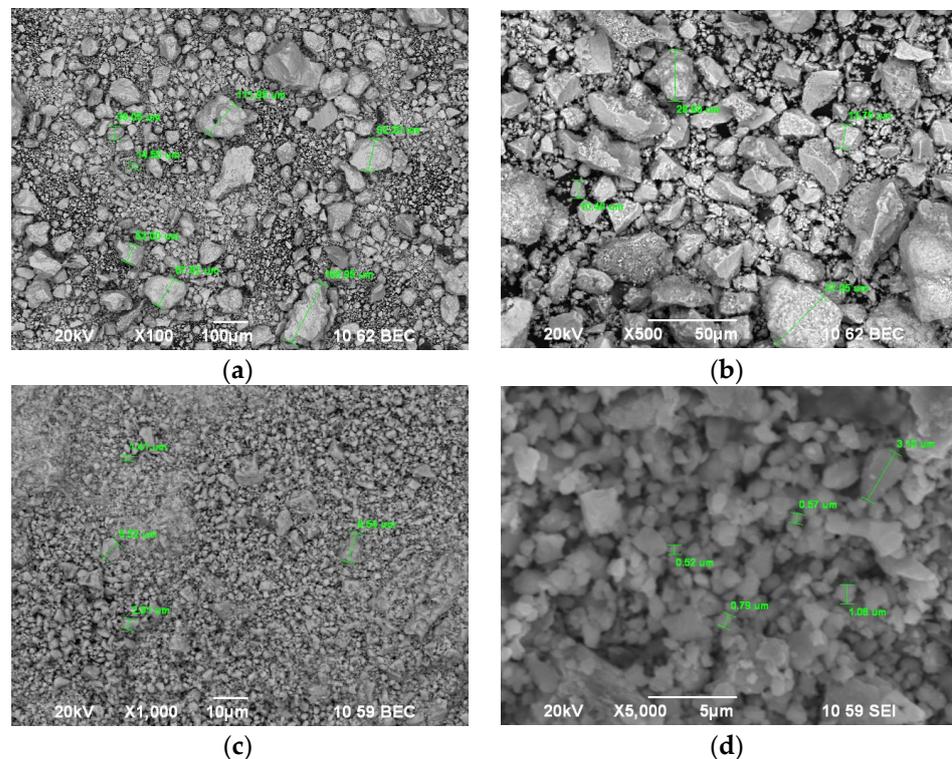


Figure 2. Morphology of substandard chromite ores on reflected electron probe. (a) Magnification $\times 100$; (b) magnification $\times 500$; (c) magnification $\times 1000$; (d) magnification $\times 5000$.

From Figures 1 and 2, it follows that the size of the dispersed particles of internal overburden rocks ranges from 20 to 120 microns, and the particle size of substandard

chromite ores is from 0.5 to 180 microns. This indicates the need for preliminary grinding of the initial charge materials to a class of less than 0.1 mm.

In the course of this experimental work, the average granulometric and chemical compositions of chromite waste, internal overburden rocks, and aspiration dust were determined and are given in Tables 1 and 2, respectively.

Table 1. Averaged granulometric composition of substandard chromite raw material, internal overburden rocks and aspiration dust.

Material	Content of Material of Class (mm) in %				
	+10	5–10	3–5	1–3	0–1
Substandard chromite ore	4.4	18.8	43.2	11.8	22.8
Internal overburden rocks	-	7.8	21.7	22.9	47.6
Aspiration dust	-	-	-	3.4	96.6

Table 2. Averaged chemical composition of substandard chromite raw material, internal overburden rocks, and aspiration dust.

Material	Content Of Components, in % Mass								
	Cr ₂ O ₃	CaO	MgO	SiO ₂	Fe ₂ O ₃	SO _{3total}	Al ₂ O ₃	C	Moisture
Substandard chromite ore	38.9	0.26	19.27	22.78	10.11	0.02	6.76	-	1.9
Internal overburden rocks	-	5.1	2.3	32.7	9.9	1.8	12.8	35.4	-
Aspiration dust	44.5	0.15	0.15	10.84	11.18	0.018	7.67	-	1.6

It follows from Table 1 that the averaged granulometric composition of the starting materials is quite fine and has a positive effect on the process of obtaining chromite pellets.

It follows from Table 2 that the chromium content in chromite ore is 38.9%, and in the aspiration dust, it is 44.5%; it is enough to use such a content of useful components as starting materials for obtaining composite pellets from chromite pigments.

2.2. Methodology of the Experiment

In the course of this experimental work, substandard chromite ore in terms of chemical and granulometric composition, internal overburden rocks, and aspiration dust (from the Aktobe ferroalloy plant) were preliminarily crushed in a drum ball mill to a class of less than 0.1 mm; water was used as a binder in the granulation process, and then, raw composite pellets with a moisture content of 10–15% were obtained from the charge materials taken in certain proportions using a plant with a plate granulator having a diameter of 1 m and a speed-adjusting gearbox. The produced composite chromite pellets are shown in Figure 3.

Preliminary drying of the composite pellets was carried out at a temperature of 573–673 K for 15 min; then, the temperature in the pellet layer rose to 1427 K, and the pellets were kept at temperatures of 1227–1427 K for 20–25 min. Upon reaching a temperature of 1427 K in a layer between 100 and 200 mm, a decrease in the flow of natural gas to the gas-burner device was carried out with an excess of oxygen necessary for the combustion of carbon in the composite pellets containing internal overburden rocks [42–44].

The process of obtaining calcined composite pellets is a thermal process of agglomeration and consists of the following operations: grinding of the charge components; their dosing and mixing; pelletizing, drying, and high-temperature firing of granules; and their cooling and sorting, with the receipt of the finished product—calcined composite pellets. The technological scheme for obtaining composite pellets is shown in Figure 4.



Figure 3. Produced composite chromite pellets.

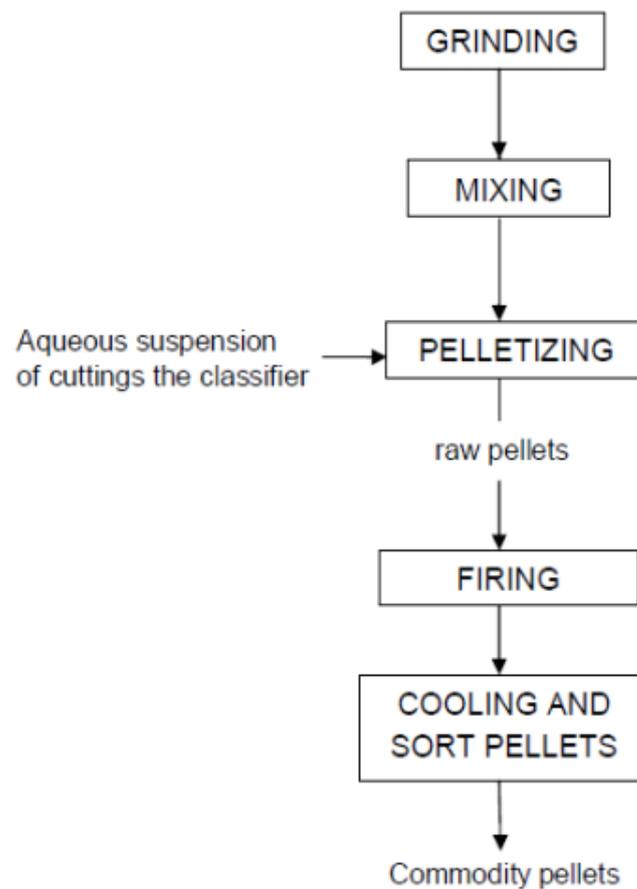


Figure 4. Technological scheme for obtaining composite pellets.

Pigment synthesis. A certain mass of potassium hydroxide was placed in a porcelain mortar and crushed, a mass of hydroxide chromate was added, and the mixture was crushed for 25–30 min until a homogeneous powder was obtained (Figure 5). The powder was poured into a porcelain crucible and calcined for 35–45 min in a muffle furnace at a temperature of 873–923 K.



Figure 5. Raw materials for synthesis of chromite pigment.

After calcination, the mixture was cooled and transferred to a porcelain mortar (for grinding). Distilled water was poured in the ratio semi-finished product: water = 1:0.5. The ground semi-finished product was transferred to a porcelain glass and washed 3–4 times with water. The suspension was filtered on a Buechner funnel, and the precipitate was washed 5–6 times with water. After that, the pigment was dried at 348–375 K. To improve the color of the pigment, it was subjected to secondary calcination at 873–923 K for 3–4 h [45,46].

3. Results and Discussion

The process of roasting composite pellets containing carbon in an oxidizing environment, in contrast to the roasting of pure chromite pellets, was accompanied by intense heat release due to the combustion of solid fuel from the surface of the pellets and required a certain technological, thermotechnical, and gas-dynamic operating mode of the firing unit [47,48].

Therefore, research was carried out on the heat treatment of composite pellets at different firing temperatures in a shaft furnace with heated air sucking through the layer of the material being fired.

Research data on the change in the chemical composition of composite pellets, depending on the content of solid fuel in them, and the firing temperature at 1073, 1173, 1273, and 1373 K for 20 min are given in Table 3, and the change in the strength properties of the composite pellets is shown in Figure 6.

Table 3. Change in the chemical composition of composite pellets depending on the firing temperature, K at 20 min exposure.

Material	Pellets, Firing Temperature, K									
	Raw Materials		1073		1173		1273		1373	
	Cr ₂ O ₃	C								
Purely chromite	20.9	absent	21.2	absent	21.8	absent	22.4	absent	22.6	absent
Chromite with 5% of internal overburden rock	19.8	4.3	21.1	2.2	22.0	2.0	22.2	2.0	22.2	1.9
Chromite with 7.5% of internal overburden rock	19.4	6.0	21.2	3.0	21.8	2.9	22.1	2.6	22.2	2.6
Chromite with 10% of internal overburden rock	18.9	8.6	21.3	4.0	21.6	3.9	22.2	3.6	22.2	3.5

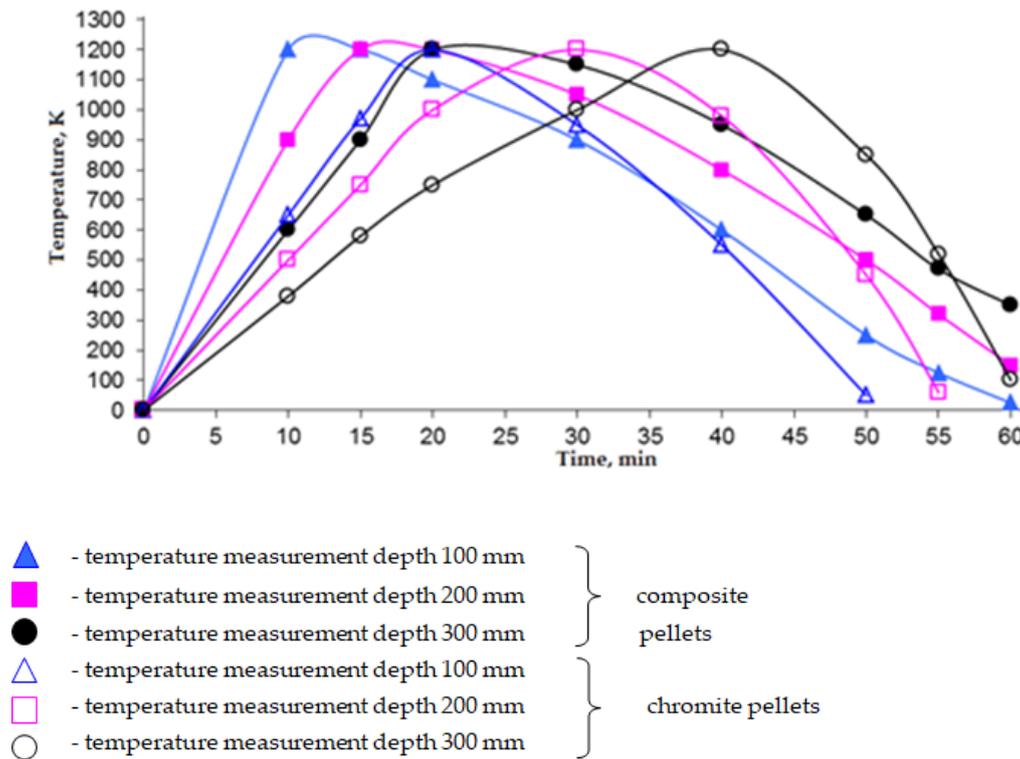


Figure 6. Change in temperature from layer height during roasting of chromite and composite pellets.

It follows from Table 3 that due to the increase in the firing temperature from 1073 K and above, the chemical composition of the composite pellets becomes stronger, and this is explained by the burnout of solid fuel from the surface of the pellets. Moreover, with the increase in the content of internal overburden rocks, the heat treatment time of the pellets decreases.

In the process of the thermal treatment of composite pellets containing internal overburden and aspiration dust in a shaft furnace, it was found that at a temperature of 1073 K, in the high temperature zone of the furnace, the temperature in the material layer rises by 473–523 Kelvin, which can be explained by the burnout of solid fuel from the surface of the granules. To determine the duration of pellet roasting in relation to the technology of the production of chromite pellets on roasting machines, using calcined pellets as a bed, studies were carried out on the heat treatment of composite pellets from a mixture of chromium fines and aspiration dust containing internal overburden rocks on a bed of calcined composite pellets and without underlayment.

The height of the bed layer was 100 mm, and the height of the main layer of pellets subjected to heat treatment was 300 mm.

The combustion products of natural gas with a temperature of about 990–1020 K, up to the ignition temperature of carbon, located in the internal overburden on the surface of the pellets, were used as a heat carrier. After the carbon fire, the supply of natural gas to the hearth was stopped, and only air was supplied.

It follows from Figure 6 that when studying the thermotechnical characteristics of the heating process of the composite pellets, it was found that during the heat treatment of the pellets containing carbon from internal overburden rocks, on a bed of calcined pellets, compared with the heat treatment of pellets without an underlying layer of the bed, with the same content of internal overburden rocks in pellets being 7.5%, the heating of the pellets along the height of the material layer (curves 2 and 3) is 373–393 Kelvin higher. This significantly affects the strength properties of the composite pellets after calcination, as well as the time of their heat treatment. When studying the process of roasting chromite and internal overburden rock containing pellets, we took averaged samples and carried out numerous experiments to

determine the optimal values. Based on the experiments performed, the optimal values do not exceed the permissible error in the range of 0.1–0.2% [49,50].

In the course of the research, the distribution of carbon over the volume of the composite pellets, determined during the self-grinding of the pellets, was studied in accordance with the research methodology of the authors [51].

When determining self-grinding, a mill was adopted, having: speed of rotation—80 rpm, working volume—5170 cm³, and working surface—1060 cm³. As an indicator of resistance to grinding, the value *p* was chosen, the reciprocal of self-grinding, and was equal to the difference in the amount of weight of the pellet sample remaining in the mill and dust. The grinding resistance index was determined by the formula [52]

$$p = M - Mb/M \times 100\% \tag{1}$$

where *M* is the weight of the pellets before grinding (g), and *Mb* is the weight of the pellets after grinding (g) at a constant number of revolutions of the mill and sampling every hour.

Based on the previous formula, it is possible to judge the strength properties of the composite pellets, i.e., the lower the self-grinding index, the lower the strength characteristics of the pellets. The ratio of the amount of the pulverized material formed to the initial mass of the pellet is determined by the formula [53]

$$\frac{M_{n.m.}}{M_{ok}} = 1 - \left(\frac{r_i}{r_o}\right)^3 \tag{2}$$

where *M_{n.m.}* is the weight of the pulverized material (g), *M_{ok}* is the weight of the pellet (g), *r_i* is the current pellet radius (mm), and *r_o* is the initial pellet radius (mm).

This formula can be used in determining the carbon content by volume of pellets by chemical analysis.

It follows from Table 4 that pellets calcined on a bed of calcined pellets have greater strength than pellets that have undergone heat treatment without a bed. This is explained by the fact that during the heat treatment of pellets without an underlying layer, due to the partial destruction of the lower layers of the pellets, the gas-dynamic firing mode is disturbed, which helps to reduce the time of normal heat treatment of the pellets by almost 1.5–2 times.

Table 4. Dynamics of change in the strength of composite pellets from chromite waste and aspiration dust containing 7.5% of internal overburden rock, depending on the heat treatment time.

Material	Strength of Pellets In Compression of Fractions, mm				By GOST 15137-77	
	20	18	16	14	to shock,	abrasion,

	%+5 mm%–0.5 mm					
Raw	23	24	20	20	-	-
Calcined without a bed during 25 min	1490	2040	1620	1290	93	5
Calcined on a bed of pellets during 45 min	1900	2470	2240	1610	94	4

In the course of studying the distribution of carbon over the volume of composite pellets by chemical analysis, it was found that in the surface layer, which is about 0.1%, and in the inner layer, which is 10–15% of the volume of the pellets, the carbon content is equal to its initial value (Figure 7).

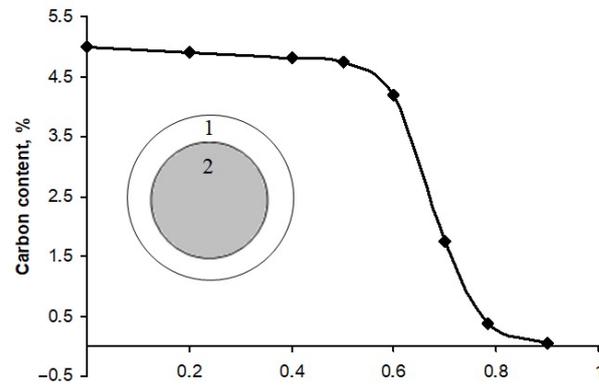


Figure 7. Dependence of carbon distribution by volume of composite pellets. 1—surface, light layer, not containing carbon; 2—inner, dark layer, containing carbon.

The decrease in the carbon content in the composite pellets taken for analysis from the bed can be explained by the burnout of carbon from the pellets during repeated heat treatment. As a result of experimental studies, it was established that the optimal amount of solid fuel required for the normal conduct of the heat treatment of pellets with internal overburden rocks in an oxidizing environment is from 2 to 3.5%.

It was established that in the process of burning carbon-containing composite pellets, in comparison with carbon-free chromite pellets, the heat treatment time is reduced by almost 1.5 times, which is explained by the burning out of carbon in the pellets.

It follows from Figure 8 that the content and ratio of excess oxygen to carbon in the pellets make it possible to raise the temperature in the layer of the material subjected to heat treatment by 200–250 K due to the heat of combustion of carbon (solid fuel); and makes it possible to improve the quality of composite pellets, in comparison with pure chromite ones, in terms of strength and yield of the finished product, and reduce the consumption of natural gas supplied for combustion in the furnaces of roasting machines.

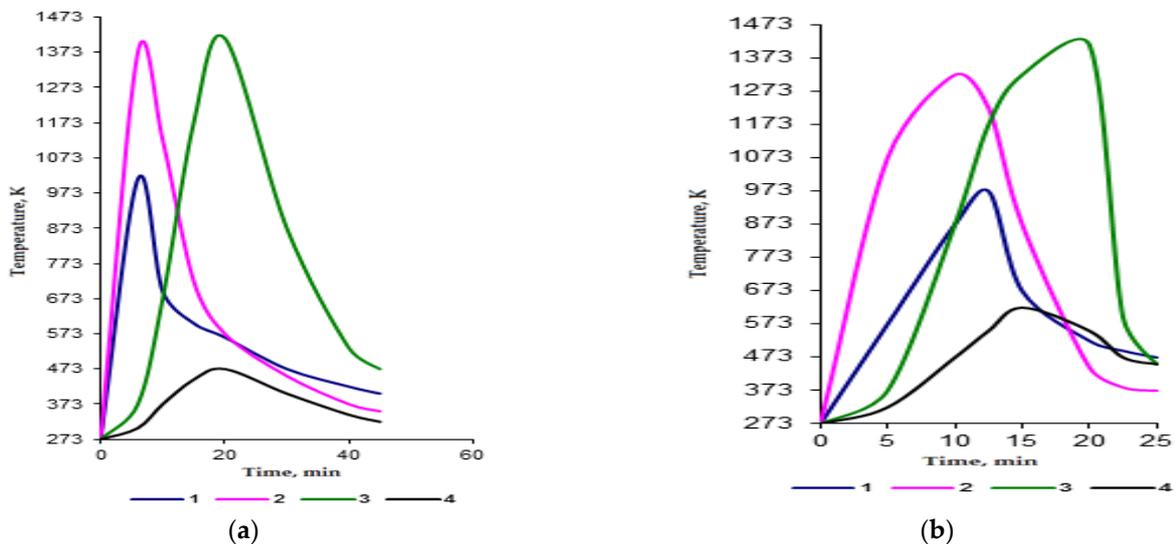


Figure 8. Change in temperature along the height of the material layer during the heat treatment of composite pellets containing carbon from internal overburden rocks on the bed of calcined pellets containing carbon from internal overburden rocks (a) and without the bed (b). Temperature value: 1—in the hearth; 2—at a depth of 100 mm from the surface of the pellets; 3—at a depth of 200 mm; 4—on the firing grate (400 mm from the surface of the pellets).

During the experimental tests for roasting composite pellets, the process of temperature change along the height of the pellet layer was studied at a temperature of 1173 K in the hearth of the roasting bowl. The results are shown in Table 5 and Figure 9.

Table 5. Change in temperature along the height of the pellet bed.

Name	Temperature Measurement Depth (mm)			
	Time, min	100	200	300
Chromite pellets containing carbon and aspiration dust	Temperature, K			
	15	1427	1427	1173
	20	1327	1427	1473
	25	1293	1403	1473
	30	1173	1323	1423
	35	1033	1213	1343
	40	873	1073	1223
45	723	928	1098	

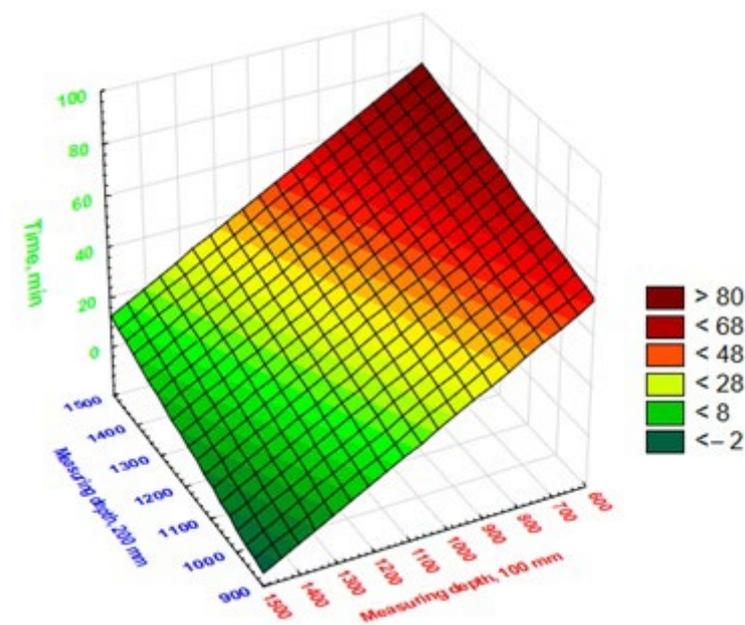


Figure 9. Change in process temperature along the height of the pellet bed.

It follows from Table 5 that, in this mode, the temperature in the lower layers is about 1427 K, in the time interval of 15–25 min, and a reduction in natural gas consumption of up to 50% is achieved. The results of the experiment are shown in Figure 9.

It follows from Figure 8 that temperature changes along the height of the composite pellet bed under the influence of time during the firing process are characterized by a change in the square shape of the plane from red to saturated green [54].

Based on the results of the experimental studies, the composite pellet was obtained, having a compressive strength of 150–200 kg/pellet and containing 49–50% of chromium oxide and 0.5–1.0% of carbon in its composition. The phase composition of the obtained chromite pellets containing carbon and aspiration dust was determined using an incident beam monochromator and is shown in Figure 10.

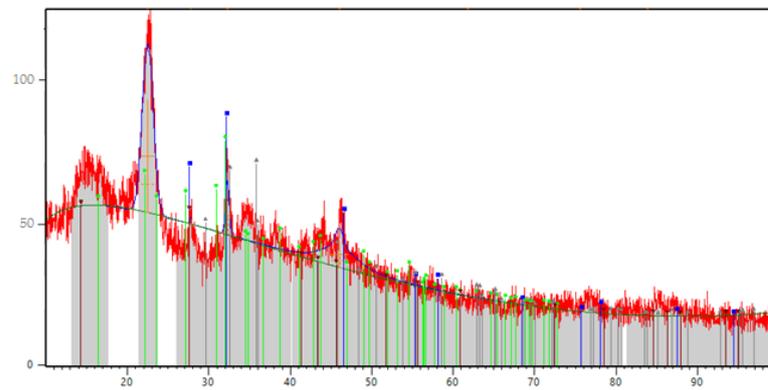


Figure 10. Defactogram of chromite pellets.

The chemical composition of calcined composite pellets containing carbon and aspiration dust is shown in Figure 11 and Table 6.

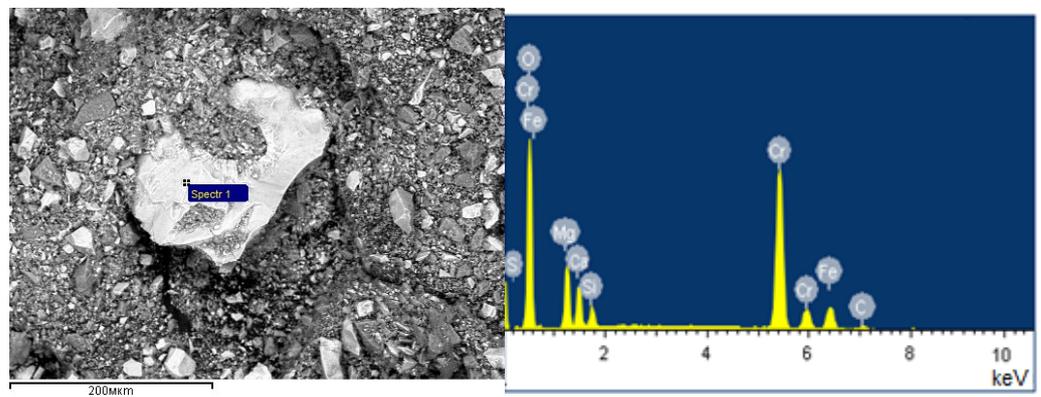


Figure 11. Micrograph of composite pellets.

Table 6. Chemical composition of calcined composite pellets containing carbon and aspiration dust.

Sample Number	Content of Components, in % Mass							
	Cr ₂ O ₃	CaO	MgO	SiO ₂	Fe ₂ O ₃	SO _{3total}	C _{free}	
1	49.9	0.56	14.0	27.23	7.91	0.07	0.77	<0.1
2	49.4	0.60	14.0	27.4	7.82	0.06	0.62	<0.1
3	49.7	0.60	14.1	28.0	6.61	0.05	0.84	<0.1
4	49.8	0.55	13.85	28.6	6.12	0.55	0.93	<0.1
Average	49.7	0.50	13.98	27.8	7.12	0.57	0.79	<0.1

It follows from Table 6 that the average content of chromium oxide in the composite pellet is 49.7%; this content of chromium is enough to use as a semi-product for the production of chromite pigments. Scheme of the recycling of composite chromite pellets with the pigment production is shown in Figure 12.

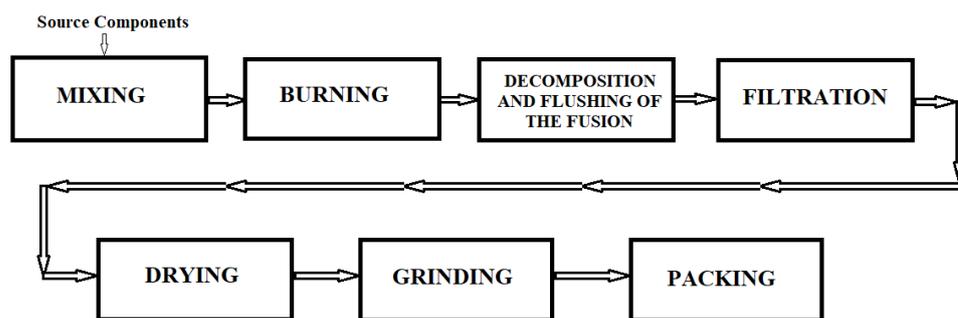
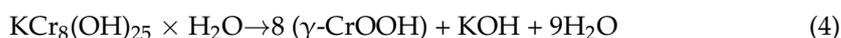
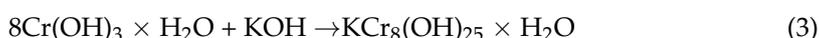


Figure 12. Scheme of the recycling of composite chromite pellets with the pigment production.

The chemistry of obtaining chromite pigments based on composite pellets when interacting with a solution of potassium hydroxide [55] is given as follows:



The chemical reaction is localized in the area of the interface between the solid phases of the starting material and the reaction products. Kinetic patterns were studied for chromite pigment having an emerald green color, and the hiding power was 38–42 g/m².

The resulting chromite pigment is a modification of chromium oxohydroxide with the formula $\gamma\text{-CrOOH}$. The density of the resulting pigment is 3.4 kg/m³. The quality indicators of the obtained chromite pigment are presented in Table 7.

Table 7. Quality indicators of chromite pigment samples.

Requirements of Technical Specification 20.12.24-335-35749547-2020		
Indicators	Norm	Obtained Sample
Mass fraction of the main substance in terms of CrOOH·H ₂ O, % not less than	88	91 ± 1
Mass fraction of water and volatile substances, % no more	9	7.5 ± 1
pH of water extract	6.5–8.5	7.3 ± 0.5
Mass fraction of substances soluble in water, % no more	1.0	0.35 ± 0.1
Hiding property, g/m, no more	50	38 ± 1
Residue on sieve No. 0063 after wet screening, % no more	0.06	0.05 ± 0.01

It follows from Table 7 that the obtained pigment sample in all quality indicators corresponds to and does not exceed the established norm according to the requirements of the technical specification. The characteristics of the obtained chromite pigment are presented in Table 8.

Table 8. Characteristics of chromite pigment samples.

Composition, Mass. %		Hiding Property, g/m ²		Color Characteristics				
CrOOH·H ₂ O Substances	Water Soluble	H ₂ O	X	Y	Z	λ, nmP, %		
94	0.3	2.2	38	14	22	21	496	33
95	0.3	3.1	37	15	18	18	502	31
92	0.6	6.2	39	16	22	22	501	31
95	0.4	6.1	37	17	23	23	501	28
94	0.4	5.6	39	12	19	18	497	36

It follows from Table 8 that the obtained pigment sample corresponds to all characteristics and does not exceed the established norm according to the requirements of the technical specification.

It follows from the research results that during the granulation of the proposed charge mixture, with a pellet moisture content of 10–15%, raw granules are obtained with a compressive strength of 2.3–3.2 kg/pellet. In the process of roasting composite pellets, in comparison with chromite pellets that do not contain carbon, the heat treatment time is reduced by almost 1.5 times, which is explained by the process of burning out the carbon in the composite pellets.

In the heat treatment of composite pellets containing carbon, a decrease in natural gas consumption by up to 50% was found in comparison with the roasting of pure chromite pellets; this is due to the burnout of about 50% of the carbon of the solid fuel in the pellets. The average carbon content in the composite pellets after heat treatment is 2.35%, and in the bed of calcined pellets containing 2.4% of carbon, after the heat treatment, it is about 1% [56–62].

The increase in the content of Cr₂O₃ in the composite pellets by 9–10% of its initial content in the raw material is explained by the increase in the extraction of chromium oxide into the charge due to the chromium oxides contained in the aspiration dust, as well as the removal of volatile and organic substances from the composition of the charge subjected to the heat treatment. The composite pellets with a compressive strength of 150–200 kg/pellet and containing 49.7% of chromium oxide and 0.5–1.0% of carbon were obtained. To obtain a bright and with a purer color tone Cr₂O₃, it is necessary to have in its composition a fraction of particles ranging in size from 0.05 to 0.5 mm in an amount of up to 13%.

The resulting chromite pigment differs from analogues with a rich color, high light, and weather resistance. It is also resistant to concentrated sulfuric, hydrochloric, and nitric acids and alkalis and withstands heating up to a temperature not exceeding 368 K.

4. Conclusions

Based on the conducted research, the following findings and conclusions can be drawn; in particular, it was found that:

- Industrial waste, such as substandard chromite ores and overburden and aspiration dust, according to their physicochemical characteristics, can act as a secondary mineral raw material for the formation of a raw mixture in the form of composite pellets with subsequent production of a pigment-dye;
- Composite pellets can be obtained from industrial waste, in particular, raw granules with a pellet moisture content of 10–15% with a compressive strength of 2.3–3.2 kg/pellet, as well as calcined pellets with a compressive strength of 150–200 kg/pellet containing 49.7% chromium oxide and less than 1.0% carbon in its composition;
- The resulting chromite pigment is a modification of chromium oxohydroxide with the formula γ -CrOOH with a density of 3.4 kg/m³ and has an emerald green color and a hiding power of 38–42 g/m²;

- The synthesized light green chromite pigment based on Cr^{3+} oxides with brightness exceeding foreign samples, when tested as a dye, showed that, unlike the traditionally obtained Cr_2O_3 , it retains its color tone in a tinting medium and gives a pleasant emerald green color.

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