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Виконавець: **Студент 6 курсу, групи** 184м – 16-3ММФ

____________ Печерський Вадим Андрійович
(підпис) (прізвище, ім'я, по-батькові)

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завідувач кафедри
Збагачення корисних копалин
(повна назва)
____________ Левченко К.А.
(підпис) (прізвище, ініціали)
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студенту _184м – 16 – 3ММФ Печерський В.А.
(група) (прізвище та ініціали)

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Мета НДР Зменьшення втрат ільменіту з відходами магнітного збагачення розсипних руд Бирзулівського родовища у Кіровоградській області в умовах ТОВ ВКФ «Велта». ____

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Наукова новизна: застосування високоградієнтної магнітної сепарації з попереднім розділенням їх живлення на класи крупності -0,8+0,25 та -0,25мм.

Практична цінність: втрата ільменіту з відходами збагачення призводить до зменшення ефективності переробки в цілому, тому розробка альтернативних технологій переробки цих руд з отриманням товарних продуктів та зменшення втрат з відходами збагачення є актуальною задачею.

4 ВИМОГИ ДО РЕЗУЛЬТАТІВ ВИКОНАННЯ РОБОТИ

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7 ДОДАТКОВІ ВИМОГИ

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____

Завдання видав ___________ Березняк О.О.
(підпис) (прізвище, ініціали)

Завдання прийняв до виконання _____ Печерський В.А.
(підпис) (прізвище, ініціали)

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Предмет досліджень є ільменітові руди розсипного родовища.

Метою дипломної роботи є зменшення втрат ільменіту з відходами магнітного збагачення розсипних руд Берзулівського родовища в умовах ТОВ ВКФ «Велта».

В дипломній роботі запропоновано оригінальне рішення, яке полягає у застосуванні високоградієнтної магнітної сепарації з попереднім розділенням їх живлення на класи крупності -0,8+0,25 та -0,25 мм. Перший клас збагачується на роликовому сепараторі зі стрічкою, а другий – на сепараторі відхиляючого типу. Таке рішення дозволило підвищити ефективність схеми збагачення в цілому.

У розділі охорона праці та здоров'я розроблено та обґрунтовано заходи щодо зменшення або ліквідації небезпечних і шкідливих факторів, з експлуатації та обслуговування обладнання, проведена санітарно-гігієнічна оцінка умов праці, розроблено заходи з охорони навколишнього середовища.

РОЗСИПНЕ РОДОВИЩЕ. ІЛЬМЕНІТ. МАГНІТНА СЕПАРАЦІЯ. ВИЛУЧЕННЯ ІЛЬМЕНІТУ.

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INTRODUCTION

1.1 Objectives

Subject: Ilmenite ores of the placer deposit

Object: Technology of enrichment of loose ilmenite ores

Objectives: Reducing losses with wastes of enrichment

Tasks:

- Study of separation of ilmenite on a highly graded belt and separator of deflecting type.

- Development of optimal enrichment technology.

Relevance:

Ilmenite is economically important mineral with a chemical composition of $FeTiO_3$ that is the primary ore of titanium, source of titanium dioxide.

Ilmenite concentrate - is a fine-grained material of natural size without taste and smell. Specifically designed for the production of welding electrodes, ferrotitanium, pigmentary titanium dioxide, titanium sponge, titanium metal, etc. [19]

Titanium – inert, resistant to corrosion and strong silver metal. It is an important constituent in a small number of minerals and about 90% of titanium Earth crust occurs in ilminite, rest part is in minerals such as anatase, brookite, leucoxene, perovskite, rutile, and sphene. [22]

Titanium has a wide range of applications: jewelry, prosthetics, bicycle frames, surgical tools, mobile phones, jet engines, spacecraft, military equipment, bearings, body armor, and other high-tech products.

1.2 Deliverables

As a result of the application of the enrichment and use schemes in the concentrate, the degree of extraction will increase by 4.86%, in addition, we will receive a concentrate of 2.33 t/h with an ilmenite content of 97.5% (in the conditions of LLC Velta). Annual income will increase by $ 2.5 million.

Chapter I. Overview of the magnetic separation basis

1.1. Introduction

Increasing the efficiency of enrichment production requires work and the introduction of new technological processes and equipment, providing highly technical and economic indicators in conditions for a gradual decline in the quality of commodity mineral raw materials.

Technological processes should be improved in the direction of energy costs and materials for the production of concentrates, the complete use in the national economy of all components of raw materials, use of the harmful influence of enrichment on the left environment. Rational use of mineral raw materials at all stages of its extraction and processing is one of the most important economic ecological and ecological tasks.

1.2 Fundamentals of theory of magnetic separation

The process of magnetic separation is carried out in the magnetic field of the separator as a result of the effect of magnetic and mechanical forces on the ore grains. Therefore, grains with different magnetic properties move along different trajectories, separating into two or more fractions, issued as separate enrichment products.

The trajectories of magnetic grains extracted into the magnetic fraction are determined by the ratio of the magnetic and mechanical forces acting on these grains in the magnetic field of the separator, and the nonmagnetic ones by mechanical forces acting on the non-magnetic components of the ore.

In order for the magnetic separation process to proceed normally (if it is carried out in the air), the magnetic force must be greater than the resultant mechanical forces directed oppositely magnetic force, and the force necessary to overcome the inertia of moving magnetic particles, i.e. In the magnetic field of the separator for magnetic grains, inequality must be maintained:

$$f_{mag} > \sum f_{mech} + f_{in}$$

f_{mag}– Magnetic force acting on the magnetic components of the ore;

f_{in} – Force necessary to overcome the inertia of moving magnetic particles and depending on the speed of their motion;

$\sum f_{mech}$– The resultant of all mechanical forces in the direction, opposite to the magnetic force.

The basic principle magnetic separation is to pass the material through a magnetic field and the different components of the material will react differently depending on their magnetic susceptibility. The materials that react strongly to this magnetic field (strongly magnetic in nature) are known as ferromagnetic material and those that are less magnetic in nature are called paramagnetic material. The materials that are non-reactive to magnetic fields or very minutely reactive are known as diamagnetic materials.

Three forces are required for particle separation mathematically, which are magnetic force (Fm), gravitational force (Fg) and a drag force (Fd)

The Figure 1 and Equation is taken from and shows that magnetic force which pulls the particle towards the magnet is directly proportional to intrinsic properties of the material as well as the applied magnetic field. [21]

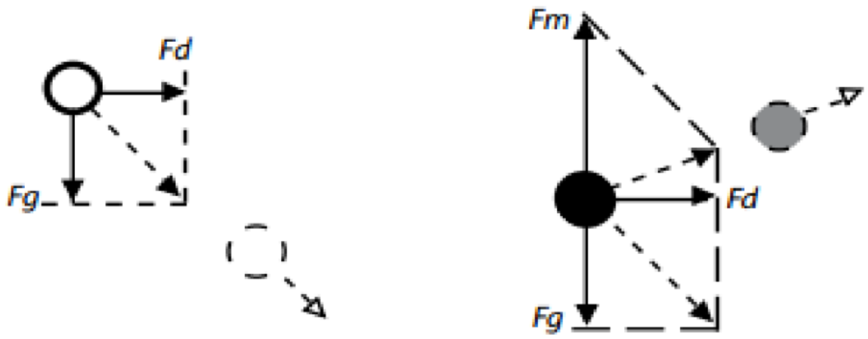


Figure 1 Forces acting on a particle during Magnetic separation process [21]

Equation of magnetic force on a particle:

$$\boldsymbol{Fm} = \boldsymbol{V} * \boldsymbol{\chi} * \boldsymbol{H} * \boldsymbol{grad\ H}$$

Where,

V = Particle Volume (determined by process)

χ = Mass specific magnetic susceptibility (determined by material type)

H = Magnetic field (determined by magnet), mT (milliTesla) or kG (kiloGauss)

grad H = magnetic field gradient (determined by magnet system design)

Magnetic field and magnetic gradient are equally important factors for creating the magnet attraction force. [21]

Table 1 Magnetic susceptibility of minerals [21]

Mineral	**Magnetic susceptibility** ($X_m 10^6$ emu/g)
Magnetite	20 000- 80 000 Ferromagnetic
Pyrrhotite	1 500 – 6 100
Hematite)	172 – 290 Paramagnetic

Ilmenite	113 – 271
Siderite	56 – 64
Chromite	53 – 125
Biotite	23 – 80
Goethite	21 – 25
Monazite	18.9
Malachite	8.5 – 15.0
Bornite	8.0 – 14.0
Rutile	2.0
Pyrite	0.21
Cassiterite	– 0.08 Diamagnetic
Fluorite	– 0.285
Galena	– 0.35
Calcite	– 0.377
Quartz	– 0.46
Gypsum	– 1.0
Sphalerite	– 1.2
Apatite	– 2.64

1.2.1. The main magnetic quantities

Magnetic flow (Φ). A magnetic flux is called scalar the physical quantity F. When the magnetic flux varies through a cross section of the electric circuit attached to it, an electric charge ΔQ passes through it. The determining equation for the magnetic flux is the relation $\Phi = \Delta Q \cdot R$, where R is the electrical resistance of the circuit. From this equation it follows that the dimension of the magnetic flux

$\Phi = L^{2}*M*T^{-2}*I^{-1}$.

Unit of magnetic flux SI [Φ] = 1 Cl * 1 Ohm = 1 Cl * Ohm = 1 Wb

Magnetic induction (B). A magnetic induction is a vector physical quantity that is a force characteristic of a magnetic field. As the determining equation for the magnetic induction in the construction of SI, the equation is chosen:

$\boldsymbol{B} = \boldsymbol{\Phi} / \boldsymbol{S},$

where Φ is the magnetic flux penetrating the surface by the area S.

The numerical value of magnetic induction is determined by this relation, and its dimensionality $\Phi = \boldsymbol{L2 * M * T - 2 * I - 1.}$

Unit of magnetic induction $[\boldsymbol{B}] = \boldsymbol{1\,Wb / 1\,m2} = \boldsymbol{1\,Wb / m2} = \boldsymbol{1\,T}.$

Tesla (T) is equal to the magnetic induction at which the magnetic flux through a cross section of 1 m^2 is 1 Wb.

The strength of the magnetic field (H). The magnetic field strength H is the force characteristic of the magnetic field. As the determining equation for the strength of the magnetic field in the construction of the international system of units, the ratio $\boldsymbol{H = n * N/l}$ is chosen, where **I** is the strength of the electric current flowing in the solenoid, in which **N** turns are laid on the length **l**; **n** is the number of turns per unit length of the solenoid.

Unit of magnetic field strength: $[\mathrm{H}] = n \cdot m - 1 \cdot 1/n \cdot A = 1\,\mathrm{A}/m.$

Absolute magnetic permeability (μ_a, μ). The absolute magnetic permeability of the medium μ_a is a scalar physical quantity that characterizes the magnetic properties of the medium and is equal to the ratio of the magnetic induction B to the magnetic field strength H at a given point: $\boldsymbol{\mu a = B / H}$. It follows from the relation that the dimension of the absolute magnetic permeability $\boldsymbol{\mu a = L \cdot M \cdot T - 2 \cdot I - 2}.$

Magnetic susceptibility (χ, χm). The magnetic susceptibility of the substance χm is the scalar physical quantity characterizing the ability of a substance to be magnetized in an external magnetic field, equal to the ratio of the magnetization of the substance to the magnetic field intensity: $\boldsymbol{\chi m = M * H.}$ The magnetization of the substance and the intensity of the magnetic field have the same dimensions, hence, the magnetic susceptibility is a dimensionless quantity expressed by dimensionless units.

1.2.2. Classification of minerals and ores by magnetic and electrical properties

Minerals and ores by magnetic and electrical properties subdivided into the following groups:

1. **Strongly magnetic**, or ferromagnetic, possessing specific magnetic the susceptibility of the substance $\chi > 3.8 * 10^{-5}$ m^3/kg (ferrite, magnetite, titanomagnetite, franklinite, icocyte, monoclinic pyrrhotite, etc.).

2. **Weakly magnetic**, or paramagnetic minerals with specific magnetic the susceptibility χ is from $7.5 * 10^{-6}$ to $1.26 * 10^{-7}$ m^3/kg, i.e. with a susceptibility of hundreds and thousands of times less than strongly magnetic (oxides, hydroxides, carbonates iron and manganese, ilmenite, wolframite).

3. **Non-magnetic** and **diamagnetic minerals** with a magnetic the susceptibility χ is, respectively, $< 1.26 * 10^{-7}$ and < 0 (quartz, aluminosilicates and etc).

4. **Minerals - conductors** with high electrical conductivity – from 10^{-1} to 10^{4} S m (galena, magnetite, titanomagnetite, pyrite, etc.).

5. **Semiconductors** with specific electrical conductivity from 10^{-1} to 10^{-8} S/m (siderite, calcite, diamond, beryl, etc.).

6. **Nonconductors** (dielectrics), possessing an insignificant specific the electrical conductivity is less than 10^{-8} S/m (quartz, calcite, etc).

Of all the elements of the periodic system, a pronounced only three metals possess ferromagnetism: iron, nickel and cobalt, and conductors are all metals. 55 elements have paramagnetic properties, with 16 elements being paramagnetic in pure form, and in compounds - diamagnetic (oxygen, sodium, magnesium, aluminum, zirconium, tin, etc.); seven elements exhibit the property of paramagnets, when one or more of the atoms are in the compounds (nitrogen, potassium, copper, rubidium, gold, titanium).

Magnetic and electrical properties are not constant physical quantities and vary depending on the strengths magnetic and electric fields created by electric currents or static electricity, temperature and pressure sample, current frequency, particle size, particle shape, time magnetization, as well as electrification, humidity, crystal lattice, presence of defects and impurities in it. Especially large variability the electric charge received by particles at various methods of friction (depolarization factor), etc.

1.3. Magnetic methods of ore dressing

Magnetic methods of ore dressing are based on different magnetic susceptibility of the separated materials. They are used for the enrichment of ores of ferrous, non-ferrous and rare metals and in other areas of industry, including food, as well as medicine. Magnetic methods are used for the enrichment of iron magnetite, manganese, copper-nickel and tungsten ores, as well as for fine-tuning ore concentrates, ferromagnetic reinforcement for separation in heavy suspensions, removal of iron impurities from quartz sands, pyrite from coal and to The separation of the material in a magnetic field is mainly carried out in constant and inhomogeneous fields. **(2)**

Highly intensive magnetic separation of weakly magnetic ores on the roller and rotary separators involves the attraction of magnetic grains to the projections of rolls or ferromagnetic plates and the continuous removal of the attached grains from the zone of a strong magnetic field for their subsequent loading into a magnetic product. To ensure this removal, the separators are equipped with complex and expensive rollers and rotors, drives, and bearings. The coefficient of use of the magnetic system of such separators is low since part of the space between the poles is used only for transporting the magnetic product from the zone of its attraction to the unloading zone. A large part of the consumed power (60-

70%) is spent not on the extraction of the magnetic product, but on the rotation of the rolls. (3 c.4)

1.4. The physical basis of continuous magnetic separation

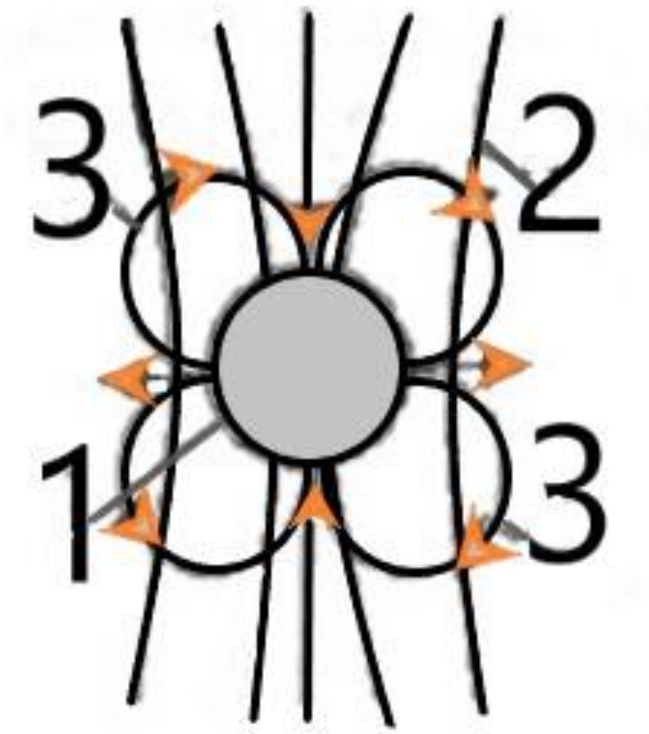


Figure 2 Magnetic fields and forces in the vicinity of a ferromagnetic body

In a homogeneous magnetic field, the magnetic lines are parallel to each other and are equidistant from each other. When entering the field of the ferromagnetic body 1 (Figure 2), magnetic lines 2 are curved in such a way that they pass through the iron in part of the path, the magnetic permeability of which is tens of thousands of times greater than the air permeability. As can be seen from the figure, in those areas of the ferromagnetic body that faces the poles of the magnetic system creating a magnetic field, magnetic lines are concentrated - this is the zone of attraction of magnetic grains. Here we consider grains with a positive magnetic susceptibility. The zones of repulsion of magnetic grains are called the place in the vicinity of the ferromagnetic body, where the magnetic lines are discharged (rotated 90 degrees relative to the zones of attraction).

In an inhomogeneous magnetic field, a magnetic force acts on the magnetic grain, directed toward an increase in induction. Because of this, the magnetic grain, which is mimed in the zone of flaking, will move from the ferromagnetic body to the zone of attraction along a curve of gravity (lines of magnetic forces 3), where it will be attracted. In this way, the flaking zone is remote from the ferromagnetic body by the attraction zone of the magnetic grains. (3 c.5)

The lines of force cover the entire space in the vicinity of the ferromagnetic body. Consequently, the magnetic grain placed at any point of this space will move towards the zone of attraction and will sooner or later and with more or less force be pressed against any wall located in the path of its motion under the action of the magnetic force. Remove from the ferromagnetic body without turning In the zone of attraction will be only the grain, which in the repulsion zone is placed strictly in the plane of the symmetry of this body. This case has no practical value for separation. Nevertheless, it is the opportunity to create conditions under which the grain will move from the ferromagnetic body without pressing it to the walls. The solution of such a problem would allow creating a separator, in which the enriched material will decay under the action of magnetic force and gravity and leave the separator in the form of separate fluxes of magnetic and nonmagnetic grains. The removal of magnetic grains from the separator will occur without the use of any moving parts such as a ram, roller or rotor.

1.5. Magnetic Method of Separation

Magnetic separation is a method for the enrichment of minerals based on the use of the difference in the magnetic properties (magnitudes of the magnetic susceptibility, residual induction, coercive force, etc.) of the divided mechanical mixture (minerals, their intergrowths, etc.) of up to 150 mm in an inhomogeneous constant or alternating magnetic field.

The first information about the use of magnetic separation for the enrichment of iron ores appeared in the 18th century. In industry, magnetic separation for the first time was applied in Sweden in 1892. Physical the mechanism of separation of magnetic separation of both strongly magnetic and weakly-magnetic ores consist in the fact that mineral grains possessing a higher magnetic susceptibility, are attracted to the poles of the magnetic system magnetic separators and with the help of transport devices in the receiving devices of magnetic products, and non-magnetic or weak. In the practice of enrichment, magnetic separation is mainly in inhomogeneous constant magnetic fields.

Magnetic separation is also used for ores of non-ferrous and rare metals, mining and chemical and non-metallic raw materials, as post-processing operations after gravitational enrichment methods, as well as for the removal of metal and Iron-containing impurities from materials (kaolin clays, molding sands, etc.)

Magnetic separation is carried out in magnetic separators. The main problem solved by magnetic separators - is the enrichment of ores and minerals, separation of undesirable components of ferromagnetic inclusions from different types of production. Because of this quality improvement is achieved in final products. The use of magnetic separators is economically advantageous, since no additional costs. In addition, they are safe, simple and convenient to operate. The degree of ore dressing depends on the degree of grinding. The smaller the breakage of the ore, the higher the degree of the enrichment. Good results are obtained when the ore is crushed <0.2 mm. The scheme of magnetic separation is shown in Figure 3.

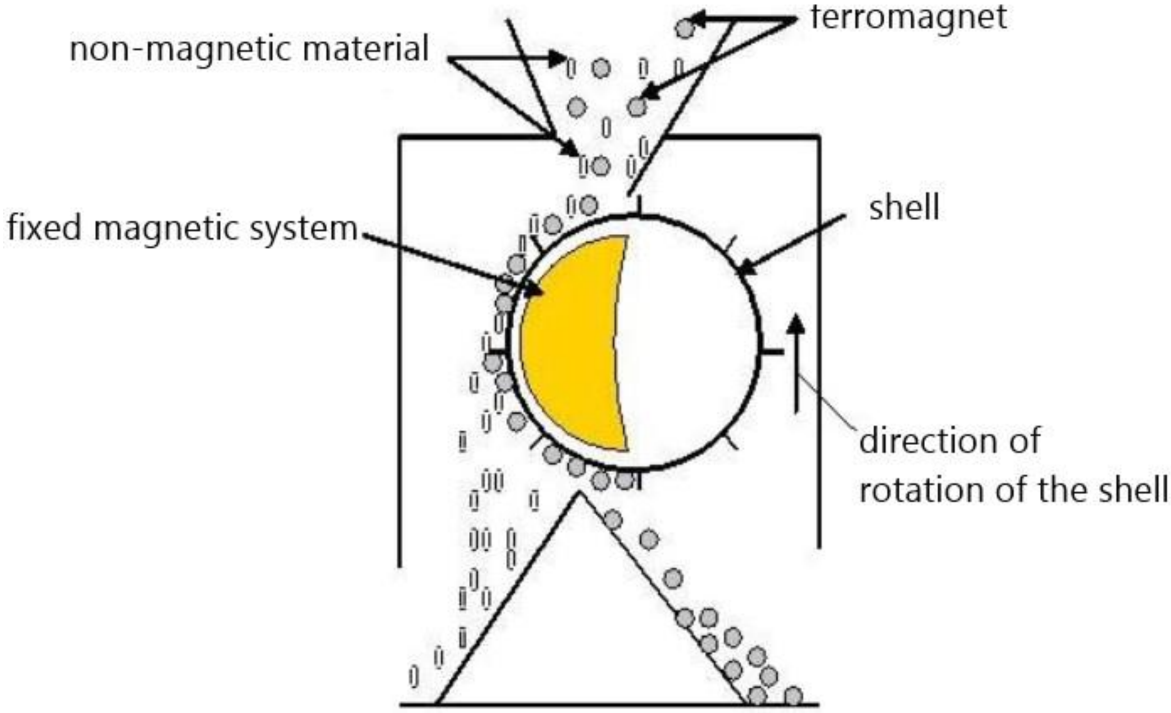


Figure 3 Magnetic separation method

The separated product is fed to the separator working part (drum, roll, transport belt). When a magnetic field enters the zone of action of the magnetic field, the product separates from the magnetic properties of the material - the magnetic product separates into the hopper for magnetic material, and the material to which the magnetic force does not act moves to storage.

1.5.1. Efficiency of the magnetic separation process

The effectiveness of the magnetic separation process depends on the following main factors:

1. **From the strength or strength of the magnetic field**, which depends primarily on the current strength and number of turns (electromagnetic separators with high magnetic field strength can be used for weakly magnetic minerals, and with low intensity for strongly magnetic minerals).

2. **From the distance between poles**, i.e. from the thickness of the magnetic layer separating them (the inter-pole space). The closer the poles are to each other, the

less the magnetic resistance of the air parts of the circuit, the higher the voltage of the magnetic field.

3. **The length of stay of ore grains in a magnetic field** or, in other words, the speed of the passage of particles of material through the separator. The greater this speed, the less time the ore particles will be exposed to the action of magnetic forces, but the greater the productivity of the magnetic separator. The process of magnetization of ore grains (as well as of iron itself) does not occur instantaneously, but proceeds in time, depending on the magnetic properties of the ore and the magnetic field voltage. The smaller the permeability of a mineral (or a group of particles) to be separated into a magnetic fraction, the smaller the velocity of the material passing through the separator, i.e. The longer the residence time of this material through the separator, i.e. the longer the residence time of this material in a magnetic field.

4. **From the size of the starting material.** According to Coulomb's law, the force of magnetic attraction of any two bodies is proportional to the product of the amount of magnetism enclosed in them, and inversely proportional to the square of the distance between them. The relative attraction force (the attractive force per unit volume) for a large the particle will be much larger than that of the shallow one, since in a large particle the pole, unlike the pole of the magnet, is much closer to this pole than the same pole for a small particle, so that the large particle will be much more attracted than the small one. For magnetic separation of larger grains, a weaker magnetic field can be used than for small grains. In addition, the fine grains of particles, getting stuck in the intervals between the large particles that are constrained in the movement, and only in the case of a sufficiently powerful magnetic field, can overcome the resistance of the large grains and undergo separation.

5. **From the moisture content of the material.** The process of dry separation is adversely affected by increased moisture content in the starting material. With

increasing humidity, the ore grains stick together, and the separation proceeds unsatisfactorily. When there is a lack of moisture, a lot of dust is formed.

1.5. Analysis of existing structures of magnetic separators

The success of magnetic separation is caused by the magnetic field voltage and the associated small distance between the poles.

Factors affecting magnetic enrichment:

1. The strength of the magnetic field. An increase in the field strength leads to an increase in the magnetic force and, as a consequence, allows to extract into magnetic fraction minerals with a lower magnetic susceptibility. This has influence on yield and quality of separation products. However, the magnetic field strength can lead to increased clogging magnetic fraction. Insufficient field strength is the cause of the loss of magnetic minerals with tails.

If the processing scheme of enrichment includes several successive magnetic separations, during the purification of the non-magnetic fraction.

The intensity of the magnetic field in each subsequent operation should be increased. The refinement of magnetic concentrates is carried out with a gradual reduction of the field strength.

2. Parameters of the working area (length and height). As well as the power supply width, divide the throughput, i.e. the productivity of the separator. With the diameter of the drum (roll), the length of the working area increases, and this allows Increase the extraction of magnetic minerals and the performance of the separator. Increased productivity is also achieved by increasing the width of the (a length of a drum, a roll).

3. The frequency of rotation of the drum, the separator roller is determined to a considerable extent by its productivity and quality of enrichment products. She is

selected in depending on the method of enrichment (dry or wet), the method of the power supply (upper or lower), the specific magnetic susceptibility and the size of the section minerals, the required quality of enrichment products (obtaining concentrates or dump tailings).

4. The magnitude and magnetic properties of the ore being enriched. With a sharp difference in the size of the minerals being separated makes it difficult to choose the right tension- the parameters of the working zone, the speed regime, and separator. All this leads to deterioration in the technological enrichment bodies. The best enrichment indicators are obtained using preliminary classification of the material that maximally brings together the upper and lowers the lower limits of the size of the minerals to be separated. Depending on the physical and chemical characteristics of the material being separated and its size, different designs of magnetic separators are used:

- Drum,
- roller,
- belt,
- screw,
- disc,
- rotary.

Separators of any of these types can have primary magnets (excited from the coil) and secondary (excited by induction). Also in the constructions, either permanent magnets or electromagnets are used. Any of these types of separators can be adapted for the separation of dry ores (dry separation) and some of them for wet separation. Dry methods of separation include:

- magnetic,
- electrodynamic,
- electrical,
- pneumatic.

Wet separation methods include:

- Heavyweight,
- magnetohydrostatic,
- Hydraulic.

The main feature of the classification of separators is the magnetic properties of the ore. By this feature separates the magnetic separators into two groups:

- For strongly magnetic ores;

- For weakly magnetic ores.

The predominant distributions for the enrichment of strongly magnetic materials were produced by drum separators, for weakly magnetic ones - roll and rotary separators. The main structural elements of magnetic separators are magnetic system, feeder, bath (with wet enrichment), transporting device (drums, rolls, rotors), gutters and leaks of separated products, drive and frame.

With dry enrichment on drum separators, metal-containing wastes (larger than 3 mm) are loaded onto the top of the drums. Magnetic particles attracted to the surface of the drums, and non-magnetic or weakly magnetic they are poured from the drum into the estrus and sent to a clean separation.

With wet enrichment, the pulverized ore enters the drum under the pulp. Further pulp motion is determined by the type of bath (flow, counter flow, and semi-counter flow). Type of bath is used in accordance with The size of the separated material (straight-flow - material from 3 to 6 mm; countercurrent - material with a particle size less than 3 mm; semi finished - material with a particle size of less than 0.15 mm).

Further, the designs of dry magnetic separation methods as wet separation methods are more labor-intensive and costly. Also, the wet separation method makes it necessary to dry the separated material, which also affects the energy and time costs.

1.6. Types of magnetic separators

1.6.1. Drum magnetic separators

As a rule, magnetic drum separators are executed in the form of pulleys and located at the end or along the conveyor. They are used for cleaning transported material from magnetic impurities in order to improve the quality of the material being cleaned and preventing the breakdown of expensive equipment.

Figure 4 Appearance of the drum separator

The separation of magnetic and non-magnetic materials in the drum magnetic separators occurs when they move along the drum's working surface, shell. The shell is made of non-magnetic stainless steel (sometimes with a fiberglass covering or ceramic coating for additional mechanical protection) rotating around a stationary system of permanent magnets. The magnetic system is located inside the drum and takes up to half its circumference in cross section. Magnetic particles are attracted to the surface of the drum and are retained by magnetic forces. "Adhering" to the rotating surface of the drum, the magnetic impurity is removed from the area of the strong magnetic field of the stationary system of permanent magnets and collected in the dust receptacle, thereby discharging the drum. The non-magnetic product does not experience the action of the magnetic force of attraction and almost immediately departs from the drum on a ballistic trajectory under the action of centrifugal force, gravity and frictional force. The general scheme of magnetic drum separators is shown in the Figure 5.

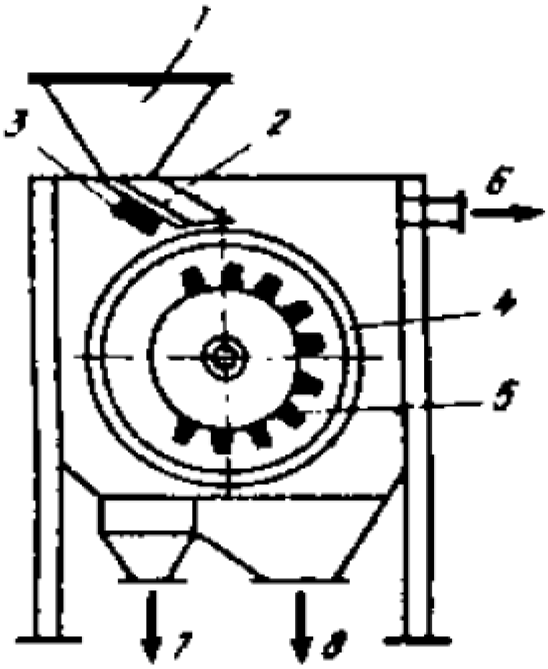


Figure 5 Diagram of a drum-type separator

Diagram of a drum-type separator: 1 - bunker; 2 - feeder; 3 - vibrator; 4 - a drum; 5 - magnetic system; 6 - dust extraction; 7 - output magnetic fraction; 8 - non-magnetic fraction yield.

The structures of the drum separators, as well as the arrangement of the magnetic system in them - very diverse. Schemes of the arrangement of the magnetic system in the drum- separator are shown in Figure 6.

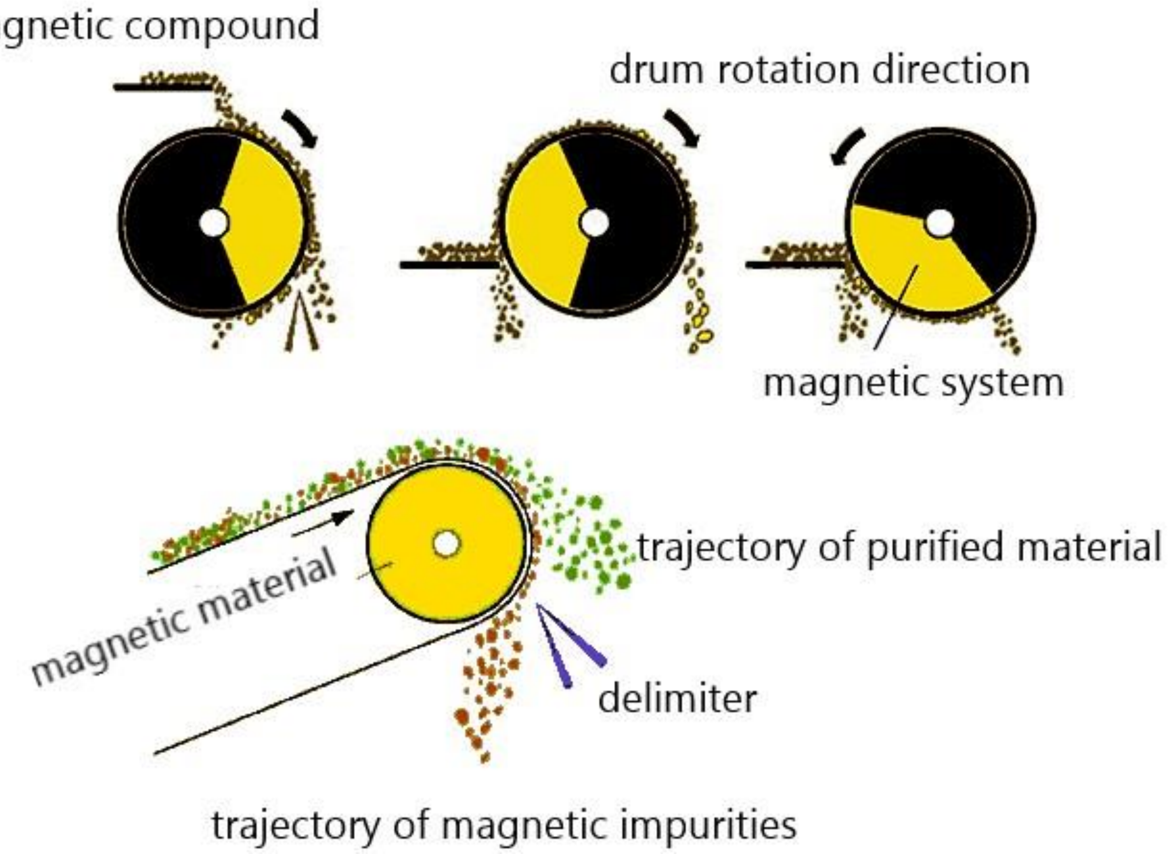


Figure 6 Types of layouts of the magnetic system in the drum

1.6.2. Barrier magnetic separator

The method of barrier separation is as follows. In a certain region of space, an inhomogeneous magnetic field is created, the gradient of which is directed upwards. The magnetic force placed on this region is acted upon by an upward magnetic force-a magnetic barrier. Non-magnetic grains under the action of gravity freely pass through the magnetic barrier vertically down and are removed into a non-magnetic product.

Magnetic grains cannot penetrate the magnetic barrier. In this way, they slip along the magnetic barrier into the magnetic separation product.

In laboratory and industrial barrier separators, rectangular or triangular ferromagnetic plates (1) are used as ferromagnetic bodies. Plates are installed with a gap in relation to each other. A set of such plates is called a matrix. The matrix is installed in the gap between the pole pieces of the magnetic system (2).

The leading edge (3) of each ferromagnetic plate is rounded in cross-section. In space, it is oriented at an acute angle to the vertical and at right angles to the direction of the magnetic field. Each such edge has an adjacent plate (4) of non-magnetic material. This non-magnetic plate covers the range of the strongest attractive magnetic forces Fn.

Two adjacent pairs of magnetic and non-magnetic form with their walls one separation channel.

The essence of the formation of the magnetic force F of a magnetic barrier on a ferromagnetic plate is the same as on ferromagnetic bodies. The magnetic field created by the magnetic system 2 concentrates on the rounded edges 3 of the ferromagnetic plates 1. It can be seen from (Fig. 1.5) that to create this concentration a part of the magnetic flux is displaced from the gap between the plates 1 and enters the inside of the plates. Since magnetic flux in the space between the plates decreases, the magnetic induction also decreases. At the surface of the pole piece, which is located above the ferromagnetic plates in the figure, the magnetic flux is uniformly distributed. Therefore, the induction in the gap between the ferromagnetic plates becomes smaller than that of the upper pole piece opposite the gap. With such an induction distribution, the magnetic field gradient, and hence the magnetic force, is directed upward from the gap between the ferromagnetic plates.

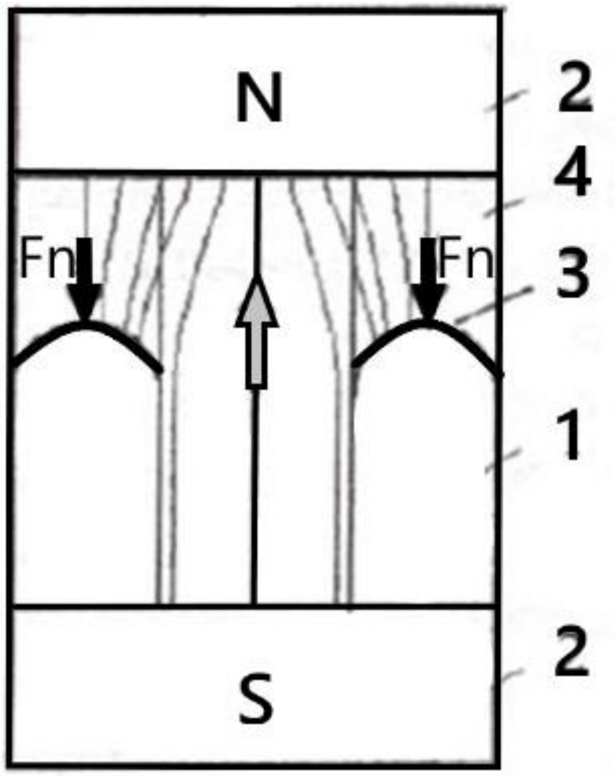


Figure 7 The scheme for the formation of magnetic fields and magnetic forces in the barrier separator channel

The matrix of barrier separators, depending on the mutual orientation of the feeding directions and the prosperity of the magnetic barrier, can be of two types. The matrix in which the power supply is applied along the magnetic barrier will hereafter be referred to as a matrix with longitudinal feed. The antenna, in which the direction of power supply crosses the magnetic barrier, will be called a matrix with an excellent supply of power. In both cases, the supply of power to the matrix is made above the magnetic barrier.

Walls, the bottom of the ceiling of each channel have smooth surfaces. On the path of movement along the grain channel of the material being enriched and no mechanical obstacles. Due to the above construction of the walls, a gradient of the magnetic field is created, directed to the bottom perpendicular to the direction of flow of the separable material moving inside the channel. Area, where the product of the magnetic induction on its gradient is the largest located above the bottom and extends over the entire length of the channel. This is the area of the magnetic barrier (gray line).

The channel is located between the pole pieces 2 of the magnetic system. The material to be enriched 3 is fed into the channel above the region of the magnetic barrier 4 along its extent. Non-magnetic grains 5 pass through the magnetic barrier on to the channel and slip downward into the receiver 6 of the non-magnetic product. Manifold grains 7 cannot penetrate the magnetic barrier. Therefore, they slip downward over the magnetic barrier into the receiver 8 for the magnetic product. Thus, thanks to the magnetic barrier, the flow of the material being enriched is divided into fluxes of magnetic and nonmagnetic particles.

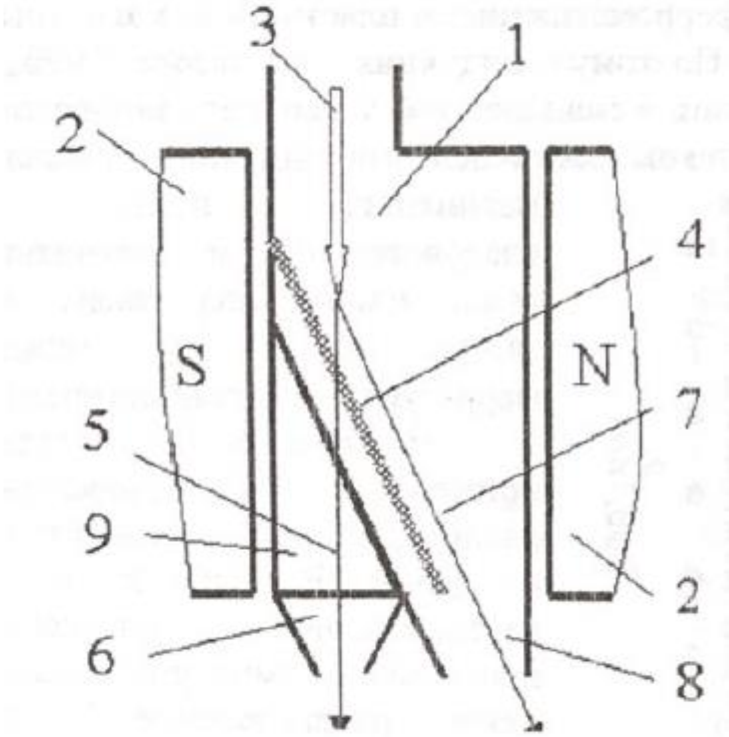


Figure 8 The longitudinal section of the barrier separator channel with cross-feeding

The numbering of positions is the same as in the figure of the channel with longitudinal feed. The difference lies in the fact that the channel is located vertically, and the ferromagnetic plate 9 has a triangular shape.

The material to be enriched is fed into the channel vertically. Non-magnetic grains are not affected by the forces of the Magnetic Barrier and are moving down into the device for receiving a non-magnetic product. Magnetic grains cannot overcome the magnetic barrier. They deviate from the vertical and are supported by magnetic forces, slide over the magnetic barrier into the receiver for the magnetic separation product.

When cross-feeding the supply, the magnetic forces of the magnetic barrier must be greater than for the longitudinal feed, since they need to overcome inertia forces magnetic grains. This increases the capacity of the separator. Therefore, cross-feeding is advisable to use for light and fine-grained materials, the non-magnetic grains of which are slowly lowered under the action of force under the magnetic barrier.

1.6.3. Deflecting Magnetic Separator

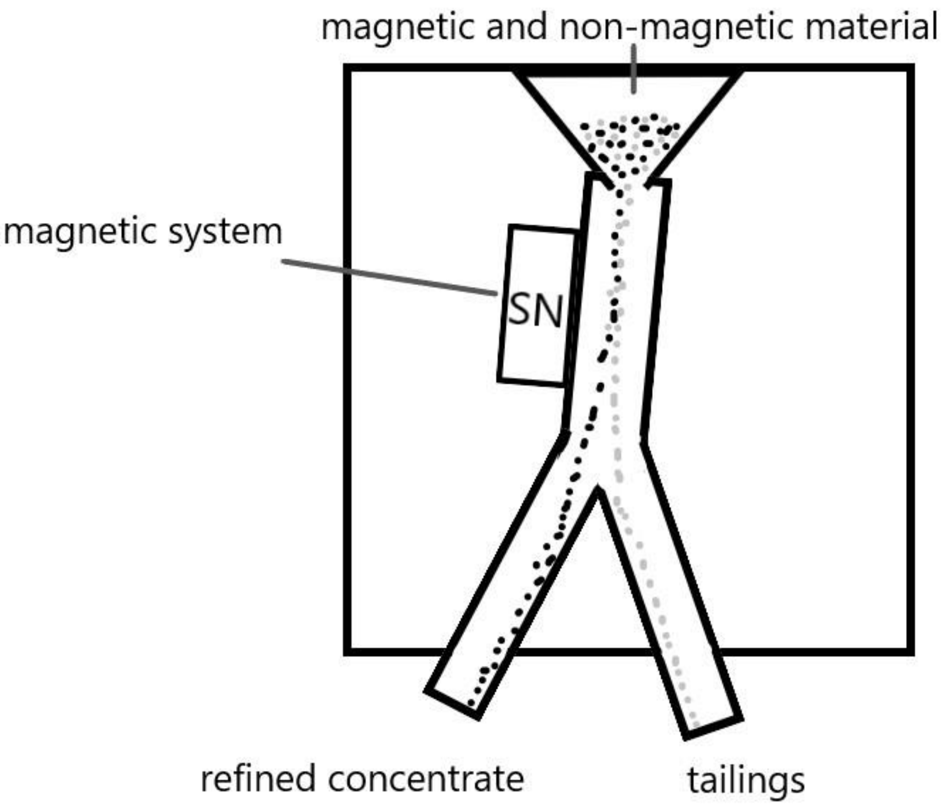


Figure 9 Deflecting magnetic separator

1.6.4. Belt magnetic separator

The separator refers to the field of magnetic enrichment of weakly magnetic to obtain high quality products. The magnetic tape separator includes two non-magnetic rotating drums, one of which contains a magnetic system made of permanent magnets, a receiver of separation products. The magnetic system is made of permanent magnets of the neodymium-iron-boron type in the form of rectangles directed one way with the axis of rotation coinciding with the axis of rotation of the drum. The invention makes it possible to increase the selectivity of separation and the possibility of obtaining concentrates with a high content of weakly magnetic ore.

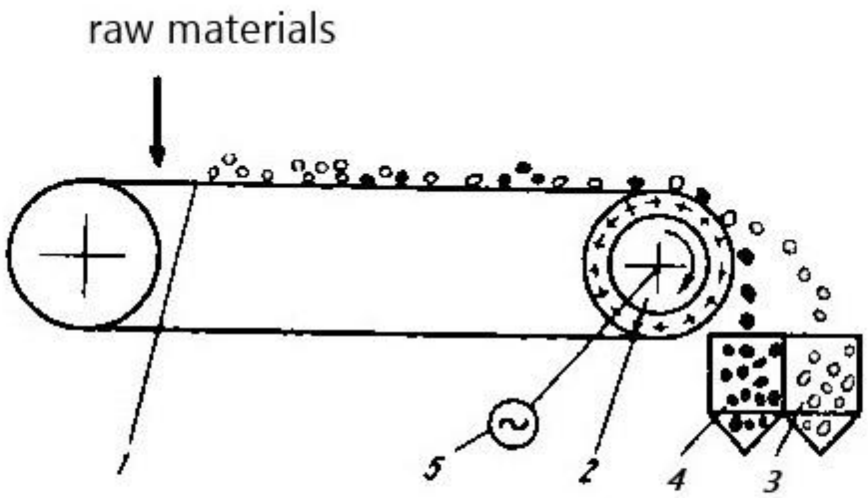


Figure 10 Scheme of the belt separator operation

Scheme of the belt separator operation: where 1 - belt conveyor; 2– drum rotor; 3-receiver of non-magnetic material; 4 - receiver of magnetic material; 5 - drive.

1.7. Technological characteristic of ilmenite

In the earth's crust, 70 natural compounds (minerals) of titanium are known. All these are compounds of titanium and other chemical elements with oxygen. Among these minerals, the most valuable in the common are three minerals: ilmenite, leucoxene, and rutile.

Ilmenite (titaniferous iron ore) is a mineral of the general chemical formula $FeTiO_3$ (36.8% Fe, 31.6% O, 31.6% Ti), the composition is unstable.

Ilmenite is a compound of ferrous oxide (a chemical sign of Fe) and titanium dioxide. The name of the ilmenite was obtained from the Ilmen Mountains, located in the Urals, where it was found for the first time. (4)

Ilmenite is found in the form of small flat opaque crystals and compacted grains of black color with a bluish tinge and semi metallic luster. Hardness of ilmenite 5.0 - 6.0 density - 4.7 - 4.8 g/cm³.

Ilmenite crystallizes in the trigonal system, forming complex rhombohedral crystals, granular masses, and solid clusters; is opaque. In its pure form, at ordinary temperatures, ilmenite is nonmagnetic, which is important for its industrial recovery. Crystals containing more than 25% Fe_2O_3 in the form of a solid solution are magnetic. Ilmenite and titanomagnetite are valuable ore for the production of titanium and its derivatives (titanium oxide, ferrotitanium, and others).

Ilmenite is an iron titanate. The color of the mineral is black with a gray-steel or brownish hue. Glitter - metal, semi metallic.

Magnetism of ilmenite is higher than it differs from other black minerals, with the exception of magnetite, which is more magnetic than ilmenite. If you magnetize the needle, the magnetite grains will not only attract but also gather in chains. Ilmenite is not going to be such a needle in the chain. Magnetite from ilmenite differs also in the shape of grains; it forms equilateral octahedral crystals (octahedral).

In hot and humid climates, the ilmenite is oxidized, the ferrous oxide (FeO) contained in it passes into iron oxide (Fe2O3) and is gradually removed from the mineral by water. At the same time, the color, magnitude and specific gravity of ilmenite vary. By losing iron, it becomes less magnetic and easier. Its color changes from black through all shades of brown to yellow.

1.7.1. Origin of ilmenite

Large deposits of ilmenite are in Russia in the Southern Urals, where this mineral was first discovered in the Ilmensky Mountains. Ilmenite is found in many deposits in Norway, Sweden, Finland, in the ores of the Bushveld complex in South Africa and Sudbury ore region in Canada, besides ilmenite, lunar soil is rich.

Ilmenite occurs in basic and alkaline magmatic rocks, in alkaline pegmatites. During the crystallization of rich Ti natural ore melts with an excess of FeO and Fe2O3, so-called titanomagnetite ores are formed. Significant deposits of ilmenite and titanomagnetites are associated with rocks of the gabbroid type. Known as an igneous mineral in kimberlites; forms clusters in alkaline syenite pegmatites. Also magmatic phenocrysts, ingrown skeletal crystals, and plates in some chromites. As accessory mineral in the form of separate crystals is formed in the last stage of magmatic crystallization in ultrabasic, basic, middle, acidic and alkaline rocks. Ilmenite is isolated in the form of flattened, rarely rhombohedral crystals. Usually found in granular masses and aggregates. The best collection of samples of the mineral are black, glistening aggregates of well-formed crystals of complex shape- the so-called titanium (or iron) roses. Inclusions of ilmenite are often present in quartz, minerals from the plagioclase group.

Ilmenite is replaced by a rutile, often forms a mixture with hematite (blood), to which it looks very similar and can well be used as its imitation. In addition, samples of ilmenite with a high content of iron oxide also have magnetic properties. You can distinguish these minerals by the color of the line: in ilmenite it is black, and in hematite - brownish-red.

Mineral satellites: magnetite, hematite, pyrrhotite, rutile, apatite, ulvospinel, feldspar, biotite, zircon.

Ilmenite of igneous origin is present in alkaline, basic, ultrabasic rocks and kimberlites (picroilmenite). They find it in alkaline and, rarely, granite pegmatites. Ilmenite of hydrothermal origin is found in crystal alpine veins. In them, as a rule, it forms lamellar crystals, often included in quartz crystals and/and substituted with rutile (the so-called "sagenite"). On the surface, ilmenite is relatively stable and can accumulate in alluvial and coastal-marine placers. In hot and humid climates, the ilmenite is oxidized, Fe^{2+} passes into Fe_2O_3 and is gradually removed from the mineral. As a result of this process, the color of ilmenite changes, the magnetic density decreases, and the specific gravity decreases. Its color changes from black through all shades of brown to yellow. The color of the dash for such oxidized differences is brown, yellowish-brown, sometimes with a reddish tinge. When the ilmenite is completely oxidized, a microporous aggregate of titanium dioxide is formed - leucoxene. Leucoxene is brownish-yellow to white, it is opaque and non-magnetic, it retains some iron oxide. There are also cases of decomposition of ilmenite when a mechanical mixture of hematite and rutile was formed, but the external form of ilmenite crystals was preserved.

Ilmenite is one of the main ore minerals of titanium. It serves as a raw material for the production of valuable white paint - titanium white; source for the production of ferrotitanium and valuable titanium alloys used in the aerospace industry. In addition, ilmenite is used as a filler for rubbers, paper, plastics, ceramics, enamels. Large, well-formed crystals of this mineral have a high mineralogical and collection value.

Table 2 Physical Properties of Ilmenite

Physical Properties of Ilmenite	
Chemical classification	Oxide
Color	Black
Streak	Black
Luster	Metallic, submetallic
Cleavage	None
Mohs Hardness	5.5 to 6
Specific Gravity	4.7 to 4.8
Diagnostic Properties	Streak, sometimes weakly magnetic
Chemical composition	Iron titanium oxide – $FeTiO_3$ Sometimes has significant amounts of magnesium and manganese in solid solution with iron to yield a composition of (Fe, Mg, Mn) TiO_3

Crystal System	Hexagonal
Uses	The primary ore of titanium. A minor source of iron. Used to make a titanium dioxide.

1.8. General data on the deposit

Birzulovskoye placer deposit of ilmenite is located near Korobchino village of Novomyrgorodsky District, Kirovograd Region, near the Bolshaya Vys River. From the western outskirts of the village Korobchino the deposit can be traced in the south-west direction and is represented by a solid ore body of a simple configuration 5.5 km long and 2.5 km wide. Birzulovskoe placer deposit of ilmenite was discovered by the South Ukrainian geological expedition in the process of prospecting in 1969-1970. (Fedorenko NS). In 1971-1973 years. in the area of the field, prospecting and appraisal work was carried out, which made it possible to give a preliminary estimate of reserves in category C2 (Skorobach V.I.). In 1974-1976 years. Preliminary exploration has been carried out that made it possible to perform the inventory calculation for category C1 + C2. In the years 2005-2007 partial reconnaissance was carried out, which enabled preliminary geological and economic assessment of the deposit. The area of the works area is located in the central part of the Ukrainian Shield, within the southern part of the Korsun-Novomirgorod Pluton, in the western part of the Novomyrgorod Massif of the main rocks, and is confined to one of the gulf-shaped branches of the upper Lebedino-Balakley Depression. The productive stratum is represented by Lower Cretaceous-green glauconite-quartz kaolin sands, less often light gray quartz sands and secondary sandy kaolins lying on the weathering crust of the main rocks (gabbro-norites, gabbro-anorthosites, anorthosites) of the Korsun-Novomirgorodsky pluton. Covered with placer clay, loams and sands of Paleogene, Neogene and Quaternary age with a total thickness of 22 to 42 m. The average thickness of the reservoir in the Birzulovsky deposit is 5-9 m, the average ilmenite content is 130-170 kg/m^3, the volume weight is 1.71 t/m^3, the specific gravity is from 2.56 t / m^3 to 2.99 t/m^3 (average 2, 7 t/m^3), the coefficient of strength on the scale of prof. Protodjakonov - 0,5 - 0,6. Technologically, the sands of the Birzulovsky deposit are easily enriched (they easily disintegrate and desludge). Desiccated sands are effectively enriched on simple gravity apparatus (screw separators). In turn, the gravitational concentrate is easily subjected to refinement by magnetic separation. Ilmenite concentrate is of practical interest for its use as a raw material for the production of pigmentary titanium dioxide. Studies of the sands of this field show that the heavy fraction is represented in them by ilmenite, light quartz and kaolinized clay. To enrich them, a complex scheme can be adopted, used at the Irshanskiy ore mining and processing enterprise, which includes obtaining a crude ilmenite concentrate by wet gravity separation on screw separators and its development using dry magnetic enrichment methods. According to calculations made with a significant margin, the maximum water inflows in the initial period of quarry development will be 741 m^3/h. During operation, water inflows will drop to 105 m^3/h and remain constant for the entire life of the quarry.

1.9. Mineral and chemical composition of samples

The rocks of the productive strata are represented by ilmenite-containing quartz, glauconite-quartz heterogeneous grains and sandy kaolins. The average mineral composition of the ore: quartz is 60-70%, kaolinite is 20-30%, ilmenite is 5-10%, and feldspar is 1-4%, leucoxene, apatite, iron hydroxides, glauconite, zircon, tourmaline, limonite and others.

As can be seen from Table 3, the minerals of the light fraction predominate in the mineral composition of the samples. Quartz dominates among them; kaolinite is present in a smaller amount, as well as feldspar, hydromica, and glauconite.

Table 3 Physical Properties of Ilmenite

Minerals	№ 1	№ 2	№ 3	№A	№ B
	Mass fraction of mineral, %				
Ilmenite	11,48	14,8	9,00	3,1	3,1
Leucoxene	0,13	0,4	0,30	signs	signs
Rutile	signs	signs	0,06	signs	signs
Magnetite	signs	0,02	0,04	-	-
Hydroxides Fe	1,23	0,5	0,76	-	-
Sulphides	-	0,03	0,05	-	-
Limonite	-	-	-	signs	signs
Siderite	-	0,08	0,18	signs	-
Garnet	-	signs	0,02	-	-
Apatite	-	0,24	0,10	-	-
Zircon	-	0,03	0,08	signs	signs
Tourmaline	-	0,05	0,06	signs	-
Other accidents. min.	0,13	signs	0,09	-	-
Total heavy fraction:	12,97	16,15	10,74	3,1	3,1
Quartz	69,99	61,7	62,84	74,3	68,1

Feldspar	3,36	1,3	1,86	-	0,3
Kaolinite	12,77	20,0	22,60	0,4	1,0
Hydromica	0,46	0,15	0,13	-	-
Calcite	-	-	-	-	1,9
Chlorite				0,9	0,7
Glauconite	0,45	0,7	1,88	0,1	0,6
Sludge				21,2	24,3
Total light fraction:	87,03	83,85	89,31	96,9	96,9

The comparative chemical composition of the samples is shown in **Table 4.**

Table 4 Chemical composition of samples

Components	Mass fraction,% in samples				
	№ 1	№ 2	№ 3	№ A	№ B
SiO_2	76,76	71,06	75,6		
TiO_2	6,45	8,9	5,25	2,23	2,23
Al_2O_3	5,93	5,99	8,46		
Fe_2O_3	3,47	3,21	3,05	1,1	1,1
FeO	2,48	5,66	2,20	3,5	3,5
MnO	0,09	0,09	0,09	Fe_{tot}=4,99	Fe_{tot}=4,99

MgO	0,26	0,32	0,22		
CaO	0,54	0,55	0,50		
Na_2O	0,08	0,05	0,08		
K_2O	0,79	0,55	0,80		
P_2O_5	signs	0,10	0,05	0,091	0,091
SO_3	0,03	0,10	0,08		
H_2O	0,97	1,05	1,10	Cr_2O_3-0,185	Cr_2O_3-0,185
other impurities	2,4	2,86	2,6		
Total	99,78	100,49	100,08		
TiO_2 ilmenite				58,98	58,98

1.10. Granulometric composition of samples

The bulk of the initial sands is concentrated in the granular part (class -1.6 +0.05 mm - 65-75%, class +1.6 mm (screening) - 5-6% and 20-30% class - 0.05 mm (slimes).

The granulometric composition of the initial sands and the distribution of ilmenite by the size classes are presented in **Table 5,6,7.**

Table 5 The granulometric composition of sands and the distribution of ilmenite according to the size classes

Class size, mm	Probe 1			Probe 1a		
	class output, %	Ilmenite		class output,% Mass. Share,%	Ilmenite	
		Mass. Share,%	Distribute on,%		Mass. Share, %	Distribute on,%
+2,5	2,83	0,2	0,05	4,96	1,5	0,5
-2,5+1,6	5,84	0,345	0,2	2,63	1,1	0,2
-1,6+1,25	9,55	1,36	1,2	3,96	3,4	0,9
-1,25+0,8	11,73	5,82	6,3	10,63	10,24	7,2
-0,8+0,5	15,93	12,9	18,9	22,44	23,7	35,4
-0,50+0,31	16,22	24,37	36,4	7,86	31,6	16,5
-0,3+0,20	10,24	22,42	21,1	10,58	23,1	16,2
-0,2+0,125	4,77	14,57	6,4	10,11	20,6	13,8
-0,125+0,071	1,63	15,2	2,3	3,15	22,8	4,8
-0,07+0,05	0,96	28,3	2,5	0,88	22,0	1,3
-0,05	20,30	2,5	4,65	22,8	2,1	3,2
Total:	100	10,86	100	100,00	15,05	100

Table 6 Granulometric composition of sands and distribution and sorting by size class on the basis of analysis of sands of KO UkrGGRI, Simferopol, sample No. 3

Class size, mm	class output, %	Mass. Share,%		Distribution,%		Mass. Share TiO_2, % in mineral
		ilmenite	TiO_2	ilmenite	TiO_2	
+3	1,9	1,08	0,65	0,23	0,2	60,0
-3+2,5	0,8	0,30	0,18	0,03	0,03	60,0
-2,5+1,6	2,6	0,65	0,39	0,03	0,19	60,0
-1,6+1,0	4,8	4,26	2,52	2,27	2,30	59,0
-1,0+0,63	6,96	13,9	7,68	10,75	10,18	55,3
-0,63+0,50	5,0	21,9	12,31	12,14	12,18	56,2
-0,50+0,315	11,08	21,0	11,82	25,89	25,0	56,3
-0,315+0,20	12,81	12,55	7,28	17,89	17,8	58,0
-0,20+0,10	19,02	7,71	4,55	16,32	16,5	59,0
-0,10+0,063	1,81	18,23	11,25	3,67	3,88	61,6
-0,063+0,056	0,12	18,80	11,42	0,25	0,26	61,6
-0,056+0,04	1,10	18,29	11,34	2,25	2,38	61,6
-0,04	32,0	2,30	1,49	8,16	9,1	64,3
Итого:	100,0	9,00	5,25	100,00	100,00	58,3

Table 7 Granulometric composition of sands and distribution of ilmenite according to size classes

Class size, mm	Probe №A			Probe №B		
	class output,%	ilmenite		class output,% Mass. Share,%	ilmenite	
		Mass. Share, %	distribution, %		Mass. Share,%	distribution, %
+2,0	3,09	0,2	0,18	5,74	0,9	0,46
-2,0+1,0	5,81	0,41	0,71	4,72	1,14	1,75
-1,0+0,56	8,50	3,07	7,73	12,96	4,0	16,83
-0,56+0,28	36,96	4,67	51,14	28,01	4,53	41,20

-0,28+0,14	19,69	5,85	34,13	19,24	5,16	32,23
-0,14+0,10	2,80	5,93	4,92	3,64	3,92	4,63
-0,10	2,20	1,86	1,19	2,69	3,32	2,90
Sludge	20,95	-	-	23,00	-	-
Total:	100,00	3,38	100,00		3,08	100,00

1.11. Characteristics of minerals

Ilmenite is the main useful mineral of the samples studied, the main carrier of titanium. It is present in the form of angular, angular-rolled and pelletized grains ranging in size from 1.6 mm to hundredths of a millimeter. The color of the mineral varies from black to brown and light brown, and the color intensity decreases as the degree of change in the mineral increases. A conductor in an electrostatic field. Often on the ilmenite grains, films and leucoxene primers are observed.

The average chemical composition of the ilmenite fraction of the samples is shown in Table 8.

Table 8 Results of chemical analysis of the ilmenite fraction

Component	Mass. Share,%		
	probe 1	probe 2	probe 3
SiO_2	1,20	0,55	1,40
TiO_2	56,18	58,4	56,8

$A1_20_3$	0,52	0,32	0,40
Cr_20_3	0,039	0,06	0,04
Fe_20_3	16,99	20,4	16,8
FeO	22,20	18,34	24,5
MnO	0,46	0,53	-
MgO	0,29	0,01	0,03
P_20_5	0,072	0,07	0,02
S	0,012	0,04	0,01
-Δ S	0,004	0,015	0,003
other impurities	1,50	1,41	-

The high mass fraction of titanium dioxide and iron trioxide, as well as a reduced mass fraction of iron oxide, is due to a significant degree of variation in ilmenite. The density of unaltered ilmenite is 4.7 g / cm3. In **Table 9**. shows the distribution of ilmenite in terms of density.

Table 9 Distribution of density ilmenite

Number of the probe	Yield,% by density range (g/cm^3)					
	<4,0	4,0-4,1	4,1-4,2	4,2-4,3	4,3-4,5	>4,5
1	0,2	6,0	12,8	12,8	13,0	55,2
2	0,8	5,6	3,6	23,3	24,5	42,2
3	0,8	6,0	6,2	17,0	18,0	52,0

In the process of changing ilmenite, its magnetic properties also change. Unchanged ilmenite is a strong paramagnet; leucoxene - the final stage of ilmenite change - diamagnet.

Table 10 Mass fraction of the main components in ilmenite of different magnetic strength

Current on the windings electromagnet, A	The yield of the fraction, %	Mass, share,%			FeO/Fe_2O_3	Fe^{3+}/Fe_{tot}
		TiO_2	Fe_2O_3	FeO		
1,0	31,0	54,1	14,15	26,9	1,9	0,32
1,25	49,4	56,75	22,4	15,65	0,7	0,56
1,5	16,1	60,7	27,4	7,23	0,26	0,77
2,0	3,3	62,3	29,7	3,6	0,12	0,88

Studies of the physical properties and morphology of ilmenite from the Birzulovskaya placer show its heterogeneity in terms of the degree of variability. Leukoxen in large classes is present in the form of films and crusts on the ilmenite grains; in small and fine classes is found in independent grains and debris. His quantity is a hundredth and the first tenths of a percent. It's unintelligent. Density of 3,6-4,0 g/cm. Producer. Color from brownish gray to pinkish white. In the chemical composition contains 80-90% of titanium dioxide, 2-5%, iron trioxide and up to 10-15% of water.

Rutile is present in the number of hundredths of a percent. Forms fine elongated grains up to 0.1 mm in size and their fragments. Color red, brown. It's unintelligent. The density is 4.0-4.2 g/cm. The conductor, in its composition contains up to 95% titanium dioxide.

Magnetite forms small grains (up to 0.2 mm). Strongly magnetic. The density is more than 4.5 g/cm^3. Black color. Conductor.

Hydrogen oxides of iron form independent grains, thin films on other minerals, and impregnate aggregates of kaolinite. The color is brown and brown in different intensities. It is weakly magnetic. The density of free grains is up to 4.0 g/cm.

Sulphides are mainly represented by marcasite in the form of individual grains, aggregates and bonds. Color yellow-brown. The density is higher than 4.5 g/cm3. Magnetic properties are not permanent: they occur in both magnetic and non-magnetic fractions. Conductors in the electrostatic field.

Siderite - iron carbonate is present in the tested samples in a small amount, up to 0.18%. Usually it is rounded kidney-shaped grains and debris, mainly in small classes. Color gray, brownish gray. It is weakly magnetic, it falls partly into the ilmenite fraction. Density up to 3.8 g/cm^3. Nonconductor.

Apatite occurs in the form of shallow elongated and isometric grains in the non-magnetic fraction of classes less than 0.4 mm. Usually it is colorless or slightly frayed grains. The density is 3.2 g/cm^3.

Garnet is observed in weakly magnetic and non-magnetic fractions in the form of isometric grains. The color is brown, greenish, pink, yellow and brownish-yellow. Density of 3,3 - 3,6 g/cm^3. Nonconductor.

Zircon is found in the nonmagnetic fraction of small classes in the form of isometric and elongated prismatic crystals. Color pinkish. The density is more than 4.5 g/cm. Non-conductor.

Tourmaline is a mineral of a non-magnetic fraction. Usually these are isometric grains of greenish, brownish color. The density is about 3.2 g/cm^3. Nonconductor.

Among the accessories, small amounts of disthene, sillimanite, staurolite, baddeleyite, spinel, and monazite were encountered in the nonmagnetic fraction.

Minerals of light fraction

Quartz is the main rock-forming mineral of samples. Grains are angular-rounded and octane, in large classes often in aggregates with feldspar and kaolin, sometimes with iron hydroxides. Transparent, non-magnetic. Sometimes because of the splices, it falls into the electro-magnetic fraction. The density is 2.65 g/cm^3. Nonconductor.

Feldspar is present in small and large quantities in large and middle classes. Usually located in the unit with kaolin and quartz. It is kaolinized. The color is white or brown due to iron hydroxides. Non-magnetic, but in the intergrowth with hydroxides of iron and ilmenite can fall into the electromagnetic fraction. The density is less than 2.6 g/cm. Non-conductor.

Kaolinite is a finely divided mineral, developed mainly in slimes. Because of aggregates and bonds, it is also present in the granular part of the samples, often in intergrowths with other minerals. White color. It's unintelligent. Mineral of light fraction. Nonconductor.

Hydromica - scales of silvery, yellowish color occur predominantly in small classes. Usually kaolinised - easily kneaded.

Glauconite is developed in the form of small (mostly up to 0.5 mm) rounded and kidney-like grains of green, sometimes brownish color. Density up to 2.9 g/cm^3. Weakly magnetic - falls into the electromagnetic fraction with an average and strong magnetic field strength. Nonconductor.

Table 11 Classification of minerals of ilmenite sands of the Birzulovsky deposit by physical properties (density and magnetism)

Classification by magnetic field	Classification by density, g/cm^3		
	heavy >3,6	average 2,9-3,6	light <2,9

Electromagnetic fraction	Ilmenite siderite magnetite hydroxides sulphides of garnet	-	glauconite hydroxides in joints
Non-magnetic fraction	Leucoxene rutile zircon sulphides Garnet baddeleyite spinel sphene	Apatite Garnet tourmaline kyanite sillimanite	Quartz Feldspar kaolinite hydromica

Current ilmenite quality certificates:

Table 12 Ilmenite quality certificate, Grade I

Characteristics, mass share,%		**Min,%**	**Max,%**
1.	Ilmenite	95,0	97,5
2.	TiO_2	54,00	57,0
3.	Fe_2O_3	16,0	20,0
4.	FeO	18,0	27,5
5.	V_2O_5	0,24	0,26
6.	P_2O_5	0,035	0,11
7.	Cr_2O_3	0,025	0,050
8.	SiO_2	1,5	2,5
9.	Al_2O_3	0,40	0,50
10.	MnO	0,75	0,85
11.	CaO	0,10	0,12
12.	MgO ,	0,35	0,55

Table 13 Ilmenite quality certificate, Grade II

Characteristics,mass share,%		Min,%	Max,%
1.	Ilmenite	95,0	97,50
2.	TiO_2	56,50	59,00
3.	Fe_2O_3	20,0	25,0
4.	FeO	15,0	23,0
5.	V_2O_5	0,24	0,25
6.	P_2O_5	0,060	0,11
7.	Cr_2O_3	0,030	0,055
8.	SiO_2	1,5	2,5
9.	Al_2O_3	0,40	0,80
10.	MnO	0,70	0,80
11.	CaO	0,11	0,15
12.	MgO	0,35	0,45

Chapter 2. Overview of the enrichment technology

2.1. Technological scheme of enrichment

The enrichment plant includes two independent gravity sections with a capacity of 320 tons per hour (gravity No. 1) and 240 tons per hour (gravity No. 2) for processing initial sands and a refinement section with a capacity of up to 60 tons per hour to enrich the ilmenite black concentrate. Schemes of enrichment of gravity No. 1 and gravity No. 2 are similar. **(Figure 11)**

2.1.1. The technology of primary (gravitational) enrichment of initial sands

At the enterprise for extraction and processing of ilmenite sands of Birzulovsky deposit the following technology of gravitational concentration of output sands is accepted:

The initial sands produced in the quarry are blurred by hydraulic monitors 250 through a grid with a cell size of 60x60 mm and fall into the sump of pumps 16/12 GR-II- (7) -840R-160- and in the form of a pulp with a solids content of 15-20% by hydrotransport on a polyethylene pipeline with an outer diameter of 560 mm (gravity No. 1) and 500 mm (gravity No. 2) are transported in the receiving sump (item 1 gravity (hereinafter "g")). The design of the receiving sump allows to remove a part of the pulp with the size of 4mm past the screening on the fixed grate, which eliminates the overload of the receiving sump and screen in case of load fluctuation.

Blasted sands in the receiving sump of grain size of 4 mm arrive on the control screening machine at a fixed inclined screen (item 2 g).

Supersonic product (pebbles, fragments of silicon) is directed by gravity gravitationally beyond the gravity for further transportation to the dump; a 6 mm thick product is accumulated in a jet sump with a volume of 600 m3 (gravity No. 1) and 380 m3 (gravity No. 2). Plums of the jet sump are sent to the sump (item 9 g) and the pump (pos.10 g) are supplied for desliming in the hydrocyclones ГЦР-350 (taper angle 10 deg.) In order to reduce losses of ilmenite.

The sands of the ink sump are pumped to the main desliming operation in hydrocyclones ГЦР-500A (item 7 g). The discharge of the operation of the basic desliming is cleaned in hydrocyclones ГЦР-350 (angle of conicity of 20 degrees) (Item 8d) of the control desliming. The discharge of this operation on a polyethylene pipeline with an outer diameter of 500 (560) mm is sent to the recycling water reservoirs. Sands of basic and control desliming are further classified on inclined screens (item 12 g) in the class ± 2,8 mm. Underscreen product of screening granularity +2.8 mm is sent to the dump, overscreen -2.8 mm is the initial feed of gravity separation.

Gravitational enrichment of prepared sands is carried out according to the gravity scheme using the spiral separators NHM / 8 / C / 3 and SC20 / 7 / B / 3 (MULTOTEC, South Africa) on gravity No. 1. After screening, the sands fall into the sump (item 13 g) and pump (item 14d) are fed to the main spiral concentration (item 16 g), on which three products are separated: concentrate, intermediate product and tails. The main concentration product is sent to the industrial product sump (item 17g) and a pump (Item 18g) to be sent for cleaning by spiral separators at the stage of industrial concentration products (item 19d). Concentrates of the main and industrial products are combined in a sump (item 20 g) and a pump (item

21g) are fed to the 1st clean concentration (item 22 g), the concentrate of which through a sump (item 23d) with a pump (item 24d) is fed to the 2nd purifying concentration (item 25 g), resulting in a rough ilmenite concentrate. In turn, the tails are also subjected to cleaning in the control stages of the spiral separators. Tails of the main concentration are sent to the sump (item 26g) and a pump (item 27d) are fed into a thickening funnel (item 28d). The sands of the thickening funnel are sent to the 1st control concentration (item 29d). Tails of industrial products of concentration are sent to a sump (item 34g) and pumps (item 35g) are fed into a thickening funnel (item 36g). The sands of the thickening funnel are sent to the 2nd control concentration (item 37g). Tails of the first and second listed operations are combined in a sump (item 30 g) and a pump (item 31d) are fed into a thickening funnel (item 32d). The sands of the thickening funnel are sent to the 3rd control concentration (item 33d).

Plums desliming in hydrocyclones are collected in a slurry sump (item 40 g for No. 1) and a pump (item 41g for No. 1) are pumped along a polyethylene pipeline with an outer diameter of 500 (560) mm into the recycling water reservoirs.

The tailings of the first and second control concentrations are combined in the tail sump (item 38g) and the pump (item 39g) is transported via a polyethylene pipeline with an outer diameter of 500mm (gravity No. 1) and 355mm (gravity No. 2) into the waste space of the pit.

The extracted concentrate of spiral separation is accumulated in the sump of the rough concentrate (item 44g) and the pump (item 45g). is fed into the thickening funnels (item 49g) and then it is dewatered on vacuum filters (item 50g) for feeding to the drying station in the finishing station. Dehydration of the raw ilmenite concentrate from gravity No. 1 is carried out directly on this site, where after the vacuum filters the concentrate is supplied to the storage site for raw ilmenite, or immediately fed to the finishing section by a conveyor (item 54d) where the commodity ilmenite concentrate is obtained. This technology allows you to separate, if necessary, the work of the gravity from the working site.

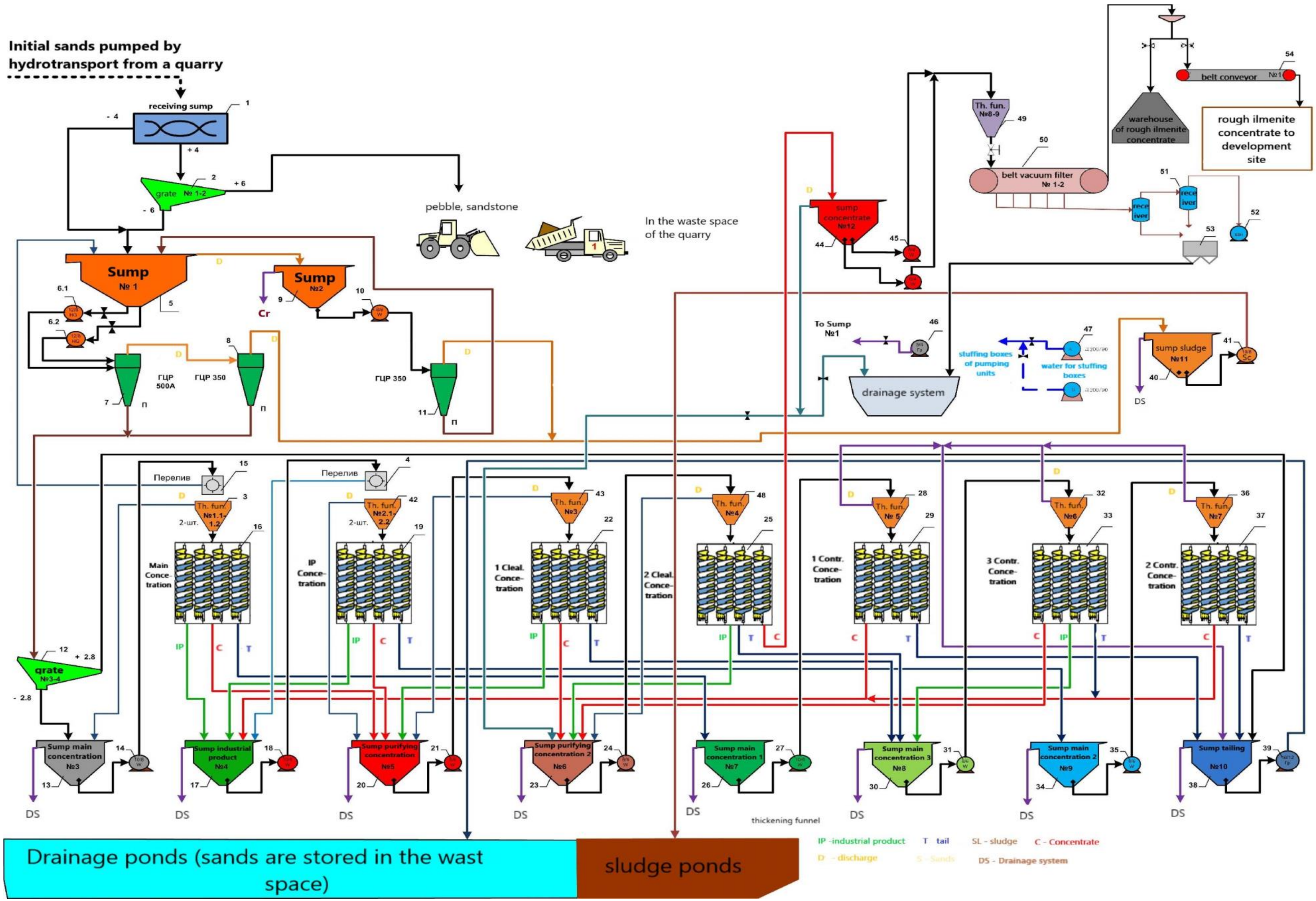


Figure 11The circuit equipment of gravitational section

2.1.2. The technology of final dressing of the rough ilmenite

The delivery of rough ilmenite from the storage site to the dressing site is carried out with the help of a front loader that delivers to the hopper (item 39 d) of the feeder (item 40 d) from which the rough ilmenite is transported along the abruptly inclined conveyor to drying drums SB1 and SB2 (items 5.1 -5.2 d). Water supply of the development site is carried out independently of gravity from the reservoir of water located in the enrichment production area.

Drying of rough ilmenite is carried out in drum furnaces with diesel fuel (item 5.1-5.4 d), after which the dried material is fed to the screening operation (item 10.1-10.4 d) in 2.2 mm class, using a conveyor (item 8.1 - 4 d) and a belt elevator (item 9.1-4 d).

Class +2.2 mm is tail, which is conveyed outside the finishing area by means of a belt conveyor (item 19 d).

Dry magnetic separation is performed on drum and roller magnetic separators with permanent magnets.

The first stage of magnetic separation is performed on the magnetic drum separators BS-31.5 / 50-H-11.07 (item 15 d) with a weak magnetic field (induction 0.3 T) to isolate particles with high magnetic susceptibility to protect the roller belt separators and the withdrawal of foreign magnetic impurities. At the same time, ferromagnetic particles, the magnetic product, make up an insignificant part in the raw ilmenite and are separated into a separate product for removal from the technological process onto the conveyor (item 19 d), and the nonmagnetic fraction is sent for separation on high-intensity drum separators BS-40/150-N -12.046 (item17 d) with an induction of at least 0.5 T.

As a result of magnetic separation on high-intensity drum separators, two products are distinguished:

- magnetic product, initial ilmenite concentrate;
- a non-magnetic product, a rough ilmenite concentrate with a lower content of ilmenite than in the original one, which is enriched with a larger magnetic field;

The magnetic product is transported to the storage bin of the finished product by means of belt elevators (item 18 d);

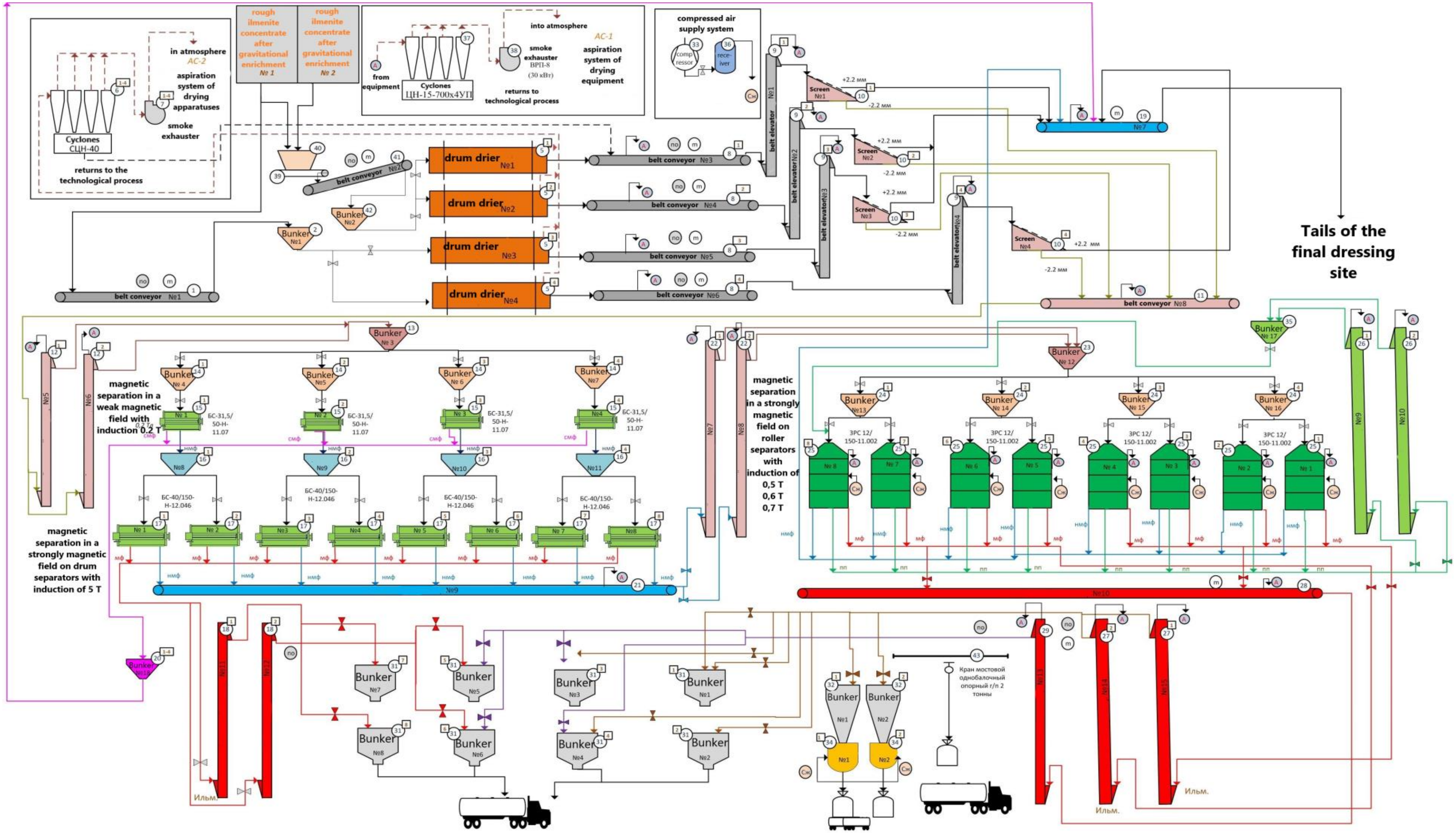
Non-magnetic product of drum separators БС-40/150-Н-12.046 with the help of belt conveyor (item 21d) and elevator (item 22d) is fed for enrichment on high-intensive roller separators 3РС 12 / 150-11.002

As a result of magnetic separation on roller separators, which occurs in three stages (the first stage is not less than 0.5 T, the second cascade is not less than 0.6 T, the third cascade is not less than 0.7 T), three products are distinguished:

- magnetic product, ilmenite concentrate;
- intermediate product, returns to the head of roller magnetic separation;
- non-magnetic product, is output to the tails.

Magnetic product, ilmenite concentrate, with the help of an elevator (item 27, 29d) is sent to the bins of the finished product.

Tails are sent to a conveyor belt (item 19 d), which transports this product outside the finishing area. Then, the tails of the evidence with the help of a front loader and a dump truck are transported to the quarry for a subsequent return to the beneficiation plant for re-enrichment.



MF- magnetic fraction SMP- strong magnetic product NMF- nonmagnetic fraction IC- ilmenite conct IP-intermediate product

Figure 12 The circuit equipment of final dressing section

Chapter 3. Research of the tailings enrichment after magnetic separation

3.1. Analysis of the technological scheme

Analyzing the scheme of the enrichment plant for ilmenite concentrate was concluded that the scheme has drawbacks, as a result of which the content of useful components in the waste is too high (15-20%).

They are related to the fact that a material with a predominant content of TiO_2 over Fe goes to the non-magnetic product - **Table 8** (Mass fraction of the main components in ilmenite of different magnetic strength),

According to the table, it can be seen that TiO_2 has a small magnetic susceptibility; hence the magnetic properties are substantially reduced.

In order to enrich this material, it will be necessary to increase the magnetic strength of the separators. There are several ways to implement this characteristic.

First is to increase the induction of the field.

The second is to use a separator with a large field gradient.

At the Department of Mineral Processing in National Mining University developed laboratory separators with increased magnetic force, which was used to enrich manganese ore, due to a larger field gradient, with a special design of the magnetic system. (1)

Based on the results of the experiments given in this article, we can conclude that in order to obtain a high-quality concentrate it is necessary to use the particle size from 0.2 to 0.8 mm and then that the best results are obtained with the joint application of belt and deflecting types of magnetic separators.

3.2. Testing of the samples

The Company provided a sample weighing 630.22g which was tested.

Preliminary tests on the roller separator showed that the concentrate is clogged with small quartz particles due to their adhesion to coarse particles and to the separator belt.

Classification of this material into three classes of fineness (-0.8 + 0.25mm), (-0.25mm) and (+ 0.8mm) was performed to obtain a high-quality concentrate and avoid contamination of the concentrate.

The material with the fineness of (-0.25mm) were separated on a deflecting magnetic separator. We carried out one main and two re-cleaning magnetic separations. A high-quality concentrate was obtained.

The material with the fineness of (-0.8 + 0.25mm) and (+ 0.8mm) were separated on a belt magnetic separator. The material with fineness of (-0.8 + 0.25mm) carried out through one main and one re-cleaning magnetic separations with further fusion of concentrates. Also a high-quality concentrate was obtained.

The material with the fineness of (+ 0.8mm) carried out through one main magnetic separation, but concentrate content we received was low-quality one.

All samples were measured on high-precision scales with the possibility of an error of 0.5% (10 mg).

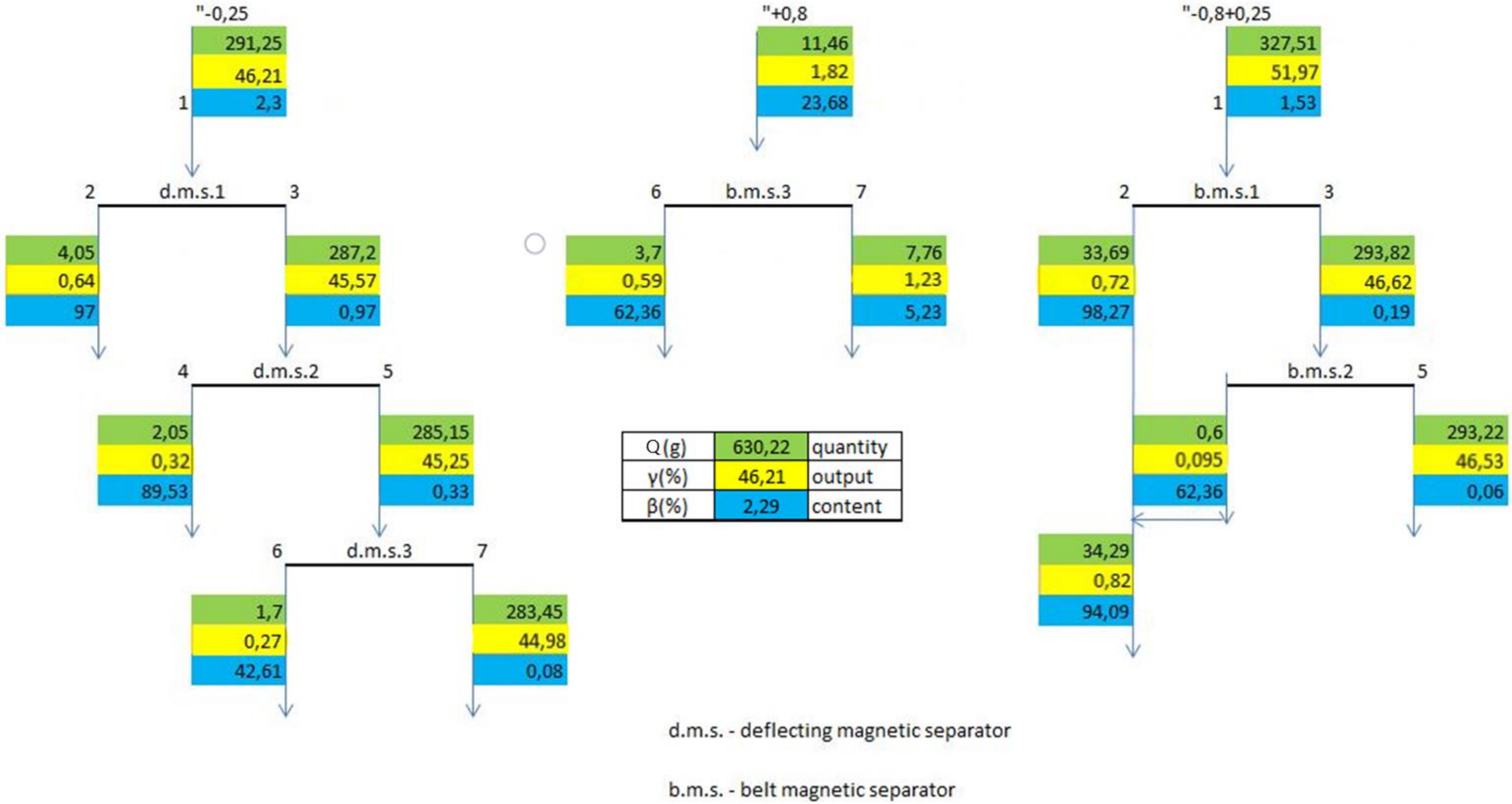


Figure 13 Testing of the samples

Table 14 Results of the tests

Names of the samples	Content, %				
	Ilmemite	TiO2	FeO	Fe_2O_3	$FeO+Fe_2O_3$
Tailing 1-0,25	0,08	30,88			
Tailing 2-0,8+0,25	0,06	59,45			
Tailing 3+0,8	5,23	59,84			
Concentrate 1-0,25	97	62,69	5,59	21,65	27.82
Concentrate 2-0,25	89,53	62,25	5,44	21,80	27.84
Concentrate 3 -0,25	42,61	52,82			
Concentrate 3 +0,8	62,36	60,45	9,77	25,82	36.67
Concentrate 2. 1-0,8+0,25	98,27	63,43	4,34	26,87	31.69
Concentrate 2.2 -0,8+0,25	62,36	62,25	6,25	25,11	32.05

Pictures of samples are attached in **Appendix 1.**

3.3. Development of tailings enrichment scheme

According to the data of the experiments, the own technological scheme of tailings enrichment with circulating loads was developed and calculated.

The tailings delivery will be carried out from the finishing section of rough ilmenite along the belt conveyor to the screen, where the material will be classified according to their size (-0.8 + 0.25mm), (-0.25mm) and (+ 0.8mm), respectively.

The material of size (+ 0.8mm) will be sent to the finishing process to the size (-0.8mm) on the roll crusher and returned to the screen for re-screening.

The material of size (-0.8 + 0.25 mm) is fed to a magnetic type separator with two stages of magnetic separation with the cleaning of the waste of the first separation stage. The magnetic product of the second stage is not conditional and is sent to the main magnetic separation as a circulating load.

The first stage of magnetic separation is carried out on a magnetic type separator (roller magnetic separator PC-B) with field strength of 1.5 T and a modernized magnetic system.

A material of fineness (-0.25 mm) is fed to magnetic separation on a deflecting type separator with two control cleanings of a non-magnetic product.

3.3.1. Selection of equipment and calculation of the scheme

Calculation of the qualitative-quantitative scheme:

When calculating the qualitative-quantitative enrichment scheme, we determine for all products of the scheme the numerical values of the main technological indicators: Q, γ, β, ε.

We determine the output of the concentrate in the first enrichment operation, solving the system of the equation of the balance of yield and content of the mineral in the separation products:

$$\begin{cases} \gamma_1 = \gamma_2 + \gamma_3 \\ \alpha\gamma_1 = \beta_1\gamma_2 + \beta_2\gamma_3 \end{cases},$$ Where

$$\gamma_2 = \frac{\alpha - \beta_3}{\beta_2 - \beta_3} \cdot \gamma_1 = \frac{50.93 - 3.8}{89.53 - 3.8} \cdot 50.93 = 11{,}28\ \%,$$

then $\gamma_3 = \gamma_1 - \gamma_2 = 50.93 - 11.28 = 39.65\ \%,$

We calculate the balance equation for the next operation, determine the yields of the seventh and eighth products: $\begin{cases} \gamma_1 = \gamma_2 + \gamma_3 \\ \alpha\gamma_1 = \beta_1\gamma_2 + \beta_2\gamma_3 \end{cases}$ where,

$$\gamma_4 = \frac{\beta_2 - \beta_5}{\beta_4 - \beta_5} \cdot \gamma_2 = \frac{89.53 - 3.27}{97 - 3.27} \cdot 11.28 = 10.38\ \%,$$

then $\gamma_5 = \gamma_2 - \gamma_4 = 11.28 - 10.38 = 0.9\ \%,$

Calculating the extraction:

$$\varepsilon_4 = \frac{\beta_4 \cdot \gamma_4}{\alpha} = \frac{97 \cdot 10.38}{17.69} = 56.51\ \%,$$

Similarly, we calculate all other operations. All further calculation were made in Excel program and represented in **Figure 14**.

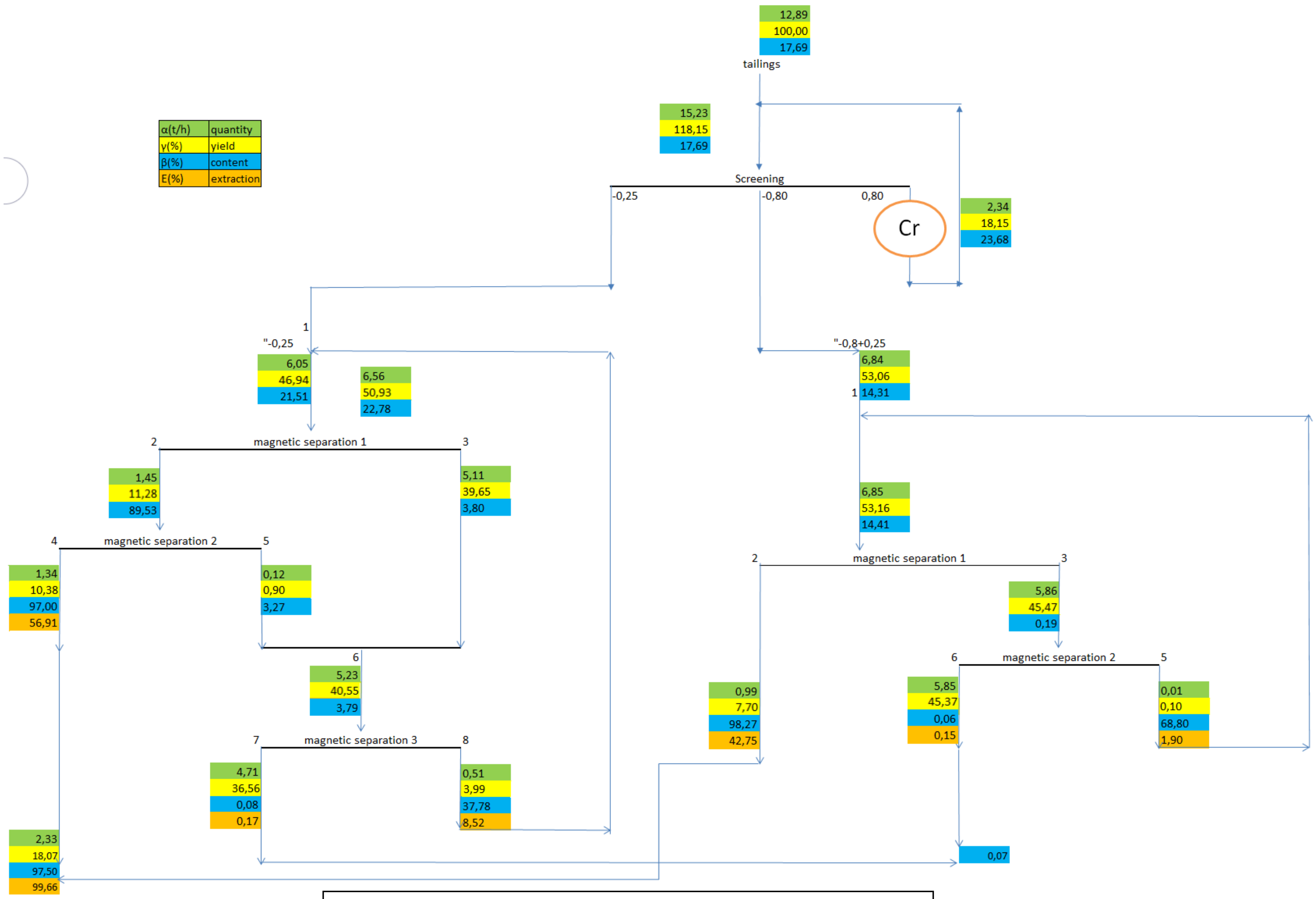


Figure 14 Developed tailings enrichment scheme

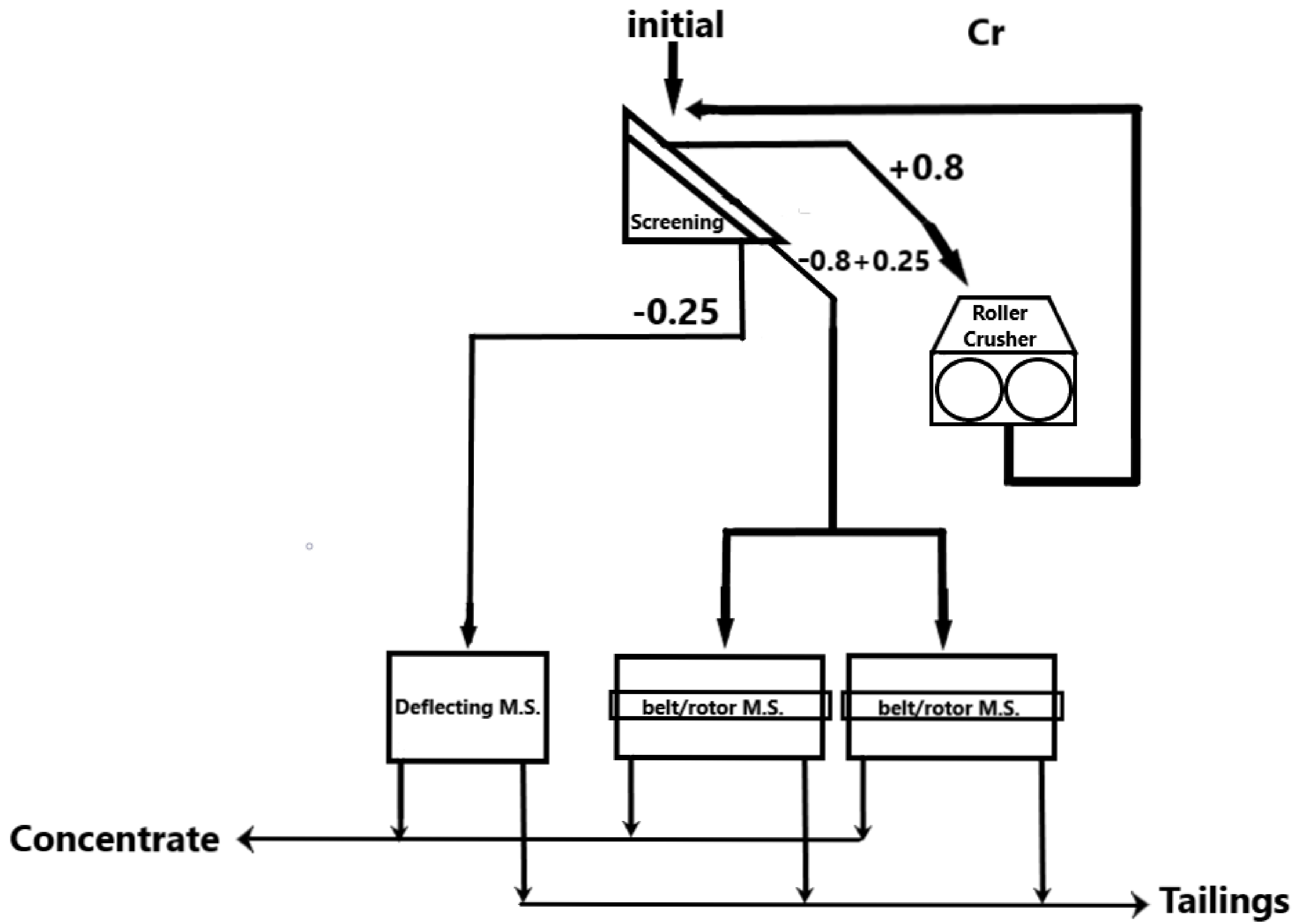


Figure 15 Equipment scheme

The selection of equipment (**Figure 15**):

Screen:

Desired choice: High-frequency vibrating screen (Double sieve 2x2) [23, p.14]

Q_{in}=12,89 t/h – initial capacity.

$\mathbf{Q_{sc}}$ – specific capacity in tons per 1m^2 = 1.25t/h/m^2;

F=$\frac{Qin}{Q_{Sc}} = \frac{12.89}{1.25}$ = 10,312m^2 – total screening area**;**

N=10,312/ 2m^2 =5.156 **–** amount of screens

Overload 15% allowed – We accept for installation 5 грохотов.

At a capacity of **5,156** we need 5 desired screens.

Crusher:

$\boldsymbol{Q_{in}} = \boldsymbol{Q_v} * \boldsymbol{\gamma}_{\text{н}} * \boldsymbol{k} = \frac{\boldsymbol{\pi n}}{\mathbf{30}} * \frac{\boldsymbol{D}}{\mathbf{2}} * \boldsymbol{\delta} * \boldsymbol{B} * \boldsymbol{\gamma}_{\text{н}} * \boldsymbol{k} = 2.34\ t/h$ **where**

$\boldsymbol{Q_v} = \boldsymbol{V} * \boldsymbol{F}$;

$\boldsymbol{V} = \boldsymbol{w}\frac{\boldsymbol{D}}{\mathbf{2}}$; **-** rotational speed of rolls;

$\boldsymbol{F} = \boldsymbol{\delta} * \boldsymbol{B}; \boldsymbol{\delta} - distance\ between\ rolls; \boldsymbol{B} - length\ of\ rolls;$

$\boldsymbol{\gamma}_{\text{н}} = 1680$ – bulk density of material;

$\boldsymbol{k}$ **-** a coefficient that takes into account the incompleteness of using the length of the rolls and the looseness of the material;

B=$\frac{60*Qin}{\pi n*D*\delta*\gamma_{\text{н}}*k}$=$\frac{60*2,34}{3,14*400*0,25*0,5*1,680*0,85} = 0,62$ m;

Desired choice: Roller mill MB-[23, p.25]

$\mathbf{B_{cr}}$=250mm;

$\mathbf{D_{cr}}$=400mm;

$\mathbf{Q_{cr}}$=1.5 t/h capacity of crusher by specification

$\boldsymbol{N1} = \frac{Q_{in}}{Q_{Cr}}$=$\frac{2.34}{1.5} = 1.56$;

$\boldsymbol{N2} = \frac{B}{B_{cr}} = \frac{0.62}{0.4}$= 1.55 ;

At a capacity of 2.34 tons per hour and length of rolls we need 1.55 or 1.56 roller mills. We accept for installation 2 roller mills.

Magnetic separator :

The productivity of the separator can be determined according to formula:

$\boldsymbol{Q} = 3.6 * v * \delta * B * \gamma_{\text{н}} * k = 6.84$ t/h, where

$\boldsymbol{v}$ =0,8 m/s – conveyor belt speed;

$\boldsymbol{\delta} =$ 1,6 – particle layer thickness;

B – conveyor belt width;
$\boldsymbol{\gamma}_{\text{н}} = 1680$ – bulk density of material;
$\boldsymbol{k}$ – coefficient, use of the width of the belt, we accept 0,9;

$$\boldsymbol{B} = \frac{Q}{3.6 * v * \delta * \gamma_H} = \frac{6{,}84}{3{,}6*0{,}8*1{,}6*1{,}680*0.9} = 0{,}98 \text{ m};$$

Desired choice: we accept for installation roller magnetic separator PC-B with an improved magnetic system. [24]

Deflecting magnetic separator (laboratory-based equipment)
$\boldsymbol{Q_{in} = N * q_v = 6.05}$ **t/h –** initial capacity**;**
$\boldsymbol{q_v}$= 2 g/s = $2*10^{-3}$kg/s – 1 channel performance;

$\boldsymbol{Q} = 3.6 * V * \delta = 3.6 * 2 * 10^{-3}$ t/h – total performance;

$\boldsymbol{N} = \frac{\mathbf{6.05}}{\mathbf{3.6*2*10^{-3}}} = \mathbf{840}$; -needed numbers of channels.
s = 3*4 =12cm^2; - area of one channel;

S = $840 * 12 = 10080$ cm^2≈1m^2; - working area of separator;

Desired choice: we accept for installation deflecting magnetic separation with working area of 1m^2.

3.3.2. Estimation of economic efficiency

The expected economic effect from the introduction into the enrichment scheme of the belt magnetic separator and the deflecting magnetic separator is that as a result of the implementation of the proposed solutions the additional yield of the ilmenite concentrate will be **2.33 t/h**. Thus, the profit received by the enterprise will be greater. The expected economic effect is calculated below.

Fund of section working time:

$$T_s = (T - T_1) * t_{sh} * c = (365 - 60) * 12 * 2 = 7320 \text{ (h/year)}$$

where **T** – calendar fund of time, days;

$\mathbf{T_1}$ – time fund of regulated breaks, days;

$\mathbf{T_{sh}}$ – duration of shift, hours;

c – number of shifts, units.

$$K = K_1 + K_2 + K_3;$$

The book value of the fixed assets of the technological operation.

Where $\mathbf{K_1}$ – capital costs for the acquisition of FA, USD;

$\mathbf{K_2}$ – expenses for transportation of fixed assets;

$\mathbf{K_3}$ – costs for the installation of fixed assets.

Transportation costs are taken in the amount of 8% of the value of the FA, installation costs - at a rate of 25%. Thus, the book value of equipment will be: **K** = K1+0,08 K1+0,25*0,08 K1 = 1,1* K1;

$\mathbf{K_1}$ = 1,1*340 000 = 374 000 USD;

The book value of the fixed assets of the technological operation: $\mathbf{П_н}$ = $К_1$ = 374 000 USD

The amount of annual depreciation is:

$$\boldsymbol{A = П_н * \frac{Н_а}{100}};$$

A = 374 000 *0,24 = 89 760 USD.

where $\mathbf{Н_а}$ – depreciation rate;

$\mathbf{П_н}$ – book value of fixed assets.

Table 15 Carrying amount of equipment and depreciation charges

Name of equipment	Amount	Carrying value of a unit of equipment, thousand	Total book value, thousand	Amount: depreciation deductions, thousand USD.

		USD.	USD.	For year	For month
1	**2**	**3**	**4**	**5**	**6**
Belt magnetic separator	1	120	132	31.68	2.64
Deflecting magnetic separator	1	120	132	31.68	2.64
Roller mill	2	60	66	15.84	1.32
Roller Screen	5	40	44	10.56	0.88
Total:			374	89.760	7.480
Unrecorded equipment (5% of recordered)				18.7	1.56
Total:				108.460	9.038

Number of staff:

$$N_я = m * H * c;$$

где **m** – number of units of equipment serviced;

H – standard of service, man / shift (we assume 0.3);

c – number of working shifts (assume 2).

$$N_{сп} = k_{сп} * N_я;$$

где **Nсп** – scheduled staff of workers;

$k_{сп}$ – the ratio of the list composition (we assume 1.34);

Operators of concentrating equipment:

Nя = 4*0,3*2 = 2.4;

Nсп = 2.4*1.34 = 3.2= 3 men

Equipment mechanics:

Nя = 5*0.3*2 = 3;

Nсп = 3*1.34 = 4.02 = 4 men.

$$C_{зп} = \left\{ \left[\left(\sum_{i=1}^{m} A_i \cdot H_i \cdot C \cdot k_{сп} \right) \cdot \left(\frac{\sum_{i=1}^{n} k_i \cdot R_i}{\sum_{i=1}^{n} R_i} \right) \cdot Д_1 \cdot k' \cdot t \right] \cdot \left(1 + \alpha/100 \right) \right\} \cdot k \cdot k_1;$$

Calculation of the payroll with accruals.

where **m** – types of serviced equipment, **A** – number of serviced equipment i-th type, items, **Hi** – the rate of service of i-th equipment, people/shift, **C** – number of working shift, **kсп** – coefficient of payroll composition, **ki** – tariff factor of the i-th level; **Ri** – number of i-th level; **n** – number of levels;
Дi – Tariff rate of i-th category, USD/h; **t** – annual fund of working time of one worker, h; **a** – surplus rate, %; **k** – coefficient of additional wages, shares units.; **k1** – wage rate; **k'** – Ratio of the tariff rate to the minimum wage.

$$C_p = \left\{ \left[\mathbf{9 * 0.3 * 2 * 1.34} \left[\frac{\mathbf{1.86*4+1.54*5}}{\mathbf{9}} \right] * \mathbf{1.8 * 2.4 * 2440} \right] * (\mathbf{1 + 0.4}) \right\} * \mathbf{1.3 * 1.52} = 354\,952{,}69 \text{ USD/year}$$

Calculation of costs under the item "Electricity".

$$C_э = \left[\left(a \cdot P + b \cdot W \right) \cdot \left(1 \pm k \right) \right] \cdot n;$$

where **a** – tariff for a unit of connected capacity (take 0.26 USD/kW); **P** – total power of current pantographs, kW; **b** – tariff for consumed electricity (we accept 0.05 USD / kWh); **W** – amount of electricity consumed, kW/h; **k** – coefficient that takes into account the efficiency of the power used (k = 0 for cos = 0.92); **n** – coefficient that takes into account the cost of maintaining substations (**n**=1,1).

$$P = \sum P / \eta \cdot \cos\varphi;$$
$$W = \sum P \cdot k_3 \cdot k_0 \cdot t / \eta_1 \cdot \cos\varphi;$$

Where P – total connected power of current collectors, kW; η - power efficiency (0.96); $\cos\varphi$ - average weighted efficiency of pantographs (0,35…0,85); k_0 – coefficient simultaneous operation pantographs (0,5…0,9); t – nominal fund of working hours; η_1 - efficiency of the company's electrical network (0,8…0,96).

P = 14.5/0,96*0,8 = 12.08 kW;

W = 12.08*0,85*0,9*7320/0,96*0,92 = 64 827 kW/year;

$C_э$ = (6,8*12.08+1,2* 64 827)*(1 – 0,02)*1,1 = 3 229 USD/ year

Maintenance costs.

The cost of repairs will be calculated as a percentage of the book value of equipment, ie:

$$C_p = p \cdot K;$$

where p – the coefficient of deduction for repairs from the book value of equipment (we assume 0,035).

Total repair costs will be:

∑**C** = 374 000*0.035= 13 090 USD

The total annual income from the introduction of equipment will be:

Э = 2,33 t/h*7320 hours*150 USD/t = 2 558 340 USD/year.

Total costs:

C$_м$ = 853 732 USD/year.

Payback period of this engineering solution:

$$C = \frac{C_m}{Э} = \frac{2\ 558\ 340}{853\ 732} = 4 \textbf{ months;}$$

Table 16 The main cost items

	Consumption	**Thousand USD/year**	**%**
1	Depreciation	108 460	12.70
2	Wage fund	354 953	41.58
3	Electricity	3 229	0.39
4	Maintenance	13 090	1.53
5	Value of equipment	374 000	43.80
	Total	853 732	100

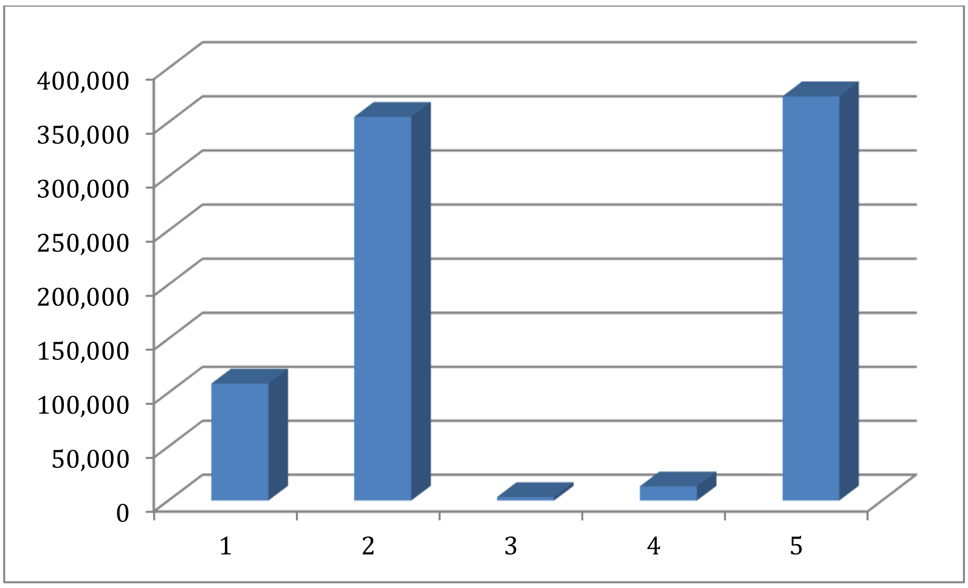


Figure 16 Cost plan

Figure 16. Cost Plan

1 – Depreciation (**12.70**%);

2 – Wage fund (**41.58**%);

3 – Electricity (**0.39**%);

4 – Maintenance (**1.53**%);

5 – Value of equipment **(43.80%)**

Economic conclusion

Additional income from the implementation of the proposed scheme for processing magnetic separation waste will be **$ 2,558,340** with a total cost of $**853,732** the payback period will be 4 months.

4. Occupational Safety and Health

4.1. Characteristics of possible harmful factors

The reconstructed industrial object - the enrichment production - is an industrial object, which includes a concentrating factory (gravitation area, refinement, warehouse of finished products), where in the process of enrichment of the initial ore sands the finished commodity ilmenite concentrate is obtained and a number of auxiliary objects

The technology of carrying out work on the enrichment production is characterized by the presence of the following dangerous factors:

1. moving machines and mechanisms;
2. mobile parts of production equipment;
3. moving goods;
4. increased dust and gas pollution of the working zone;
5. elevated or lowered air temperature of the working zone;
6. elevated or lowered temperature of the surfaces of equipment, materials;
7. increased noise in the workplace;

8. increased level of vibration;
9. increased or reduced air mobility;
10. insufficient illumination of the working area;
11. elevated or reduced air humidity.

In addition to the harmful factors that can affect the health of attendants can be attributed to the pollution of production processes in the enrichment production:

1) works on the repair of equipment, technological machines and mechanisms;

2) work on lubrication of technological equipment;

3) regulation of technological equipment;

4) cleaning and cleaning of technological equipment;

5) work performed with contaminated sites, equipment, etc.

4.2. Measures to protect workers from external and internal hazards

To prevent the negative impact of adverse external and internal factors on servicing staff, accident avoidance by the personnel in the project provides for the following measures:

• The location of the technological equipment is made taking into account the safety of the workers and the convenience of its maintenance and repair.

• The production sites are equipped with safe passage for maintenance staff, as well as transport and cargo transportation.

• All service areas, transition bridges and stairs are equipped with strong, stable fences and secured with railing 1 m high with a crossbar and a solid lining at the bottom of the railing to a height of 0,14 m.

• Work platforms located at a height of more than 1.5 m, protected by railing and equipped with stairs.

• Facilities for maintenance and stairs are designed to prevent moisture and dirt from staying on, i.e. with a slight inclination.

• Stairs to work platforms and mechanisms have a tilt angle of 45 °.

• The width of all stairs is not less than 0.6 m, the height of steps is no more than 0.3 m, and the width of the steps is not less than 0.25 m. The metal steps of the stairs and the ground are made of corrugated metal.

• Safe access to the base metal is carried out on the stairs.

All mounting holes, humps, located on the territory of the enrichment production, are protected by rails of a height of 1 m with a solid lining at the bottom of the railing to a height of 0,14 m, and in transition areas equipped with transition bridges with a width of not less than 1 m.

• In non-automatic pressure control valves, and control and measuring devices located above the floor level at an altitude of more than 1.5 m, stationary platforms with a width of at least 0.8 m are constructed.

• Minimum distance between adjacent dimensions of machines and apparatuses and from walls to equipment dimensions according to NPABO 0.00-1.52-77 is:

- a) at the main passages - not less than 1,5 m;

- b) at working passages between machines - not less than 1 m;

- c) on working passages between the wall and cars - not less than 0,7 m.

• All moving parts of machines and mechanisms (shafts, couplings, pulleys, drums, and the like), rotating, have solid or mesh fencing with 25 × 25 mm cells. Mesh fencing of drum conveyors is completed with a cell size not more than 40 × 40 mm. Tooth and chain transmissions have solid fences.

• Equipment, networks and passages are painted in colors according to the requirements of technical aesthetics and safety rules.

• Hoisting gear and moving mobile equipment are painted with special recognition colors - inclined alternating stripes, yellow and black colors.

• Special facilities are available for sampling of enrichment products directly from moving mechanisms.

• Special places are reserved for storing various materials, parts of machines and waste products at the enrichment industry.

• All surfaces of the drying unit, which are heated to a high temperature, are covered with thermal insulation. The drying unit is equipped with control equipment (thermocouple).

• The following safety measures are provided on the belt conveyors:

- installed devices that turn off the drive when breaking and slipping the tape;

- all belt conveyors are equipped with devices for mechanical cleaning of the tape and drums from the sticking material;

- the tail drums of the belt conveyors are completely enclosed with mesh fencing with the size of the cells not more than 40 × 40 mm. The enclosure of the drums is blocked with the engine of the conveyor with the help of the end switches, which excludes its start in operation with the removed fence;

- the conveyors have devices that provide stopping them from any point along its length from the main passages (cables closed with terminal switches;

- special adaptations are installed to avoid lateral displacements of the conveyor belt;

- To avoid slipping the conveyor belt, the mechanical stitching of the tape is made;

- manual lubrication of operating machines is executed with the help of special adaptations. Cleaning of concentrate from under the head, tail and deflection drums is executed by hand with the help of special adaptations only at the stopped conveyor, the electric circuit of which drive should be dismantled, and on warning devices posters warning "Do not activate - people work";

- the places of loading and unloading by belt conveyors are completely sealed;

- on conveyors, to prevent possible download from the working branch of the material, installed safety belts.

• The following safety measures are provided on elevators and screws:

- the covers of screw housings are equipped with a lock (with limit switches);

- the working branch of screws is fully sealed;

- the elevators of all their length are closed with safety housings;

- The elevators are equipped with brake devices;

- for observing the work of elevators in the casing, the inspection windows are arranged;

- The elevators have emergency switches in both loading areas and at unloading locations.

• All conveyors, elevators, augers, drying plant and other mechanisms and units make, according to technology, at the same time, therefore engines of all these mechanisms are consistently interlocked with each other. With:

a) start and stop are assumed in a certain sequence according to the technological scheme of the areas of enrichment production in general;

b) in the case of a sudden stop of any machine or conveyor, the previous machines or conveyors are automatically disconnected;

c) on conveyors and machines a local lock is installed that prevents the remote start of the conveyor or machines from the control panel.

• The production of the towing system is foreseen. The stopping and commissioning of the equipment after installation or repair will be carried out in accordance with the provisions of the beam system.

• Starting equipment (conveyors, elevators, etc.) before the movement of the mechanisms is accompanied by an audible signal.

• At the gravity section with a wet process, as well as at the refining area, which provides for washing and wet cleaning of the floors, the floors have waterproof coatings with a slope of the floor for drainage in accordance with the rules.

• Production staff is provided with overalls in accordance with the rules.

• In order to ensure safe working conditions, during the dark period of the day, the external illumination of the territory, the device of roads and pedestrian passages is provided.

4.3. Facility, noise and vibration

Sources of dust, noise and vibrational influence on the enrichment production can be both basic and auxiliary technological equipment: pump, ventilation installations, separators, conveyors, elevators, road transport.

In order to combat the noise and vibration of the working project, it is planned to install pumping units and fans on autonomous reinforced concrete foundations.

The premises of the operator (the location of the permanent servicing personnel) are protected by soundproof partitions.

For protection against vibration workers are provided with special footwear.

For protection of personnel in the service area of pumping units and other technological equipment with high noise level, silent headphones (such as VTSNIOT-2M or «Antiphoni») and silicone inserts of the type «BIRUSHI» are used.

The measures taken in the project provide a noise level at workplaces near technological equipment, 70 dBA, which does not exceed the established DSN 3.3.6.037-99 «Sanitary norms of industrial noise, ultrasound and infrasound».

To combat dust in accordance with the "Norms for the free provision of special clothing, special footwear and other personal protective equipment for workers in the mining industry," the service staff is provided with dust protection respirators and, if necessary, protective glasses.

To combat dust on sites, in warehouses and other premises of the enrichment production, the project provides for the installation of local ventilation and aspiration devices in accordance with the sanitary norms of designing industrial enterprises.

The buildings of the finishing and gravity sections have walls with smooth surfaces to prevent the accumulation of dust and facilitate its cleaning. Also, mechanized dust removal (washing with water) is foreseen.

The places of loading and unloading of belt conveyors are completely sealed and have suction with branch pipes connected to aspiration units.

Ventilation units are equipped with devices (armchairs, fittings) for monitoring and measuring the velocities, pressures and air temperatures in air ducts and devices, for adjusting the volumes of transported air, as well as for cleaning them.

When blocking the work of ventilation and aspiration units with the main and auxiliary equipment provides additional triggers directly in the vicinity of ventilation or aspiration equipment.

The air removed by ventilation and aspiration units before being released to the atmosphere is cleaned up to the concentration of dust in it, which does not exceed the maximum allowable normative documents, with the help of special cleaning devices.

In order to compensate for air that is removed by aspiration systems from the premises, an artificial inflow of air (artificial ventilation) is arranged.

In all industrial premises, where people are constantly located, artificial ventilation is arranged.

4.4 Security control

Control over observance of labor protection requirements.

Control over observance of labor safety requirements is carried out by the labor protection service in accordance with the "Labor Protection Management System at LLC" Velta ", approved by the General Director of the enterprise.

State control over observance of labor safety requirements at the enterprise as a whole is carried out by the Territorial Department of the State Committee of Ukraine for Derzhshippromnadzor in Kirovograd region.

4.4.1. Laboratory monitoring of the environment

To monitor the air condition at the workplace of the enrichment production, the regional sanitary laboratory conducts periodic sampling of air to determine the content of dust in it, as well as checking the temperature, humidity and air mobility at workplaces. These sampling should be done at least once a quarter, as well as in case of changing the technological regime and after reconstruction, overhaul of ventilation and aspiration units, drying apparatus.

For the control of the composition of exhaust gases from the motor vehicles, once a month, the selection of gases is carried out. When the regulatory values are exceeded, the regulation of engines is subject to the use of high-quality fuel.

Frequency of control over the quality of commercial drinking water in the enrichment production is carried out not less than 2 times a month. The monitoring is carried out by the local sanitary supervision authorities and the regional sanitary laboratory on the basis of concluded contracts.

Control over pollution of atmospheric air, level of surface concentration on the edge of sanitary and residential development is carried out once a year.

4.4.2. Control of electrical safety

Control of isolation resistance of electrical installations and grounding at the enterprise shall be in the timeframe and in the volumes specified in the relevant regulatory documents by a specialized electro laboratory.

Control over the level of ionizing radiation of natural radionuclides in the enrichment of raw materials in the enrichment production.

In the implementation of the project, three types of radiation control must be carried out:

• input control (VRC) of raw materials, building materials, the nomenclature of which is established by DBN V. 1.4-2.01-97;

• control in the production process (RKPV) of building products and structures, construction of the facility;

• final control of constructed objects (ORCO).

Radiological control is carried out under a separate agreement with the laboratory, which is accredited and has the right to carry out radiological control in accordance with the certificate.

Also conducted radiation control of finished products.

4.5. The sanitary protection zone

Enrichment production is classified in accordance with the particle number 173-96 "State sanitary rules of planning and development of settlements" to the enterprises of the third class of danger, and therefore the size of the sanitary protection zone is 300 m for the enrichment production with its technological processes.

5. Conclusion

In this thesis, the important practical task of waste processing on LLC Velta has been solved. In the existing gravitational separation enrichment scheme of ilmenite with followed by drying of the collective condensate and dry high gradient magnetic separation for obtaining commodity concentrates. Since it is magnetic the susceptibility of ilmenite depends on the content of iron in it - on the present time loss of ilmenite with waste of magnetic separation fluctuate in the range from 8 to 20%, which is significant. Reducing the loss of ilmenite with waste enrichment is an urgent task.

The originality of scientific and technical solutions consists in the application of high-gradient separation with the main separation of their feeding on classes of size -0.8 + 0.25 and -0.25 mm. The first class is enriched on a roller separator with a belt, and the second one on a deflecting magnetic separator. Such a solution allowed to improve the efficiency of the enrichment scheme as a whole.

The content of ilmenite in the waste was reduced from 17.6 to 0.07%, while the total extraction of ilmenite increased by 4.85%, the output of the additional commodity concentrate was 2.33 t/h.

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24. Roller [Electronic resource] / Access mode: http://www.prodecolog.com.ua/production/magnetic_separators/roller/rs-v/

Appendix 1.

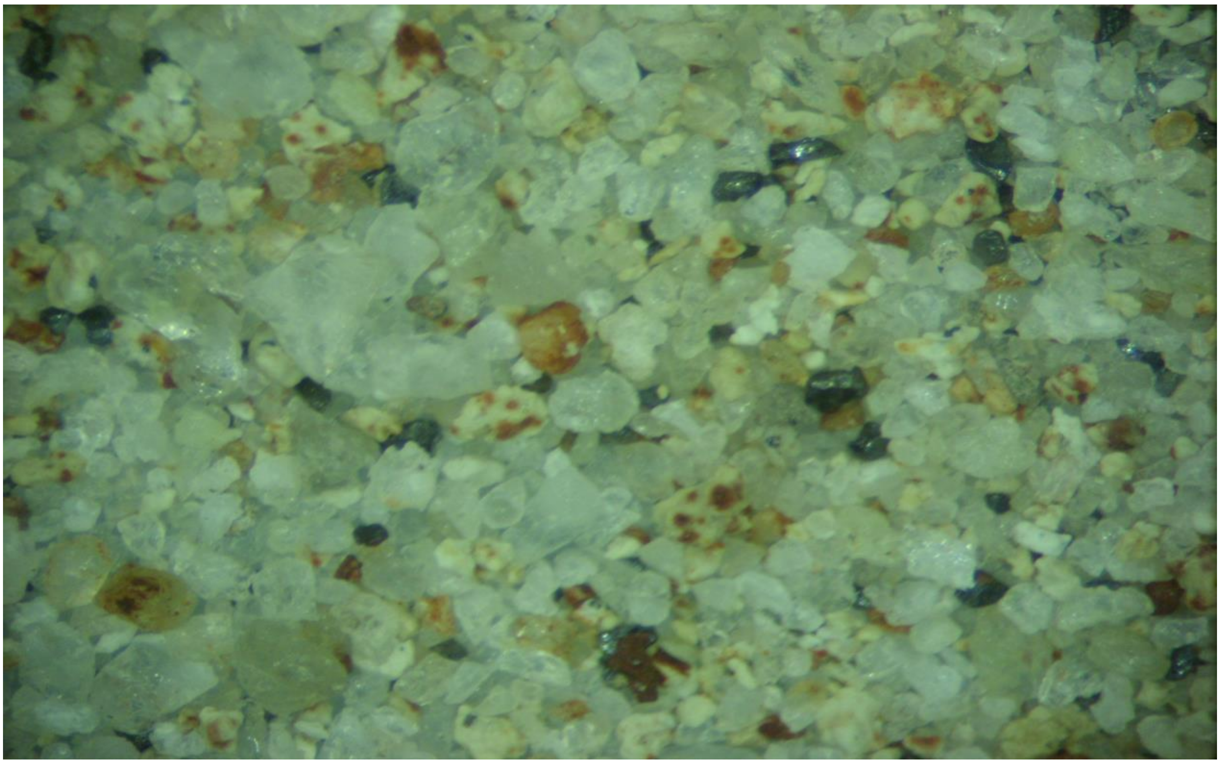

Figure 17 Initial tails -0.8+0.25 #1

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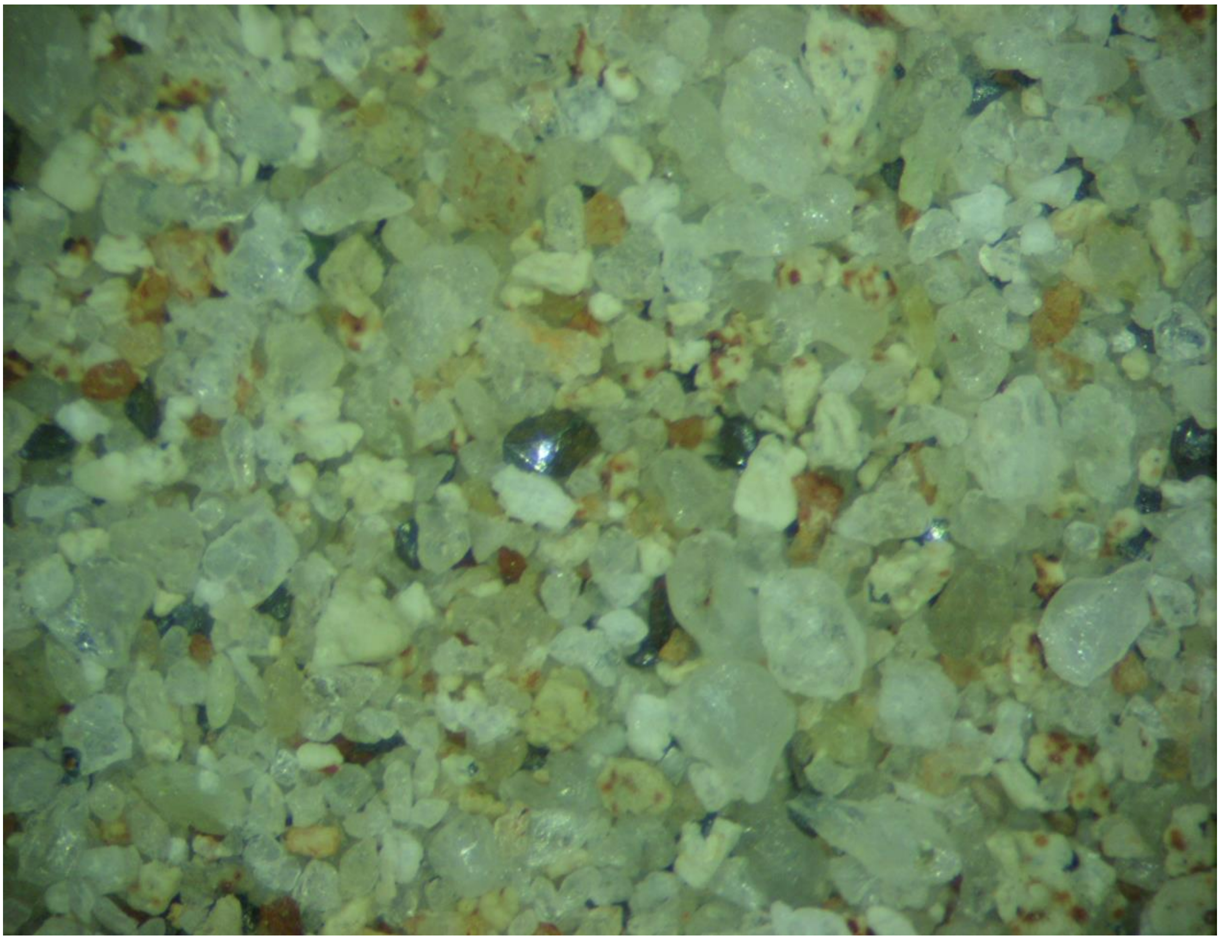

Figure 18 Initial tails -0.8+0.25 #2

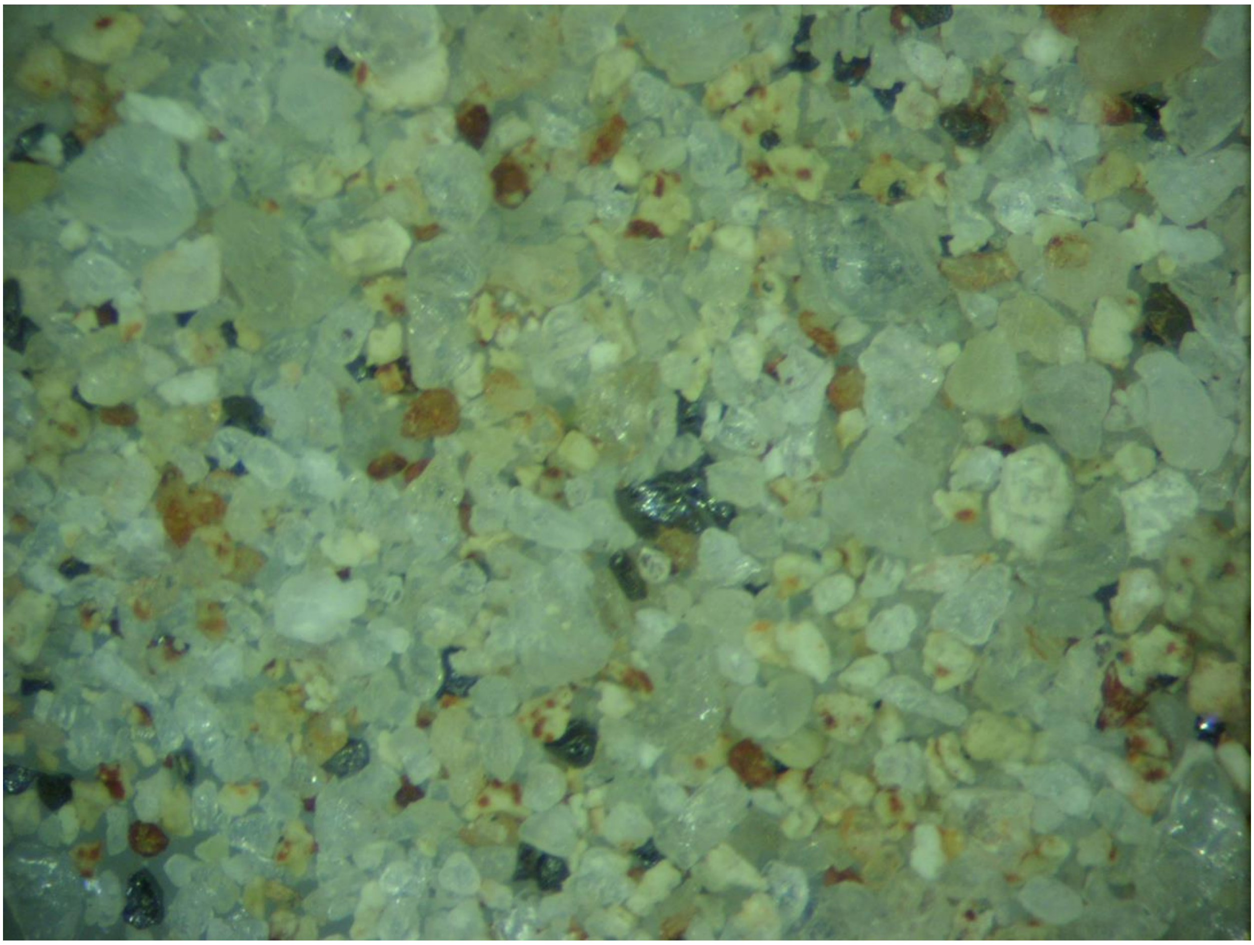

Figure 19 Initial tails -0.8+0.25 #3

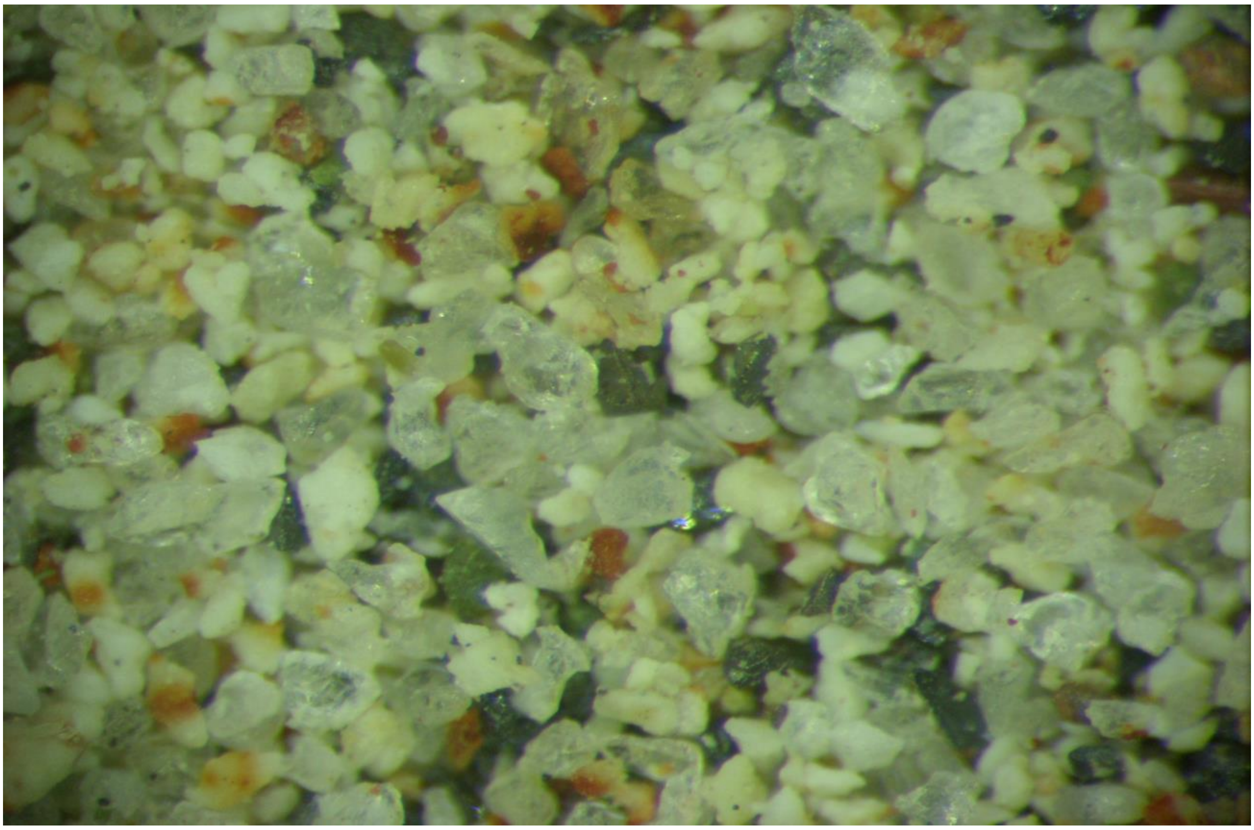

Figure 20 Initial tails -0.25 #1

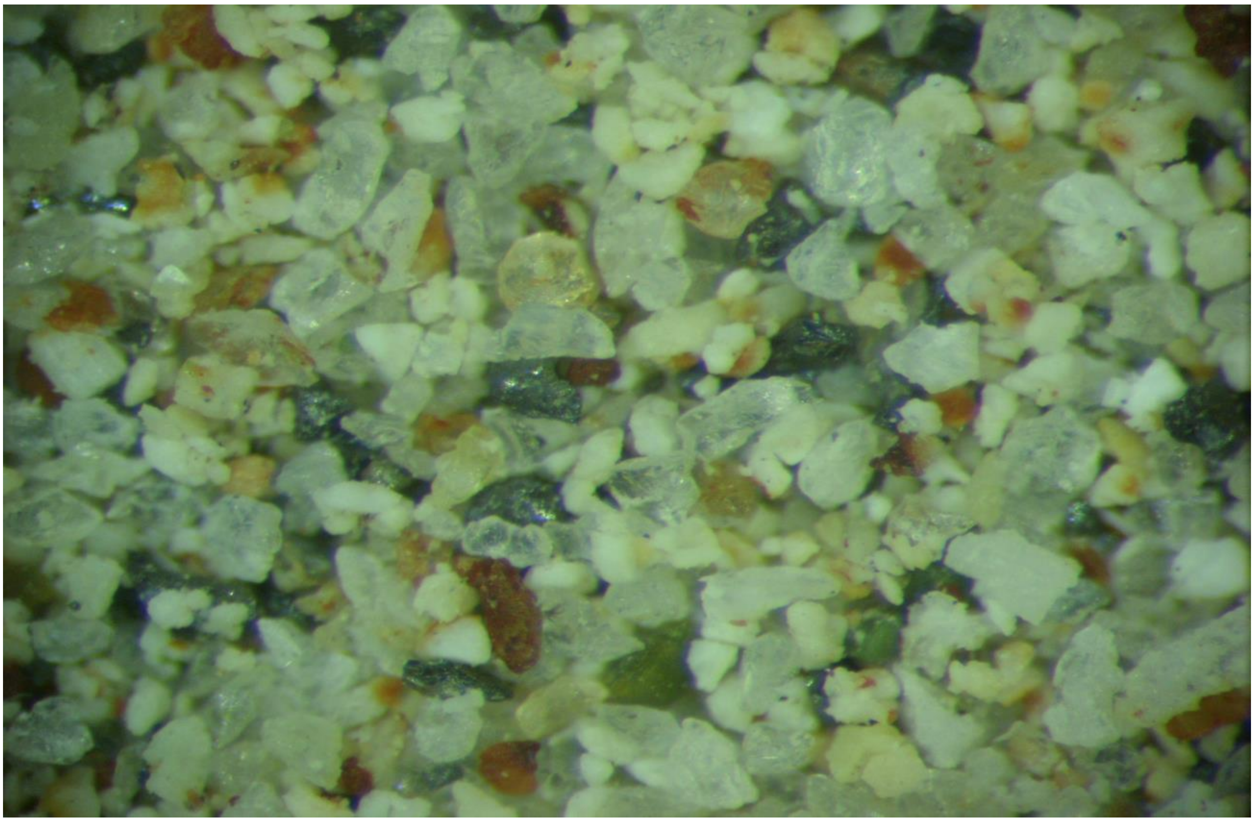

Figure 21 Initial tails -0.25 #2

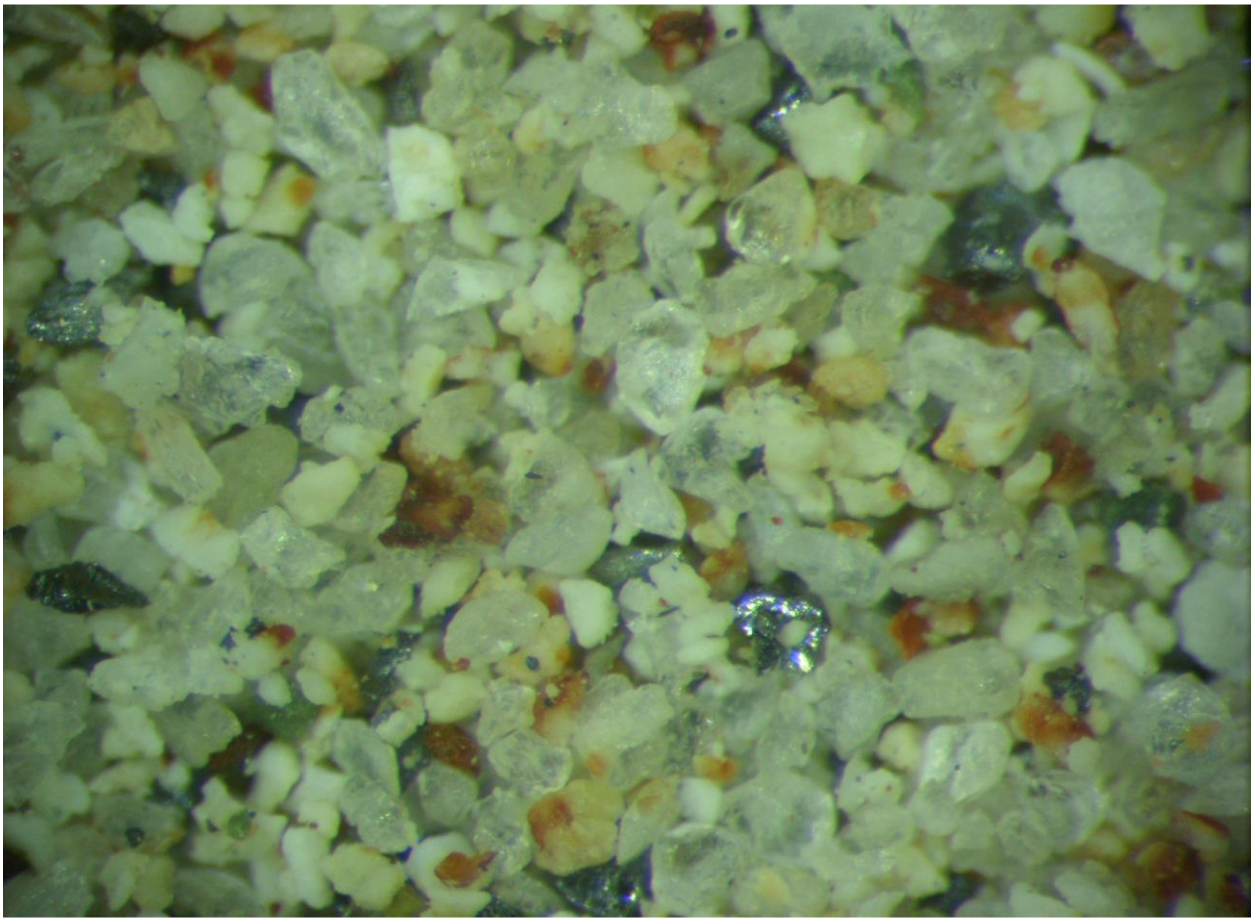

Figure 22 Initial tails -0.25 #3

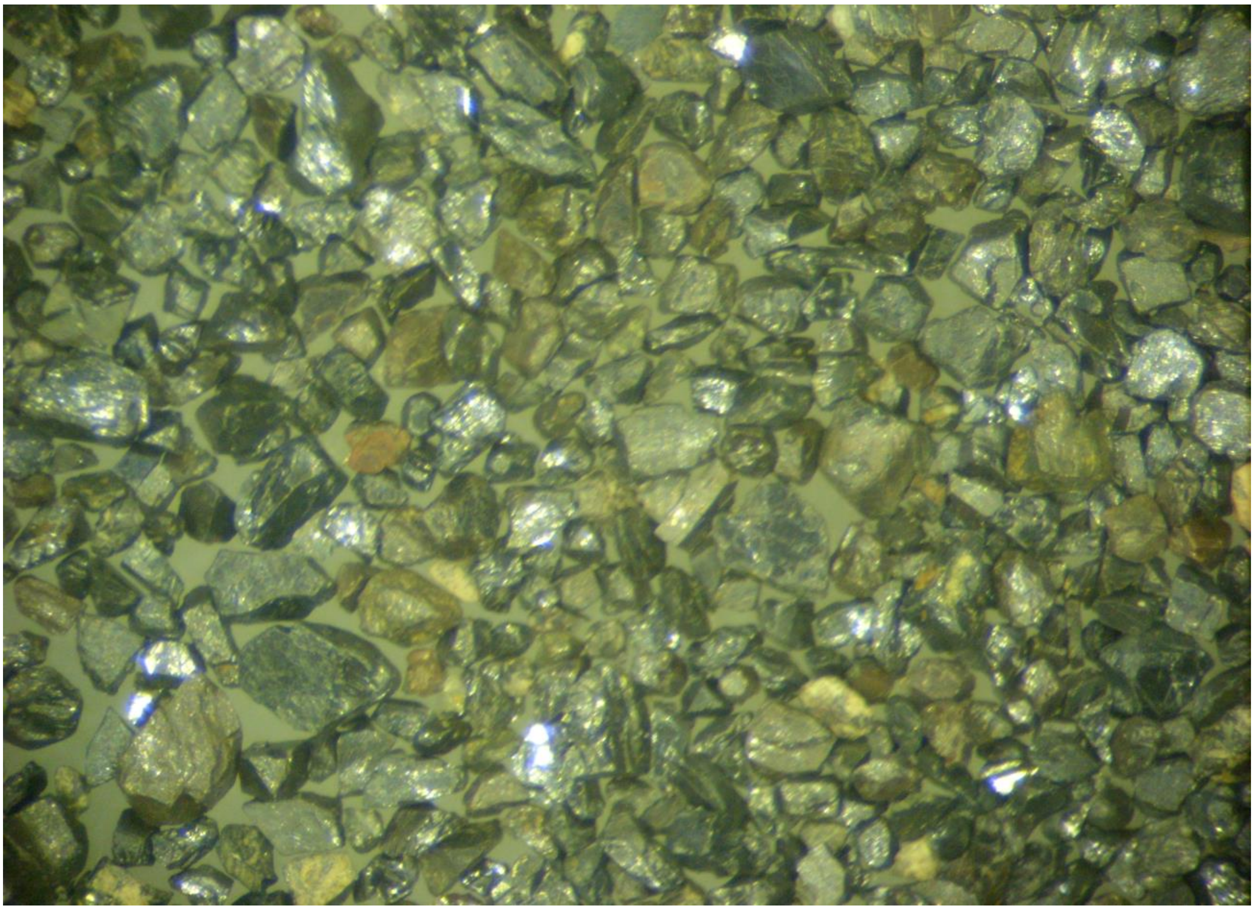

Figure 23 Concentrate -0.8+0.25 #1

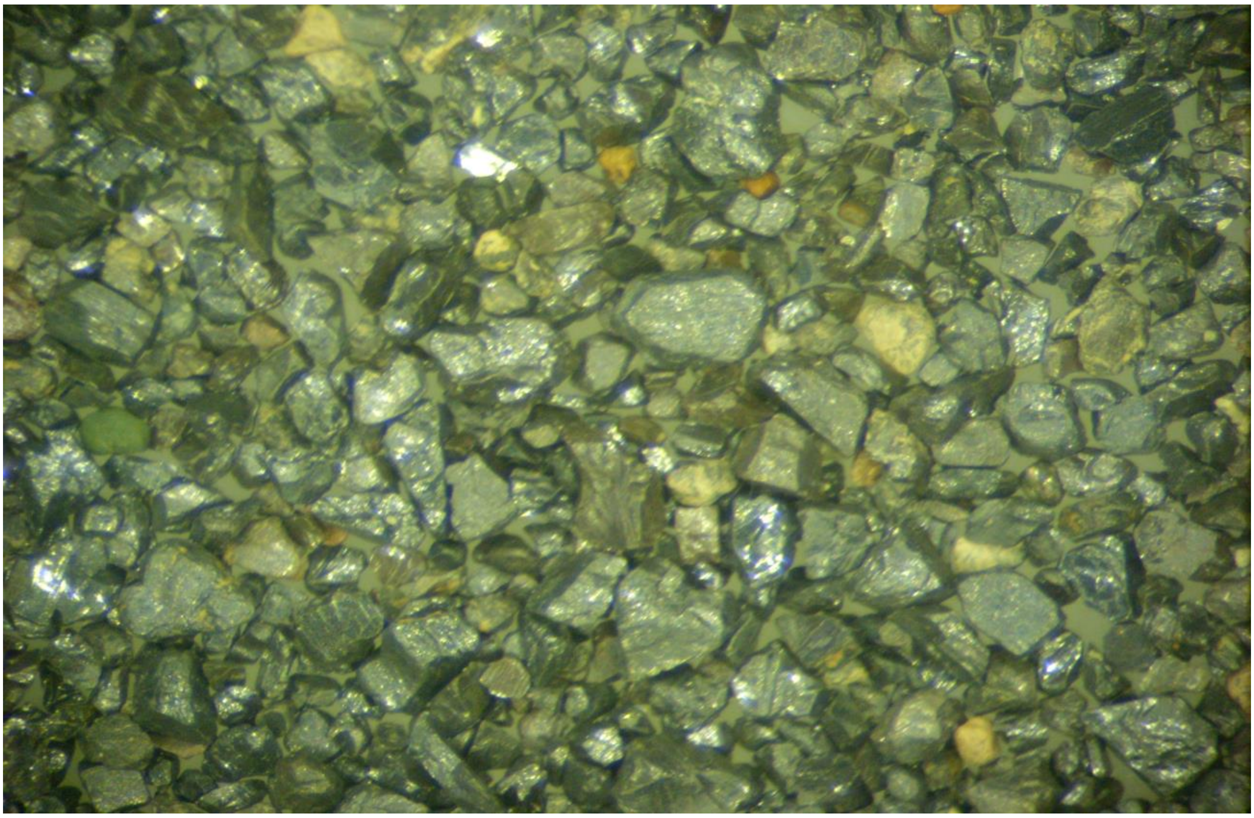

Figure 24 Concentrate -0.8+0.25 #2

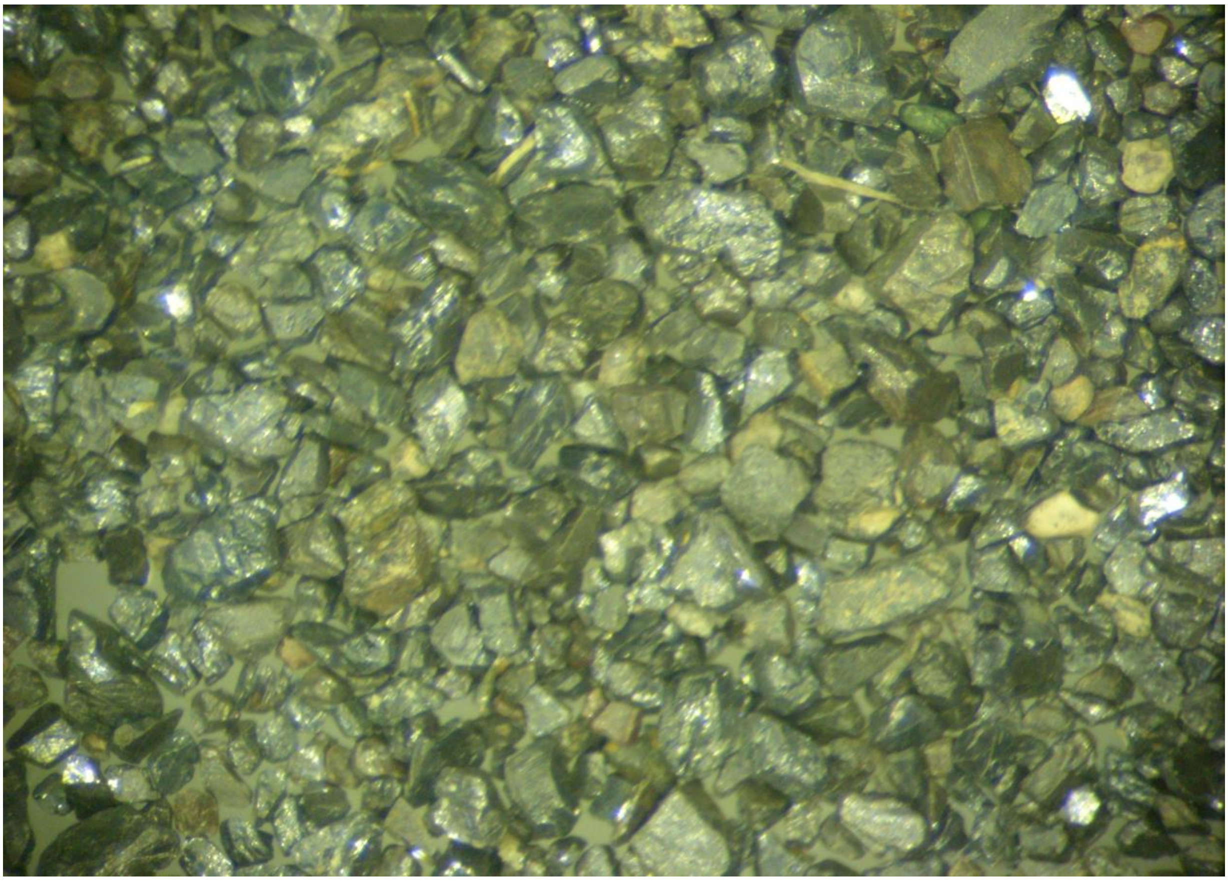

Figure 25 Concentrate -0.8+0.25 #3

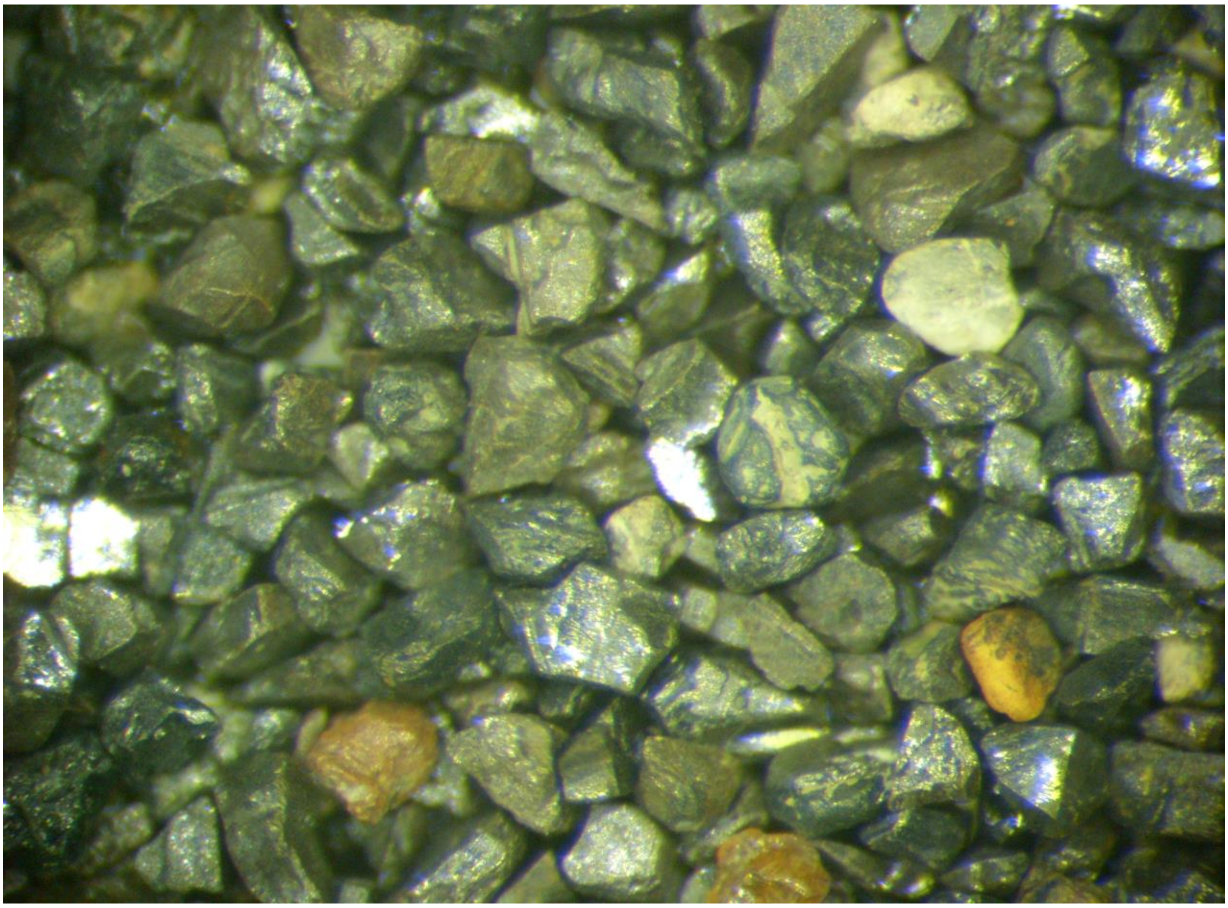

Figure 26 Concentrate -0.25 #1

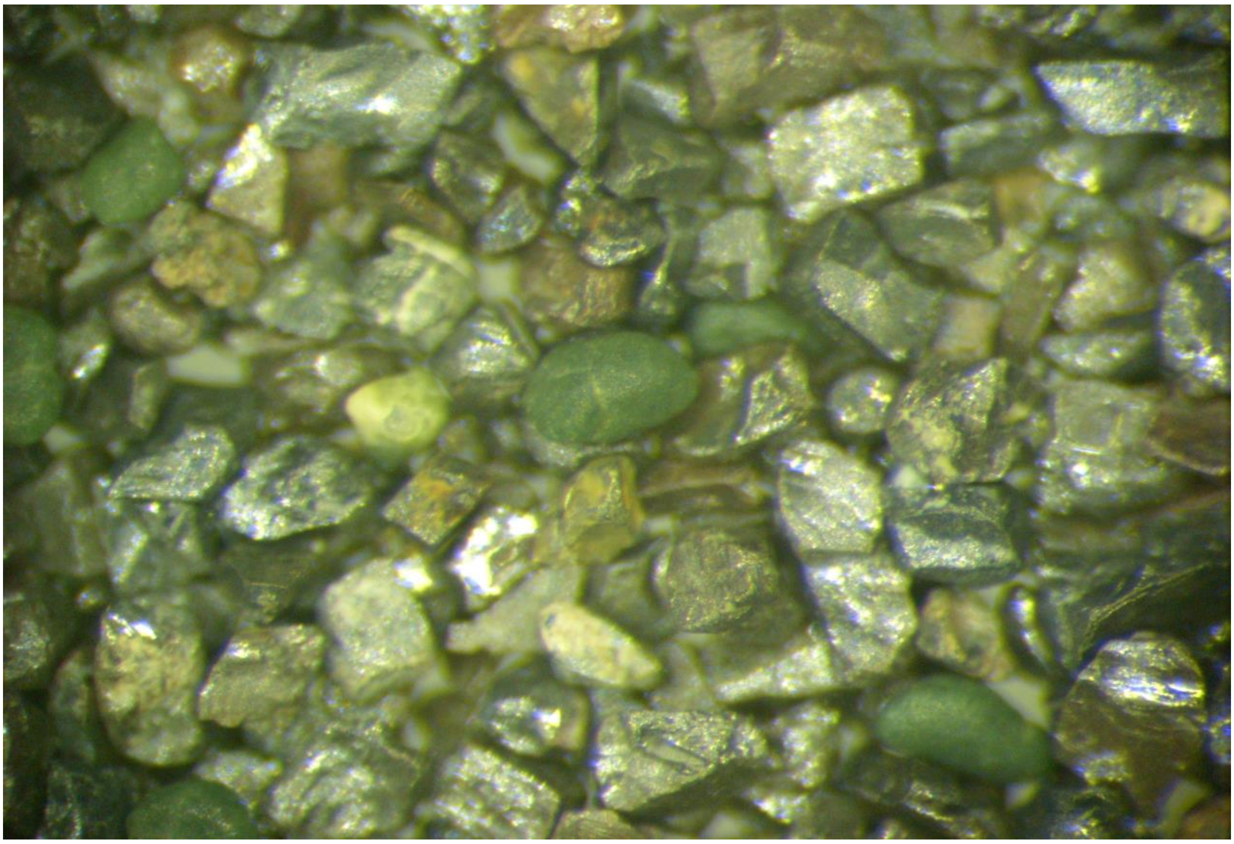

Figure 27 Concentrate -0.25 #2

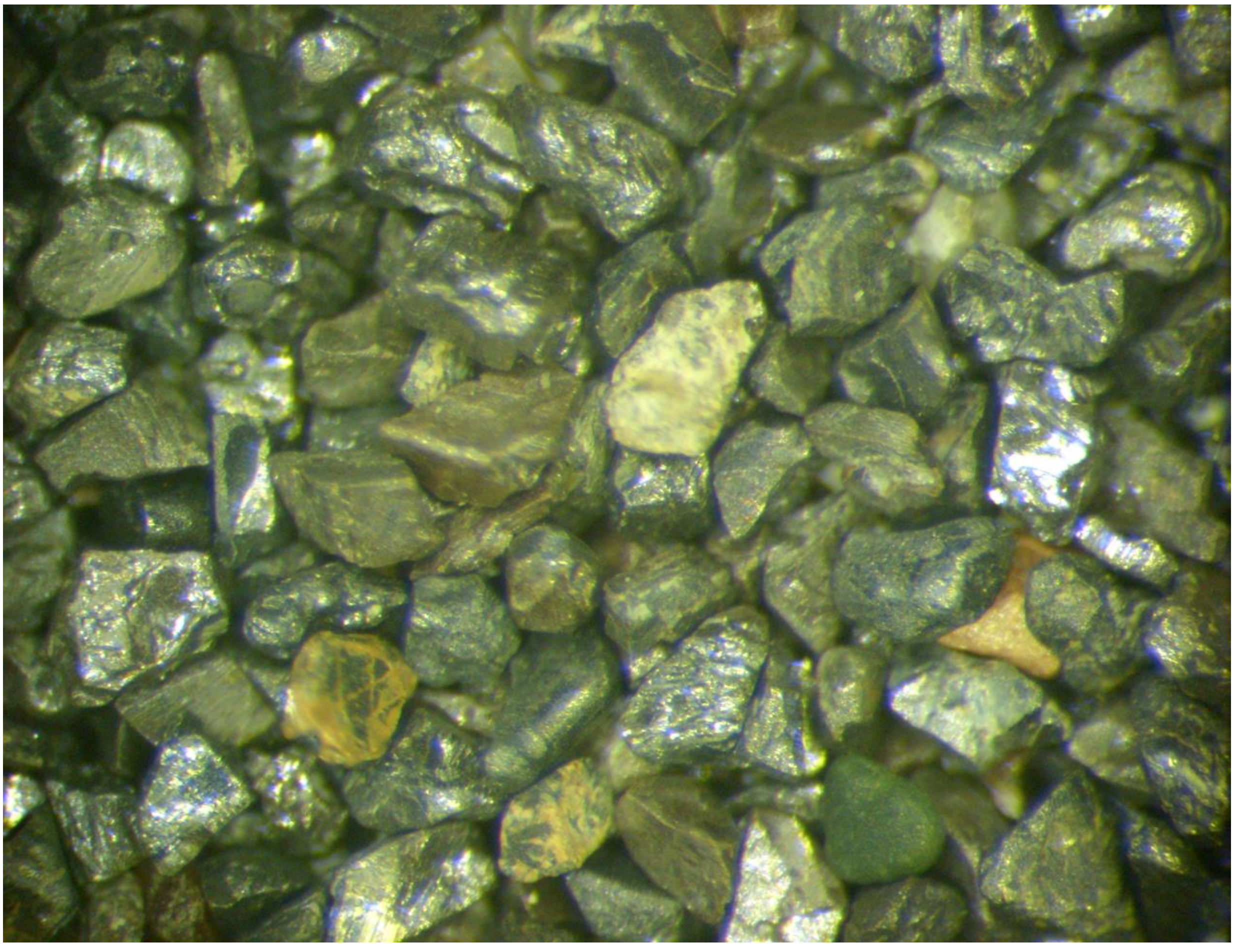

Figure 28 Concentrate -0.25 #3