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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

METHODS OF INCREASING EFFICIENCY IN OPERATING IRON ORE PELLETS BY DIRECT REDUCTION

Specialty: 3315.01 – “Metallurgical Technology”
Field of science: Technical Sciences

Applicant: **Lala Hajiaqa Azimova**

Baku – 2026

The work was performed at at the Department of “Metallurgy and Materials Technology” of Azerbaijan Technical University.

Scientific supervisor:	PhD in Technical Sciences, Professor **Rahim Izzat Shukurov**
Official opponents:	Doctor of Technical Sciences **Ramin İsmatbay Karimov**
	Doctor of Technical Sciences, Professor **Vaqif Abbas Abbasov**
	PhD in Technical Sciences, Assoc. Prof. **Telman İmran Aslanov**

Dissertation council FD 2.52 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan Technical University.

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______________	**Subhan Nadir Namazov**
Scientific secretary of the Dissertation council:	Doctor of Technical Sciences, Professor
______________	**Ahmedov Bayali Behcet**
Chairman of the scientific seminar:	Doctor of Technical Sciences, Professor
______________	**Arif Tapdıq Mammadov**

GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and degree of development. The main directions of economic and social development of the Republic of Azerbaijan are its technical re-equipment based on the widespread application of progressive scientific and technical achievements in the ferrous metallurgy industry. Here, the use of resource-saving technological processes and highly efficient equipment should ensure an increase in the strength properties and operational reliability of the produced metal. Special attention is paid to the development of the production of machine parts made of low-alloy, high-strength steels, which are widely used in the oil and gas industry and other sectors of the economy. Currently, the steels used in the manufacture of machine parts in the Republic are obtained by melting scrap steel in electric furnaces. This leads to high energy consumption in steelmaking and a lack of the required quality of the metal. In advanced countries, enriched iron ore pellets with a content of 95–96% pure iron are currently used in smelting instead of scrap steel to improve the quality of steel. The purpose of the dissertation work is to develop a technology for obtaining high-quality iron ore pellets enriched from iron ore concentrate produced in Dashkesan.

In order to ensure the implementation of these important technical and economic issues, it is possible to take into account the practical application of the iron ore pellet production technology (study of the optimal composition of the feedstock, optimization of temperature regimes in the drying and burning processes of pellets, study of the effect of additives on the structure and properties of pellets) in industry.

The main task set in the work is related to the conditions for the production of iron ore pellets and their remelting in an electric furnace. This is due to the fact that instead of smelting metal waste in steelmaking at metallurgical plants, steels obtained from smelting metal pellets with a content of 95–97% iron obtained from iron ores by direct processing are economically very efficient and important for the Republic.

Object and subject of the research. Dashkesan iron ore, bentonite, dolomite, limestone and bauxite were taken as the object of the research for the preparation of iron ore pellets.

The basicity, chemical composition, compressive strength, hardness, temperature distribution in the iron ore pellets, its drying effect on the pellets, and the moisture content of the pellets after immersion in cold and hot water were studied.

Purpose and objectives of the research work. The main purpose of the work is to implement new and environmentally friendly, technical and technological processes to reduce energy consumption and metal loss during the extraction of iron from ore by direct reduction without applying the blast furnace process through theoretical and experimental studies.

The dissertation work mainly aims to solve the following issues.

1. Development of requirements for the quality of metallic pellets to be used for metallization.

2. Development of a new energy-saving technology for the production of iron ore pellets.

3. Study of the porosity, strength, etc. properties of fluxed pellets obtained from Dashkesan iron ore.

4. Study of the properties of products obtained from the smelting of metallized pellets in an electric furnace.

Research methods and reliability of results. The accuracy and reliability of the scientific results obtained in the dissertation are scientifically substantiated and confirmed by experimental verification studies conducted using modern equipment, precision measuring instruments, and specialized laboratory facilities. A universal mathematical model of heat mass exchange in the bed layer was applied when burning the beds. Metallographic studies were conducted on a "Heohfot-2" microscope, and the strength of the nodules was measured with an IPG-1M device. For the study, the melting of the magnetite nodules was carried out in a 15 kg laboratory induction furnace.

Main provisions submitted for defense of the dissertation. To achieve the set goal, the following scientific and experimental problems were solved.

1. Energy-saving technologies for the production of iron ore pellets were substantiated.
2. Various factors affecting the change in the strength of ore pellets recovered in Dashkesan were identified.
3. Ways to reduce fuel consumption in the process of burning pellets were investigated.
4. A universal mathematical model of heat-mass exchange during pellets burning was developed.
5. The effect of melting metallized pellets under electrofusion on the quality of steel was investigated.

Scientific novelty of the research. For the first time, a theoretical generalization was made of the regularities obtained from the study of the process of obtaining iron nodules from magnetite ore materials. The strength structure of the iron lumps was determined depending on the mineralogical composition of the binder: it was shown that when dolomite, bentonite, or limestone are added in certain proportions, the strength level in the calcined lumps is maximum.

To improve the metallurgical properties of the lumps, additives such as bauxite, bentonite, dolomite, and limestone were identified, depending on their composition and quantity. For the first time, an analysis of existing methods for producing billets with a 92-96% iron content shows that the production of metallized billets from iron concentrate in a MIDREX plant is significantly more advantageous than in other plants. Thus, in the HYL/Energiron, FASTMET, and ITmk3 converters, as well as in the Finmet and up to 20 other similar units, the emissions of carbon dioxide, electricity consumption, and water consumption were increased. One of the important issues is that it is not possible to use hydrogen gas as a reducing agent there. For the reasons stated, the use of the MIDREX plant in Dashkasan was recommended.

Theoretical and practical significance of the research. The production of billets from iron concentrate at the Dashkesen Ore Refining Combine, their processing in the MIDREX plant, and the smelting of the billets in metallurgical plants of the Republic are intended to produce high-quality steel.

To improve the metallurgical properties of the pellets, additives such as fluxing agents bauxite, bentonite, dolomite, and limestone were determined based on their composition and quantity.

The practical application potential of the research work conducted is extremely broad. Thus, the scientific and technological results obtained can be applied in the production processes of the Dashkesan Ore Concentration Plant, as well as in cooperation with the Fonte GreenMet Investments Fund (Kazakhstan) company. The scientific and methodological materials developed in the dissertation can be successfully applied at the hot briquetted iron (HBI) production plant, which is currently under construction in the Shamkir district as a joint investment of "Daşkəsən Dəmir Filiz" and "Azərbaycan Metal Company," as well as at a number of other high-potential metallurgical plants.

The scientific and methodological materials developed in the dissertation are considered suitable for use as a methodological guide in the execution of lectures, coursework, and projects, as well as for bachelor's theses and master's dissertations in the faculties of Azerbaijan Technical University.

Approval of the study and application of the results. The main scientific-theoretical tenets, methodological approaches, and practical results of the research work were presented for extensive discussion at the international and nationally significant scientific conferences and specialized seminars listed below, and were positively evaluated and accepted by the scientific community:

1. 54^{th} scientific-technical and educational-methodical conference of the teaching staff and postgraduate students of the Azerbaijan Technical University. Baku, 2009.

2. I International conference on "Nanotechnologies and their application in technology". Baku, 2010.

3. International scientific conference "Problems of Metallurgy and Materials Science" dedicated to the 90th anniversary of the birth of the national leader H. Aliyev. Baku, 2013.

4. International conference "Heydar Aliyev and Azerbaijani education" dedicated to the 90th anniversary of the birth of the national leader H. Aliyev. AzTU. Baku, 2013.

5. “Prospects for the application of soft magnetic alloys in information technologies and military industry” - International scientific and practical conference. Baku-2019. AzMİU.

6. Azerbaijan and Turkey Universities: “education, science, technology” I International scientific and practical conference. Baku-2019.

7. Proceedings of VII International Scientific and Practical Conference Barcelona, Spain 1-3 August 2022.

8. International Symposium “The Great Silk Road: The Bridge Between East and West” The 29 June 2023 Kars/Turkey.

9. Mechanical Engineering: Innovative Aspects of Development: Proceedings of the International Scientific and Practical Conference. Vol.8 2025 Saint Petersburg.

The total word count of the dissertation, including the individual word counts of its structural sections. The dissertation consists of four chapters, 147 pages of computer-typed text, 19 figures, 19 graphs, 19 tables, and a list of references comprising 178 sources. The dissertation is structured as follows: the title page and table of contents (4,855 characters), Introduction (11,205 characters), Chapter I (52,888 characters), Chapter II (33,163 characters), Chapter III (42,847 characters), Chapter IV (25,390 characters), Conclusions (2,351 characters), and the list of references (28,560 characters). The total volume of the dissertation is 173,455 characters, excluding spaces in the text, as well as figures, tables, graphs, appendices, and the list of references.

Publication of the dissertation results. The main content of the dissertation has been reflected in 22 scientific works. 5 articles were published in SCOPUS-indexed journals, 4 in scientific-technical publications on the AAK list, 5 in foreign journals, and 8 conference materials were published.

MAIN CONTENT OF THE WORK

The introduction justified the topicality of the subject, the practical significance and necessity of the research, presented the purpose and objectives of the work, and formulated the main theses to be defended.

Chapter I examines issues based on scientific and practical data on iron ore, including the Dashkesan iron ore deposit, the foundation and development of the mining industry in Transcaucasia.

Iron ore is the main raw material of the iron and steel industry. Iron ores occur in nature in the form of the minerals Magnetite (Fe_3O_4), Hematite (Fe_2O_3), Limonite ($2Fe_2O_3 \cdot 2H_2O$), Goethite ($Fe_2O_3 \cdot H_2O$), Siderite ($FeCO_3$) and Pyrite (FeS_2). The main activity of the Mining and Mining Combine is the production of iron ore concentrate. Here, iron ore is enriched up to 60% after going through the production process.

The first written information about Dashkesan iron ore was given by the medieval historian Hamdulla Qazvini (13th century).

Thus, 63% of the Dashkasan iron ore deposit is considered high-grade, and 37% is considered low-grade.

The ores in the Dashkasan iron ore deposits are contact-metasomatic magnetite ores by their genesis and have the following qualities from a technological point of view.

1. By mineral composition, Dashkasan ores belong to the type of primary magnetite ores, and the amount of magnetite mineral in the ore is between 75–85% of the total amount of iron minerals (on average 80%). According to their physical properties, the strength of more than 90% of the ore in the deposits varies between f = 6–14 according to the M.M. Protodyakonov scale and, according to their technological type, mainly belongs to the type of dense ores.
2. According to the distribution of magnetite mineral in rocks, the amount of iron in Dashkesan deposits, both in areas containing pure magnetite, is more than 45%, on average, 36–43% of the reserves in the deposits are large and medium grains.

3. According to the purity of magnetite mineral, Dashkesan ores are included in the group of pure ores, it is possible to produce a concentrate containing 68–71% iron from these ores.

The above-mentioned qualities of ores in the Dashkesan deposits allow us to organize direct enriched iron production in our country at the lowest cost by rebuilding the refining plant in accordance with these quality parameters, which is also very economically advantageous.

The fine screening process used here in the production of high-quality iron ore concentrate is currently used in the USA, Canada, Sweden, Finland, Russia, Kazakhstan and other countries.

The dissertation work is focused on the production technology of iron ore pellets in order to organize a closed cycle of ferrous metallurgy in Azerbaijan at a modern level.

This closed cycle includes: the production of crushed ore concentrate (granulometric composition 100% - 0.074 mm) containing 66–68% iron, the production of round and burnt pellets from this concentrate, the reduction and metallization of these pellets and direct steel smelting from the metallized pellets.

Traditional methods, namely, coke from coal, agglomerate from concentrate, and then the production of pig iron, and then steel from pig iron, are carried out in multi-sector complexes on expensive equipment and are approximately 2 times more expensive than direct steel production from metallized pellets. Because in the second case, the costs are incurred only for the construction and operation of mines and the Refinery Plant, metallization of pellets obtained from concentrate, electric melting furnaces and continuous steelmaking facilities.

The issues raised in Chapter I of the dissertation were investigated and preliminary results were obtained. Dashkesan iron ore deposits are one of the most important strategic raw material bases of the Azerbaijani economy, containing more than 35–36% iron. Based on the above, the following research questions were posed.

1. Development of requirements for the quality of metal pellets to be used for metallization.

2. Development of a new energy-saving technology for the production of iron ore pellets.

3. Study of the porosity, strength, etc. properties of fluxed pellets obtained from Dashkesan iron ore.

4. Study of the properties of products obtained by melting metallized pellets in an electric furnace.

The second chapter studies modern methods for obtaining metallized iron ore pellets. Here, energy-saving technologies for the production of iron ore pellets are considered. This chapter examines technologies for obtaining iron ore by various methods since the beginning of the 20th century. In the 30s–50s of the 20th century, processes for obtaining porous iron in a crucible (Höganes), shaft-type furnace (Viberg) and rotary furnaces (Krupp) using coal as a reducing agent were developed. Since the 1950s, processes for obtaining porous iron in stationary reactors (HYLI) and special reactors (FIOR) using reducing gases have been developed. Since the late 1960s, it has been possible to obtain more than 14% porous iron in mine-type reactors (MIDREX and HYL) using reducing gases. In the late 1970s, restoration processes were carried out in Sweden using coal and electricity. In the 1980s, iron was produced without the use of coke with a productivity of 0.5–1.0 million tons per year. Most of these processes, with the exception of the Hismelt process, are two-stage (DIOS, Hismelt, CCF and AISI). The improvement of the Hismelt process was completed in 1990, and it was determined that the MIDREX and HYL processes dominate among the technologies for obtaining porous iron [16][1] .

Since the 1980 s, the processes of iron recovery using small-dispersed iron ore in a hot bed have become more widespread. The production of small-sized hot briquettes from the recovered material ensures the competitiveness of this process. The process of obtaining liquid metal directly from the ore has been tested for many years. Currently, this process is in the spotlight.

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[1] Azimova, L.H., Shukurov R.I., Mirbabayeva N.R. Method for Reducinq Fuel Consumption When Roastinq Pellets from Maqnetite Iron Ore Concentrate /L.H.Azimova, R.I.Shukurov, N.R. Mirbabayeva //Engineering Headway, – Switzerland: –2024. v. 7, –p. 45-50.

In the dissertation work, the principles of selecting optimal modes of thermal processing of pellet layers in a combustion machine and without a combustion machine of various compositions with maximum technical and economic indicators, ensuring the formation of given properties of the finished product obtained from the batch, were studied. The analysis of optimal modes includes the following: determination of the mechanism, kinetic regularities of the main physicochemical processes and their role in the formation of the structure and metallurgical properties of ore pellets; development of several variants of thermal processing regimes taking into account the thermo-technical calculations of the pellet layer in accordance with the given heating scheme; carrying out industrial tests, mode adjustment works, optimal realization of the temperature and gas-dynamic regime of thermal processing for the given metallurgical properties and pellets layer [10][2].

The increase in the technical and economic indicators of the operation of cooking machines and the metallurgical properties of burned pellets is determined by the development and implementation of comprehensive approaches to the regimes and structures of drying zones, which correlate the operation of subsequent technological zones with the properties of raw pellets [8][3].

During artificial drying, the moisture content of ore pellets with qT< 41.8 MCoul/t does not exceed 0.2% compared to the initial moisture content and is maintained until the end of drying. It should be noted that such cases were not observed in this zone and regime.

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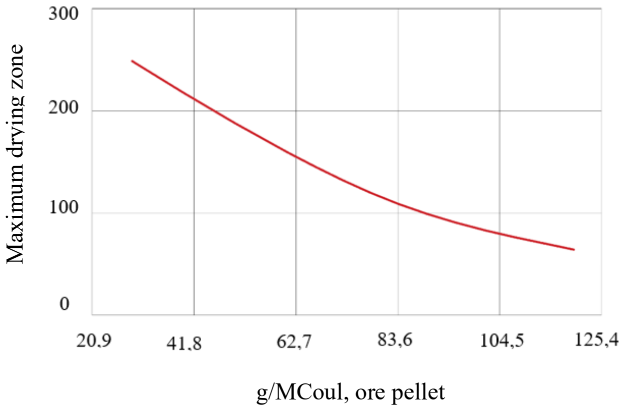
[2] Əzimova, L.H. Konveyer bişirmə maşınlarında qranulların termiki emal rejiminin optimallaşdırılması // Mühəndis Mexanikası jurnalı. AzMİU. –Bakı: – 2020. №1, – s. 3-7.

[3] Əzimova, L.H., Tağıyev, T.Ə. Qurutma texnologiyasının köməyi ilə dəmir filizi qranullarının əldə edilməsi //Azərbaycan və Türkiyə "Universitetləri: təhsil, elm, texnologiya" I Beynəl-xalq elmi-praktiki konfrans. –Bakı: –2019. – s.336-339.



Graph 1. Dependence of the maximum height of drying on the amount of heat flow

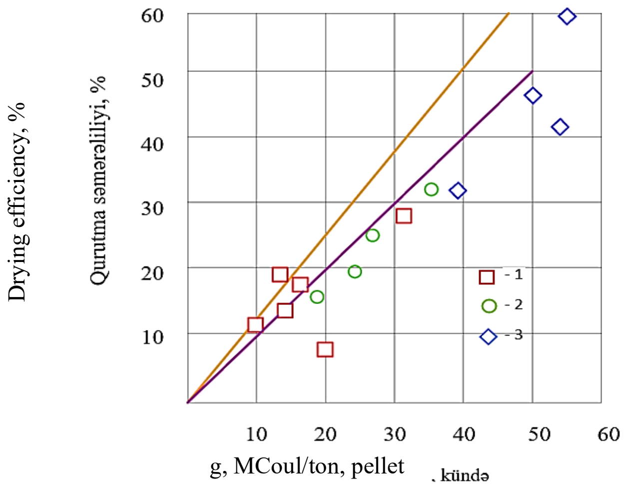
In the most intensive drying mode (qT>104.5 MJoule/t ore pellets), the moisture content is 2.2%, this value is observed mainly in the surface layer (50 mm) and in the center of the first drying.

As can be seen from Graph 1, at relatively large values of the amount of specific heat (qT>125.4 MJoule/t) and the height of the layer (Hq< 300 mm), the water flow zone is already removed in the first minute of drying [4][4].

In general, the amount of specific heat q_i is a very important parameter not only for the drying process, but also for determining the efficiency of the process. From the data presented in Graph 2, it is clear that the Lebedinsky, Kachkanarsky and Kostumukshsky ore pellets,

[4] Əzimova, L.H, Şükürov R.İ, Maşayev, Ş.M, Namazova S.R Dəmir filizi qranularinin təbəqəli qurutmasinin xüsusiyyətləri // "Ölcmə və keyfiyyət: problemlər, perspektivlər" Beynəlxalq Elmi-texniki konfrans. –Bakı: AzTU, –2018. – s. 364-366.

despite their differences in structure and properties, as well as in quality and quantity, follow a certain pattern [18][5].



Graph 2. The drying effect of ore pellets in the drying zone (qT) depending on the amount of heat
1- LebDMK, 2- КасDMK, 3- КostDMK

It has been established that the heat resistance of iron ore pellets increases with an increase in the specific surface area of the pellets and a decrease in their diameter. An increase in the plasticity of iron ore pellets has a positive effect on their heat resistance. This, in turn, is considered effective for maintaining the plasticity of the structure at high temperatures during drying and increasing its resistance to fragmentation.

The second "green" direction in metallurgy is the domain-free production of semifinished products - pellets for subsequent steel production by direct reduction of iron-rich ore using special

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[5] Азимова, Л.Г. Особенности слоевой сушки железорудных окатышей //Машиостроение: инновационные аспекты развития: Материалы международной научно- практической конференции. –Санкт-Петербург: –2025. №8, –с.17-20.

technologies (Midrex, Arex, HYL, etc.). Figure 1 shows a scheme of a widespread Midrex plant producing enriched iron ore pellets.

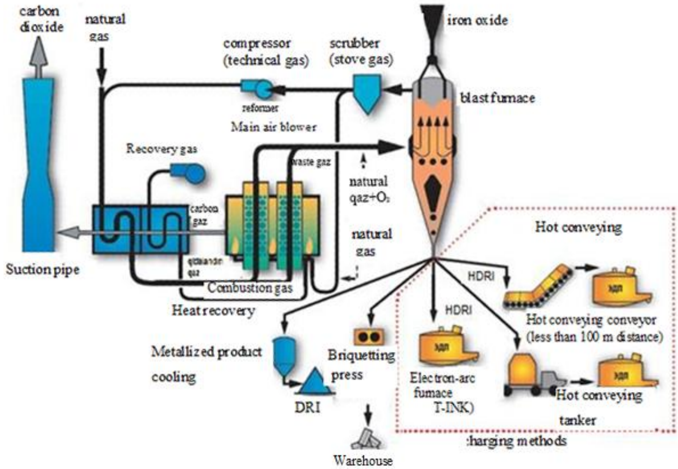

Figure 1. Scheme of the MIDREX plant

Here, the iron production process is carried out with iron ore materials loaded into the installation from above and heated reducing gases supplied in the opposite direction from below. The operation of the plant in the opposite direction allows for high productivity by making good use of the gas. Here, converted natural gas is used as the reducing agent. Converted natural gas consists mainly of hydrogen (H_2) and carbon monoxide (CO). The reducing gas is obtained by incomplete combustion of natural gas with oxygen in the oxygen reactor (reformer) of the plant. The composition of the obtained recovery gas is 29% CO, 55% H_2 and 13% oxidants (H_2O and CO_2). This gas is partially freed from oxidants and heated to a temperature of 1100–1150°C and fed to the furnace. If enriched hot pellets or hot briquetted iron are produced, then the recovered iron is not cooled in the lower zone of the furnace and is fed directly to the melting furnaces.

The dissertation work provides detailed information on the production of directly recovered enriched iron ore pellets in other modern - HYL/Energiron, FASTMET and ITmk3 aggregates, Finmet, etc. İnstallation [14][6].

In conveyor cooking machines (CCM), in addition to technological purposes (supplying air for fuel combustion, cooling the and supplying the processed gases to the smoke stack), the gas-air path system is supplied to various areas by means of recirculation of the cooling and cooking areas of the heat exchangers. The more heat transfer medium is recirculated in the CCM, the less the product of combustion gases is discharged into the flue pipe, which ultimately saves fuel. Thus, the higher the recirculation rate, the more economical the gas flow scheme in the CCM will be.

İn the third chapter, the justification for applying energy-saving technologies in the production of metallized iron castings is presented, and an analysis of the research results is provided. The characteristics of the new generation conveyor-type cooking machine and the environmental safety of the SATOP technology are studied. It is known that low-emission technologies are applied in the new generation conveyor cooking machines by using energy-saving measures and special cleaning devices. Under equal conditions, SATOP technology provides a reduction in: fuel consumption for burning pellets by 2.0–2.2 times, harmful impurities emitted into the air by 2.5–3 times, nitrogen oxide emissions into the atmosphere by 3–4 times, iron ore dust by 2.5–2 times, heat loss with exhaust gases by 3.5–4.0 times, and heating of the brakes of electrically operated parts of the equipment by 1.2–1.5 times.

Based on theoretical and experimental studies, and based on the analysis of research and experience conducted in the industry of foreign countries, a thermal scheme of a new generation of the NPVP "TOREKS" conveyor-type incinerator unit has been developed. The unique thermal energy of this type of equipment and the thermal

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[6] Əzimova, L.H, Şükürov R.İ, Mirbabayeva N. Daşkəsən dəmir filizinin bir başa bərpaetməklə zənginləşdirilmiş dəmir kündə-lərinin müasir alınma üsullarının təhlili //İnternational Symposium "The Great Silk Roud: The Bridqe Between East and West". –Kars/Türkiye: – 29 June, – 2023. – s.240-242.

energy and environmental parameters in the production of iron ore pellets of various compositions and purposes have been studied.

In our opinion, in solving problems, it is necessary to solve the regularities of the formation of a new phase during the recovery of pellets using an analytical approach. Here it is necessary to take into account the characteristics and interrelationships of the processes of micro and macro mechanisms. At the same time, it is necessary to take into account the kinetics and mechanism of the stressed state, the relationships that characterize the characteristics of pellets, including the decrease in strength and its swelling.

Complex laboratory studies conducted using microstructural and micro-X-ray spectral methods, as well as semi-industrial tests, confirmed the effectiveness of this approach, as bauxite containing $Al_2O_3{\cdot}H_2O$ added to the charge during the production of pellets reduces the formation of cracks by 1.6–1.8 times and the degree of deformation by 5–7%, while increasing the degree of metallization by 2–3% [17][7]. In this chapter, a universal mathematical model of heat and mass exchange during the burning of pellets is developed. The output parameters of the model: the operating conditions of the belt conveyor, the height of the layer, the geometric structure, the physicochemical characteristics of the wet pellets, the temperature of the layers at the inlet, the temperature and speed of the gas phase at the outlet along the length of the machine, the strength of the pellets, some characteristics of the flow equipment, fuel combustion parameters, etc. This model allows you to analyze the thermotechnical (fuel consumption and the degree of heating of the layer) and

[7] Азимова, Л.Г. Теоретические основы новых энергосберегающих технологий производства железорудных окатышей //Журнал «JARITS», –Санкт-Петербург: –2025. v. 47, –с.71-76.

technological (composition and strength of the pellets) parameters of the conveyor machine as a whole [7][8].

When obtaining the characteristics of the gas leaving the layer, it helps to select the means of absorption.

The calculation analysis performed using the model shows that an increase in the temperature of the raw billets leads to a monotonic decrease in the free moisture. Thus, when the temperature of the logs exceeds 25°C, the re-wetting zone is significantly reduced, and this phenomenon approaches zero at a temperature of 40°C.

In the fourth chapter The production technology for iron ingots from concentrate obtained from Dashkesen ore was developed, and new technologies were analyzed. The structure and phase composition of the burned pellets affect the weakening of the properties, the kinetics of the development of reaction surfaces, swelling, and thus the nature of their behavior, in full accordance with the thermal recovery treatment.

The solution to the problem of optimizing the basicity of pellets containing a large amount of loose rocks (3%) cannot be solved without compromising the total amount of iron.

Therefore, the purpose of the study was to study the effect of traditional (limestone, bentonite, dolomite) and non-traditional (bauxite) fluxes added to the charge on the formation of the structure and strength of the pellets. Our goal is to qualitatively analyze the mineral formation of some fluxes and the strength regularities of burned pellets. High-quality concentrate, bentonite, bauxite, limestone and dolomite were used as charge materials. Table 1 shows the chemical composition of the Dashkesan concentrate we studied.

Other components of the charge were crushed in laboratory conditions and then mixed with the concentrate in a specified proportion. In a laboratory grinder, pellets were prepared and

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[8] Əzimova, L.H., Tağıyev, T.Ə., Maşayev, Ş.M. Birbaşa reduksiyaetmə üçün dənəvərləşdirilmiş dəmiq filizinin istehsal texnologiyasının təkmilləşdirilməsi yolları //"Maqnityumşaq ərintilərin informasiya texnologiyalarında və hərbi sənayesində tətbiqi perspektivləri". Beynəlxalq elmi-praktik konfrans. –Bakı: AzMİU. –2019.– s.321-323.

separated into fractions with a diameter of 12–16 mm. We placed the wet pellets in layers in muffle furnaces and subjected them to thermal treatment modes. In all experiments, the operating mode of the burners was unchanged at 1200–1260^{0}C. The storage time was 1–9.5 minutes.

Table 1.
Chemical composition of the studied Dashkesan magnetite concentrate (average particle size 550 µm)

Composition	Indicators
Fe_3O_4	65
Fe	67
SiO_2	2
MnO	0.6
Al_2O_3	0.8–0.9
S	0.08
P	0.05
Moisture	10

For microstructural and mineralogical studies, 4 test pellets were used, as shown in Table 2.

Table 2.
The composition of the charge used to produce enriched iron pellets from Dashkesan ore concentrate at a temperature of 1200 - 1290°C.

Experience №	Structure , % *			
	Lime	Bentonite	Bauxite	Dolomite
1	0.3	0.5	-	0.5
2	0.3	0.35	-	0.5
3	0.3	0.35	0.6	0.5
4	0.3	0.35		
*Concentrate the rest				

Pellets are prepared in a laboratory vortex and divided into fractions with a diameter of 12-16 mm. Wet pellets are laid in layers in a muffle-type furnace, subjected to heat treatment. In all experiments, the operating mode of the burner machines was unchanged at 1200-1260^{0}C. The storage time was 1-9.5 minutes. For microstructural and mineralogical studies, 4 tests were used, as shown in Table 2.

This reports on the processes in the first experiment: a magnetite-containing core, not expressed structurally, appears on the polished surface of the nodules. The surface of the nodules is quite dense, while the center is porous. There is one radially-located, hair-like fissure. The structure appears to be formed from fragments, the surface of the grains is molten, and the fine grains are spherical. The nodules consist of hematite; the grains on the surface are large, but toward the center they become smaller and porosity increases. The bonds within the nodules are of the hematite type, while the silicate bonds are weak and appear as a glassy film on the surface of the hematite grains.

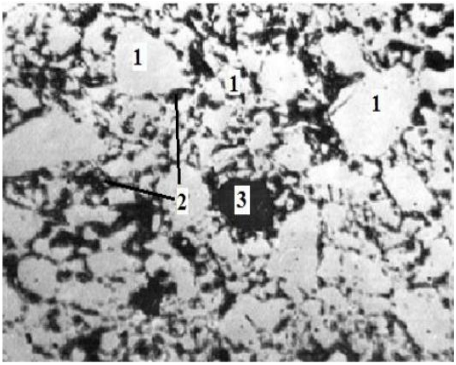


Figure 2. Mineral composition and microctructure of the core: 1 – magnetite, 2 – quartz grains, 3 – glassy phase layers, 4 – pores. x-300

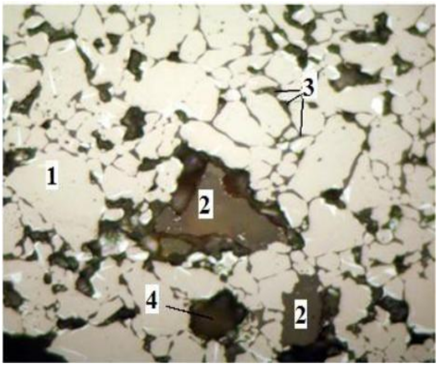
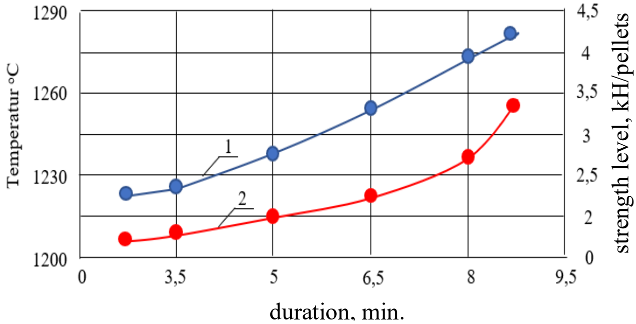


Figure 3. Mineral composition and microctructure of the nodule shells: 1 – coarse and fine hematit, 2 – glass phase, 3 – quartz grains, x-300

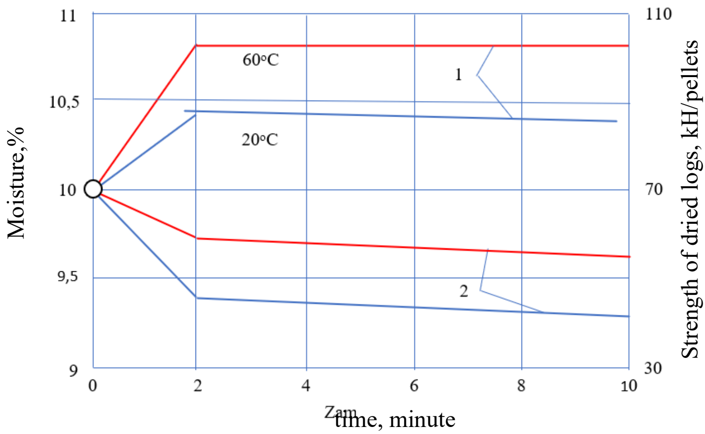
The conducted studies make it possible to establish the main mechanism of formation of the ore binding structure of pellets. Firstly, the ore composition of the fired pellets changes very little when various additives are added to the glaze, and the firing temperature has a more significant effect. Thus, when metal pellets are heated, the structure is compacted, which leads to adhesion of magnetite grains and loss of grain boundaries. The finishing depth is determined by the temperature and duration of the process. In the first minutes, the magnetite grains stick together, forming a magnetic framework up to 0.5 mm deep. This framework then permeates the entire pellet. The sintering process is accompanied by the growth of magnetite grains. Heating at 900-1000°C increases grain boundaries. Local liquid phases are formed in the structure, cementing magnetite grains during crystallization. In addition, solid-state reactions between Fe_3O_4 and SiO_2 occur in areas adjacent to the center of the pellet. Simultaneously with the recovery processes, a bond is formed and magnetite grains grow. Three fields are clearly visible in the structure of the recovered pellet: the metal shell on the surface of the pellet, the central Magnetite region, and the reaction field transitional between them. At high temperatures, the degree of metallization increases, while the grains of metallic iron grow due to coagulation and restoration of the magnetite zone. The strength level of fired fluxed pellets depends on the amount of fluxing additives - limestone, bentonite, dolomite - and is 3.5–4 kH /log. In unflushed pellets, the strength is 2.2–2.7 kH /log. Within the limits of the conducted studies, it was determined that the value of basicity affects the strength of the product depending on the level of development of liquid phase firing. However, it does not significantly affect the overall quality of the burned product [11][9]. The conducted studies show that the total porosity of fluxed pellets is higher than that of unflushed and bauxite-containing pellets. This occurs as a result of

[9] Азимова, Л.Г., Сулейманова, С.Н., Мирзоева, Г.А. Изменение прочности железорудных окатышей в процессе термической обработки //Proceedings of VII International Scientific and Practical Conference Barcelona, –Spain: – 1-3 August, – 2022. – p 77-80.

the decomposition of lime and the dissolution of bauxite at temperatures of 700–900^{0}C.



Graph 3. Strength of 14 mm pellets made in laboratory conditions from Dashkesan iron ore depending on storage time at different temperatures. 1– fluxed and 2–unflushed



Graph 4. Dependence of the strength of Dashkesan iron ore pellets on the moisture content of the room and the duration of their residence in hot water. 1 – fluxed, 2 – unflushed

The moisture content of Dashkesan iron ore pellets containing 0.35% bentonite was studied in terms of their interaction with water at temperatures of 20 and 60^{0}C. After drying, their moisture content was checked. At the beginning of the experiment, the moisture content was approximately 10%. The results of the experiment showed that the strength of fluxed and unflushed pellets changes depending on the storage time at temperatures of 20 and 60^0C. Thus, the strength of fluxed pellets is higher than that of unflushed pellets.

As a result, at a firing temperature below 1200^0C, Al_2O_3 reacts with iron and calcium oxides to form a solid, insoluble and recoverable compound - brown-mullerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$). This compound is located at the boundaries of ore grains. Mineralized pellets fluxed in lime, chalk or dolomite practically do not differ from the known structurally fused pellets.

In the dissertation, the technical and economic indicators of the production of metallized raw materials in various aggregates were developed.

Currently, the most widely used process is MIDREX technology. The production of metallized raw materials by this process accounts for approximately 60% of the world's production capacity. The basicity used in Midrex installations usually varies between 0.5–0.8.

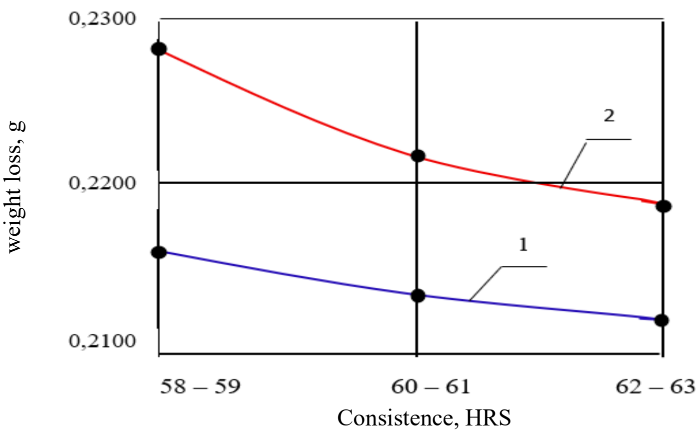
The basicity of the fused pellets up to 1leads to a decrease of iron in them.

For the effective operation of the plant, not only the composition of the charge and the formal physical properties of the pellets, but also their structure and binder properties are required. In addition, the selection and provision of an optimal and justified thermal treatment regime for each charge is one of the important factors affecting the stability of the production process and the quality of the product obtained.

For metallization and subsequent hot briquetting in MIDREX equipment, ore pellets are required to have high strength and recovery properties, as well as low plasticity. These requirements can be achieved by adding a small amount of bauxite to the charge and optimizing thermal treatment regimes.

In recent years, the production of steels of various compositions and applications from the melting of metallized nuggets has been widely applied [20][10]. With this in mind, the properties of steel obtained by melting nodules were studied. For the study, laboratory-cast ingots of the known-composition steels grades ШХ15 and 15Х2НМФЮ were produced by melting magnetite nodules in a 15 kg induction furnace. The purchased blanks were heated to 1200°C, forged, and annealed, after which samples were prepared to study their mechanical properties.

The grain size, wear resistance, and impact toughness of the studied steels were studied. Here, the wear resistance of ШХ15 steels made from fluxed and unfluxed pellets is shown. As can be seen, in 3 cases, wear resistance was studied in samples with hardness of 60-61 HRC and 62-63 HRC after quenching.



Graph 5. Wear resistance of samples of ШХ15 steels made from fluxed (1) and unflushed (2) pellets

In all cases, the wear resistance of fluxed samples is higher than that of samples made from unflushed bellets. For example, the weight

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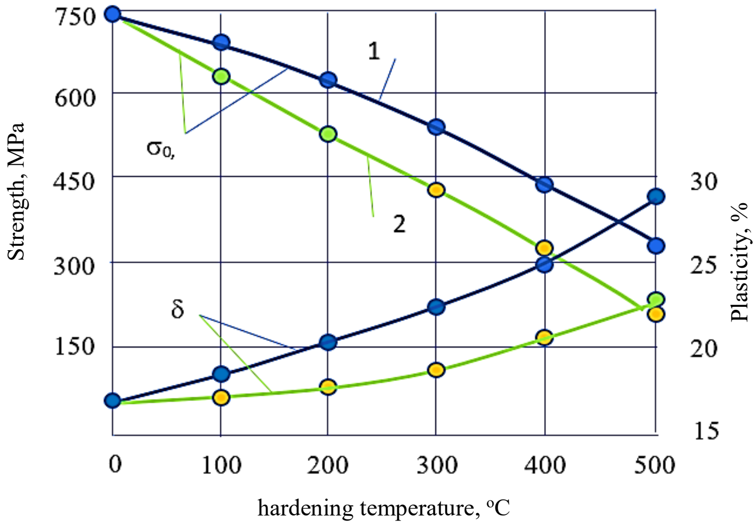
[10] Namazov, S.N., Gahramanov, V.F., Rzayev N.S., Shahverdiyev, M.A., Hamdullayeva, İ.H., Azimova, L.H. Improving the properties of spring and spring steels by changing their structure// International Journal on Technical and Physical Problems of Engineering (IJTPE) 2025. Volume 17 (3), - p.236-247

loss in a sample with a hardness of 58–59 HRC after annealing is 0.217 g, while the loss in wear in steel made from unflushed pellets is 0.230 g. The wear resistance in samples with a hardness of 62–63 HRC after annealing is 0.2130 g, while in the unflushed sample this indicator is 0.219 g.



Graph 6. **Effect of hardening temperature on the yield ($\sigma_{0.2}$) and plasticity (δ) of 15X2HMΦЮ steel. Composition of the feedstock: 1–95% enriched iron ore pellet + 10% steel crumbs, 2 – 100%-steel crumbs**

The effect of the yield strength ($\sigma_{0.2}$) and plasticity (δ) of 15X2HMΦЮ steel used for deep well pump rods on the composition of the charge material was studied [19][11].

[11] Shukurov, R.I., Mirbabayeva, N.R., Azimova, L.H. Development of high-strength deep-well pump rods for oil production based on innovative metallurgical technologies //Reliability: Theory and Applications 2nd International Scientific and Technical Conference "Infocommunication Systems and Artificial Intelligence Technologies". U.S.A. Special. – 2025. İssue 7 (83). v.20, –p.365-371.

Thus, the properties of specimens from charge material composed of 90% iron nodules and 10% metal scrap were comparatively studied with those from charge material composed of 100% metal scrap. As can be seen from Figure 6, the yield strength ($\sigma_{0.2}$) and ductility (δ) of the steels are significantly higher in the samples made from iron nodules at all annealing temperatures than in the samples made from 100% metal scrap. This indicates the high quality of the steels made from the ingots.

The economic efficiency from the production of rebar made from Daşkəsən iron ingots can be 15-20 AZN per ton of rebar.

GENERAL RESULTS

1. The additives, such as limestone, bentonite, bauxite, and dolomite, added to Daşkəsən magnetite concentrate indicate that the core of the resulting pellets is composed of magnetite. Three regions are clearly visible in the structure of the reduced nodule: a metallic shell on the nodule surface, a central magnetite region, and the transitional reaction zone between them. At high temperatures, the degree of metallization increases, and the iron metal grains grow due to the coagulation and reduction of the magnetite zone.
2. The research being conducted allows for the determination of the main mechanism of the formation of the ore-binding structure of the pellet. First of all, when various additives are added to the shaft, the mineral composition of the calcined pellets changes very little; the calcination temperature has a more significant effect.
3. The overall porosity of fused nodules is observed to be higher compared to non-fused and bauxite-containing nodules. This occurs as a result of the decomposition of limestone and the breakdown of bauxite at temperatures of 700–900°C.
4. The porosity of reconstituted pellets is up to 45-60% higher than that of oxidized pellets.
5. The strength level of pellets fused and calcined with lime, bentonite, and dolomite is 3.5–4.5 kH/ pellets. In the non-fluidized pellets, the strength is 2.6 kH/ pellets organizes.

6. To obtain high-quality pig iron from Dashkesen iron ore, it is recommended to use materials such as lime (0.25-0.35%), bentonite (0.35-0.50%), and dolomite (0.40-0.50%) in its production.

7. Research has determined that to increase the desulfurization rate by increasing the size of the pellets, heat transfer must be increased. This will also increase energy consumption. For this reason, in all cases, the most optimal option in steel smelting is to use small sized metallized pellets [9][12].

8. For the first time, the analysis of existing methods for the production of logs containing 92-96% iron shows that the production of metallized logs from iron concentrate in the MIDREX installation is significantly more favorable than in other types of installations. Thus, the emission of carbon dioxide, electricity and water consumption in FASTMET HYL/Energiron and ITMK3 units, Finmet and other plants (up to 20) is high. One of the main issues is that these units do not use hydrogen gas as a restorer. For these reasons, it is recommended to use MIDREX installation in Dashkesan.

9. In steel grade of the brand ШХ15, 15Х2НМФЮ made of magnetite logs, the properties of wear resistance and strength are relatively higher than those of those brands made of iron scrap. This circumstance indicates the high quality of steel made of logs.

[12] Азимова, Л.Г. Влияние размеров металлических гранул на процесс обессеривания и производительность сушильных машин //Azərbaycan Texniki Univertsiteti. "Maşınşünaslıq" jurnalı, –Bakı: – 2020. №1, –s. 33- 36

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Personal participation of the author in published works:

Works No. [1,6,9,10,12,15,17,18] were performed independently by the applicant.

In work No. [14] the claimant performed the formulation of the problem, theoretical investigations, and the conduct of experimental research.

In works No. [16]the claimant conducted theoretical and experimental research.

In work No. [19] the claimant performed the formulation of the problem, the theoretical research, and the preparation of the article.

In works No. [2,3,4,5,7,8,11,13,20,21,22] The tasks were performed by the authors in equal measure.

The defense will be held on 23 september 2026 at 14^{00} at the meeting of the Dissertation council FD 2.52 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan Technical University.

Address: AZ1073, Baku, H. Javid Avenue, 25, Azerbaijan Technical University

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Abstract was sent to the required addresses on 20 July 2026

Signed for print: 10.07.2026
Paper format: A5
Volume: 36804
Number of hard copies: 100