UDC 621.9

Part 3

ASH AND SLAG HANDLING

3.3. Ash and slag properties

3.3.8. The necessity and practicality of raising the quality and processing characteristics of ash and slag waste of thermal power plants for their successful use in production of cement and other construction materials

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The successful achievements in practical and efficient use of ash and slag waste from thermal power plants in a number of advanced foreign countries are well known and quite significant. The achievements of the Russian Federation in this respects are, on the contrary, extremely modest. Today, it has become obvious that no significant success can be achieved without the willed relevant decisions of supreme government bodies (legislative as well as executive) that would take into consideration the technical, economic, and processing features of the discussed problem.

At the same time, special attention should be paid to the necessity of improving the quality (consumer) and therefore marketable properties of the ash and slag materials. In such case, there probably will not be any more discussion about whether these materials are waste or by-products of thermal power plants.

Effective utilization of by-products (waste) of various plants in industry is rightfully linked to the problem of rational use of natural resources and environment protection, which is one of the most important issues of our time. The most rational and economical technical solution is development and implementation of closed cycle production processes, which do not generate any non-utilized by-products or waste (the so-called "non-waste technologies") [1-3]. When non-waste technologies are applied, the technical and economic class of any complex production process is raised dramatically, and an optimal level of ecological interaction between industry and environment is maintained.

Discussing the problem of extensive and effective use of TPP ash should primarily focus on the obstacles to solving this problem. Among the most important and priority ones should include not only the solution at the present level of the tasks of collecting and transporting ASM, but also improve their technical and particular technological features and characteristics that make ASM most useful and attractive for applications such as the production of cement and other building materials. Such technologies exist. They are almost forgotten, and today it seems necessary to recall them.

Below there is an example of the results of large-scale research and development, which were performed in the USSR with the purpose of effective non-waste solid fuel utilization for simultaneous generation of electric power and fused cement clinker. Please note that that the production of cement clinker by the fusion method (and not the usual burning method) makes it possible to intensify the processes of clinker production from Portland cement raw meal dramatically.

The idea of this method [2, 3] is production of fused cement clinker and power by combustion of various kinds of solid fuel in furnaces with slag tap. Contrary to the other described methods, the power clinker method allows the following:

- to utilize the combustible and mineral parts of the fuel effectively and with no residue;
- to reduce the cost of the produced energy and cement by combining their generation;
- to develop a new efficient technology of Portland cement clinker production by the fusion method.

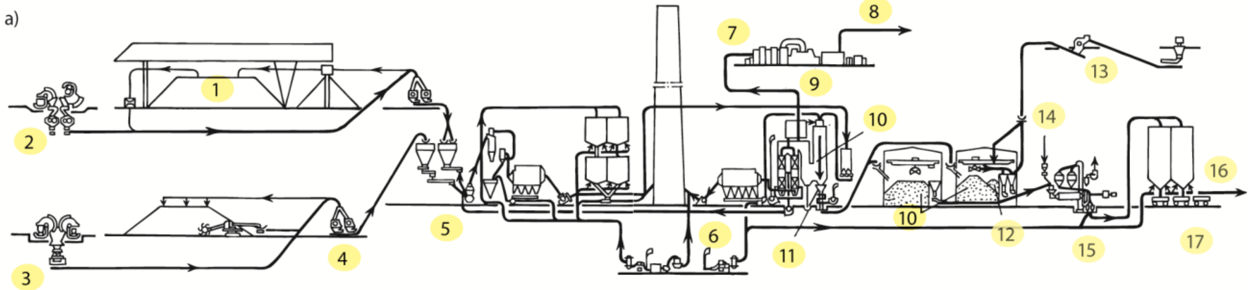
It should be noted that the technical and economic efficiency of fuel combustion processes combining to give the product obtained by melting due to the fact that energy furnace slag tap can be considered as one of the most effective types of melting devices. Note that when combining the two processes use of liberated heat carried out at a much higher efficiency than working separately technological units. So complex energo-technological scheme should minimize the total cost of fuel.

Major research, development, and experiments in this field were started by the initiative of Academician G.M. Krzhizhanovsky, an outstanding researcher and public figure. On request of G.M. Krzhizhanovsky in 1957, the Council of Ministers of the USSR passed a special order on the beginning of funding of research for solving the problem of comprehensive use of solid fuel and generation of electric power and fused cement clinker (power clinker).

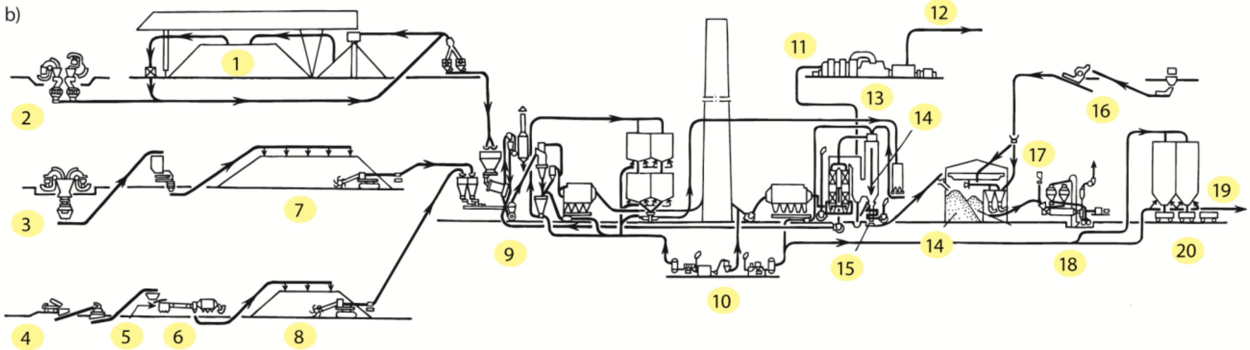
ENIN was appointed as the main entity to design the comprehensive matter and delegated the supervision of the development of high temperature furnace facilities with slag tap where the slag capture rate would be as high as possible. The solution of the main process issues of fused Portland cement clinker (power clinker) generation and use was assigned to the Giprocement institute (at the time, the head institute of the cement industry) with engagement of other specialized entities. Numerous research, development, and design institutes, construction and startup entities, and engineering plants of the USSR were engaged in this work that was completed in the 1960's.

A result of their joint efforts was the establishment of a testing and industrial facility at the Kohtla-Järve TPP in Estonia and proven possibility of practical implementation of the power clinker process.

Principal scheme of the power clinker process represented on Fig. 1. Principal scheme of the pilot unit at the Kohtla-Järve TPP — on Fig. 2.

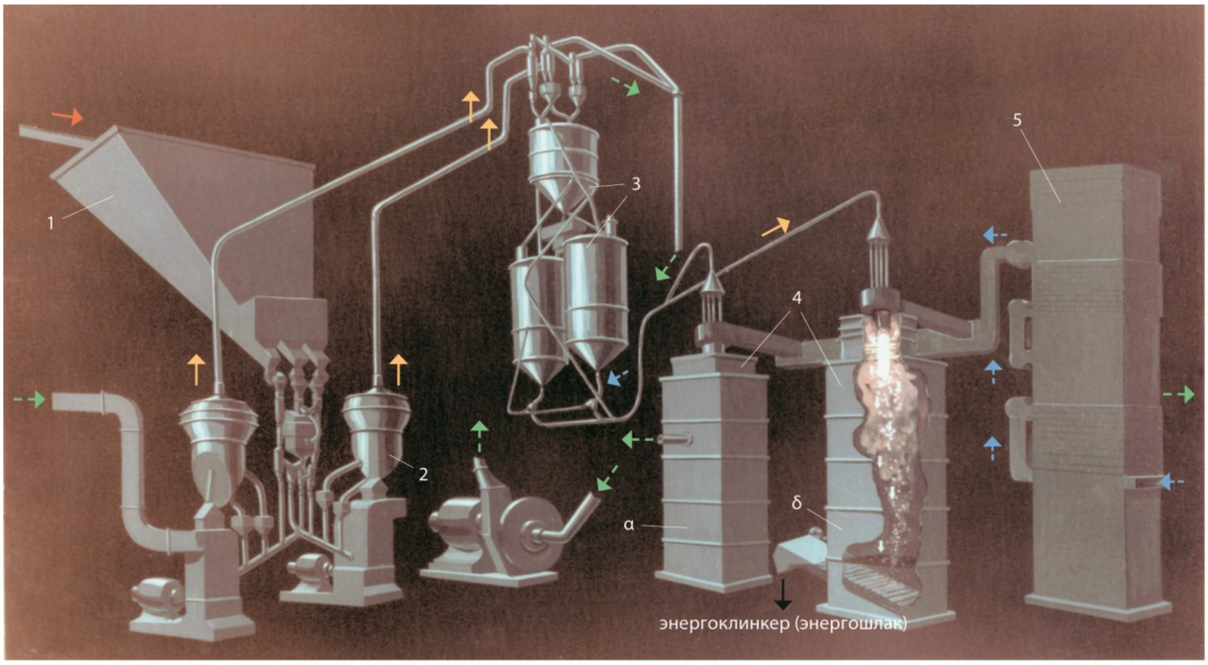


1) склад сланца-концентрата; 2) прием и дробление сланца-концентрата; 3) прием и дробление известняковой породы; 4) склад известняковой породы; 5) приготовление шихты; 6) компрессорная; 7) пар; 8) электроэнергия; 9) турбинный цех; 10) энергоклинкер; 11) котельный цех; 12) гипс; 13) прием и дробление гипса; 14) триэтаноламин; 15) помольный цех; 16) цемент; 17) силосный склад цемента



1) склад угля; 2) прием и дробление угля; 3) прием и дробление известняка; 4) прием и дробление глины; 5) мазут; 6) сушка глины; 7) усреднительный склад известняка; 8) усреднительный склад глины; 9) приготовление шихты; 10) компрессорная; 11) пар // steam; 12) электроэнергия; 13) турбинный цехт; 14) энергоклинкер; 15) котельный цех; 16) прием и дробление гипса; 17) триэтаноламин; 18) помольный цех; 19) цемент; 20) силосный склад цемента

Fig. 1. The process charts of combined generation of electric power and fused Portland cement clinker: a) option with combined use of oil share; b) option with combined use of coal



1. Бункера для кусковых материалов; 2. Мельничные агрегаты; 3. Бункера шихтованной пыли; 4. Топочные стенды; 5. Воздухоподогреватель
Размолотое топливо (шихта)
Воздух
Кусковой материал
Дымовые газы

Fig. 2. A pilot power clinker (power slag) facility

In frame of this report is not possible even to briefly enumerate all the results of work performed, furthermore these results recently were discussed in detail in the relevant review articles [3]. However, it seems necessary to point out some of the most important results:

- The Energy Institute named after G. M. Krzhizhanovsky (ENIN) has designed and tried various kinds of high temperature furnace units with combustion chambers of the straight flow and cyclone types. It has been shown convincingly that it is possible to implement the power clinker process in vertical combustion chambers only but not in horizontally located ones. The most promising (from the viewpoint of producing fused clinker that is as homogeneous by composition as possible) design of a furnace facility was the one with a band tube header [4].
- An important stage of experimental operations at a test industrial facility is determining the time that is necessary to produce fused clinker (from the moment when the blend is blown into the furnace and until the fuse flows out). Using the radioactive isotope method, it was found that the average time while the fused material stays in the furnace facility does not exceed 2–3 mins [5]. It should be kept in mind here that the usual time of ordinary clinker generation in modern furnace facilities is several hours.
- The nature and characteristics of mineral crystallization in power clinker fundamentally different from similar processes in the conventional clinker (Fig. 3). Important mineral of clinker — alite — gets opportunity of priority development, which leads to a significant improvement in strength and other construction and technical properties of fused cements [6].

Fig. 3. Comparative microstructures of clinkers of various competition (left to right: SF = 0.72; 0.77; 0.82; 0.94; 1.00): a) produced by the fusion method; b) produced by the baking method.

The high temperature gas air heater was designed and built at the pilot industrial unit heated air to 800 °C only instead of the required 1100–1200 °C. At the final stage of the experimental operations in order to reach the required temperature it was decided to use the method of oxygen enrichment of the air blow. Liquid oxygen was supplied in tanks by railway. A special gasification unit was built for transforming liquid oxygen into gaseous at the pilot industrial unit. Calculations carried out at the Central Institute of Boiler and Turbine (CKTI, Leningrad, 1979) confirms this point of view.

A group of organizations engaged in the development of the problem (ENIN, Giprocement, Leningrad division of Teploelektroproekt Institute, Leningrad division of Orgenergostroy institute) did (1965–1966) the relevant preliminary project designs, based on which the technical and economic parameters of combined and separate production of power and cement were determined. Even in the case of combustion of fuel (oil shale) with high ash content and low-calorific value savings investment could reach 12–13 %, and the annual operating costs reduced by 19–20 %.The calculations were made in the prices of 1961. It is clear that in modern prices the abovementioned values of the economic effect for various options of power clinker combustion of solid fuel will be measured in relevant numbers that will be closer to tens of billions than tens of millions of rubles.

The technical data provided above is an example of detailed development of a technology of a combined production of two valuable products, namely, electric power and cement, with residue-free (waste-free) utilization of the initial raw material, which in this case is solid fuel. Naturally, such complicated research with such a big number of developers involved could only be done in the conditions of a united research and industrial system that existed in our former country, the USSR. It was a unique development where the leadership of our country is undoubted and fixed quite substantially. However, even today it is possible to proceed with the final stage of the work related to industrial testing and implementation of the power clinker technology. Such work can be started on a quite modest scale, e.g., by reconstruction of an operating boiler unit that is obsolete or scheduled for decommissioning for technical reasons using the power clinker technology.

Further, the author of this publication will attempt to show some of the possibilities and feasibility of increasing practical interest in the use of fuel granulated slag — products of liquid slag removal energy furnaces (ash and slag mixes), and the possibility of a significant increase in the quality characteristics and properties of the ash and slag.

Granulated fuel slag is a product of slag tap removal from power furnaces at thermal power plants, a relatively new raw material for production of cement and other construction materials, especially in comparison with granulated blast furnace slag. Due to some similarity of the chemical and mineralogical characteristics of granulated fuel slag and granulated blast furnace slag (with clear differences such as the content of iron oxides), there are no principal differences in the hydration and hardening processes of binders containing such slag types. This point of view is confirmed by the results of studies of processes of hydration and hardening of cements with added granulated fuel slag, such as studies completed at the Moscow Civil Engineering Institute (MISI) under the supervision of Professor A. V. Volzhensky.

Giprocement Institute did a detailed research of granulated fuel slag produced from combustion in furnaces with slag tap removal of coals from various coal mines of the Soviet Union (Kansko-Achinsk, Krasnoyarsk, etc.) at large thermal power plants (Nazarovskaya, Krasnoyarskaya, and other major thermal power plants (GRES)). The results of the research have shown that both basic (Nazarovskaya GRES, Krasnoyarskaya TPP, etc.) and acidic (Belovskaya and other GRES) granulated fuel slag can be used successfully as an active hydraulic admixture in production of different types of cement and other construction materials.

It is known that the slag trapping factor of modern energy furnaces with slag tap removal is not as high as 100 %. At thermal power stations it is preferred to dispose granulated fuel slag to ash dumps together with dry ash that is trapped in ash collectors (the method of water ash and slag removal to dumps). Thus, consumers of ash and slag materials have to deal with a very inconvenient raw material with high moisture content. However, practical experience of the author has shown that for certain reasons at the ash dumps of TPP, which have furnaces with slag tap removal; there are fairly large areas where the ash and slag mix has not only a relatively small content of the ash component but also a lower moisture content.

The Giprocement team paid great attention to pilot industrial and implementation work for practical use of granulated fuel slag in the cement industry [7]. Here it is first of all necessary to note the major work that was performed in 1970's at the Krasnoyarsk cement plant on the use of granulated fuel slag from Nazarovskaya GRES (Nazarovo, Krasnoyarsk Region) as an active mineral admixture in production of high grade Portland cement (instead of long-distance granulated blast furnace slag from Magnitogorsk Metallurgical Combine, one of the most active granulated blast furnace slag types, which had been used by the plant). The Krasnoyarsk plant used 15000 t of Nazarovsky fuel slag to produce about 100000 tons of Portland cement. At the same time, major experimental industrial work was done at the Krasnoyarsk plant on the use of granulated fuel slag from Nazarovskaya GRES as an active mineral admixture in production of hydraulic slag Portland cement. The fuel slag content in industrial batches of cement amounted to 35 to 40 %. Slag Portland cement was used for production of hydraulic concrete that was used in the tall dam of the Ust-Ilimskaya hydroelectric power plant in East Siberia. The total amount of concrete was approximately 13500 m^3. The results of this work were shown at the Exhibition of Achievements of the National Economy of the USSR (VDNKh) many times, and the participants of this work were awarded USSR VDNKh medals twice.

The matter of consistency of the fuel slag compositions (especially for ash and slag mixes) was considered many times in the course of research and experimental / industrial work. At that, a very widespread point of view was taken into account that a polydisperse material like ash and slag mix from a TPP dump has a significantly more volatile chemical composition than granulated fuel slag. The results of chemical analyses of the samples, of contrary to the existing point of view, have shown that the composition of the ash and slag mix is very homogeneous. Apparently, the averaging of the mix composition takes place when the ash and slag mix flows around the TPP ash dump as well as during loading (at the thermal power plant) and unloading (at the cement plant) operations.

We should also focus on the possibility of a significant increase in activity and the major consumer characteristics of fuel waste.

The relatively cheap and easy-to-produce Ekibastuzsky coals are especially remarkable among coals, the mineral part of which has a distinct acidic chemical composition (Ekibastuzsky, Kuznetsky, etc.). In addition, these coals have a relatively high energy value and a low ash content. However, due to some features of the chemical composition of the mineral part of these coals (primarily the high content of Al_2O_3) it is highly refractory (melting temperature). Nevertheless, research of combustion of Ekibastuzsky coal in power furnaces with slag tap removal was performed with success at the Kazakh Institute of Power Engineering (Alma-Ata, Kazakhstan) under the general supervision of Academician S. C. Chokin who was the Head of the Institute. It should be noted that such work was also done by the Energy Institute (ENIN) named after G. M. Krzhizhanovsky at a pilot industrial facility at the Kohtla-Järve TPP in Estonia.

The suggested by Giprocement work program included, in particular, combustion of Ekibastuzsky coal with slag tap removal with coal adjustment by a certain amount of a carbonate component (limestone) as a fluxing agent. It was shown (Fig. 4) that in the case of reducing the Al_2O_3 content and increasing the CaO content in the melted material, the melting temperature of the mineral part of the fuel and limestone charge could be reduced considerably (up to 400 °C) as a result of optimal and relatively fusible (eutectic) slag compositions. At the same time, there are significant structural changes in the slag associated with aluminum-framed depolymerization slag glass. As a result, significantly grows hydraulic activity of slag and slag-based cements [7, 9].

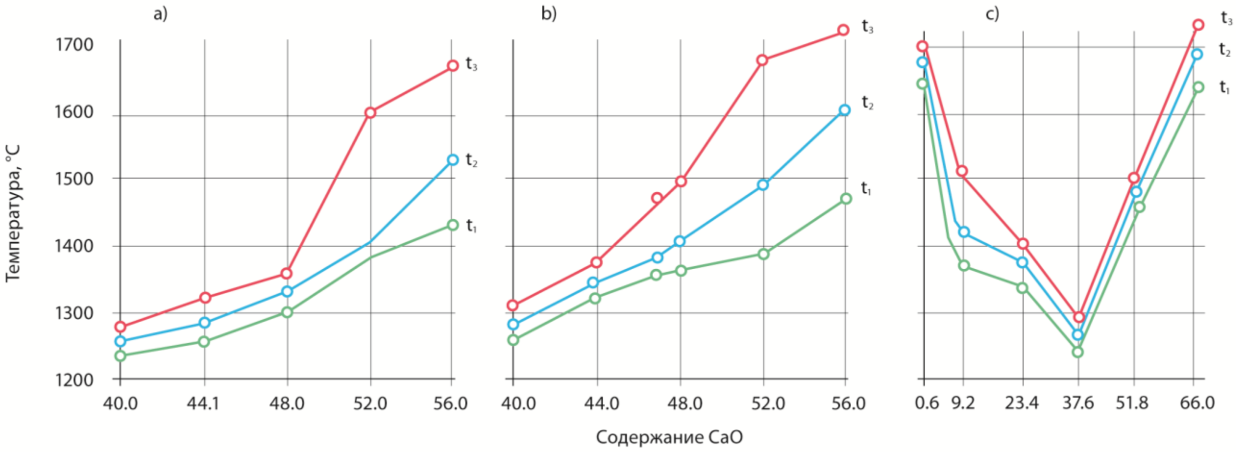


Fig. 4. The characteristics of fusibility of charge mixes based on the mineral parts of: a) Baltic combustible shale; b) Nazarovo (Kansk-Achinsk) coal; c) Ekibastuzsky coal; t_1: temperature at the beginning of deformation, °C; t_2: softening temperature, °C; t_3: starting fluid temperature, °C.

However, not only fuel slag glass may be of great interest for the production of building materials. A large and well-equipped pilot industrial facility at Kohtla-Järve TPP was used by the USSR Ministry of Energy as the main base to practice processes of combustion of various solid fuels (besides combustible shale) with slag tap removal. These included coal from the Beryozovsky deposit of the Kansko-Achinsky coal basin (Krasnoyarsk Region), the development of which had already started at that time. It was intended to base a number of major thermal power plants in Siberia on Beryozovsky coals. The mineral part of Beryozovsky coal has not only a high CaO content but according to research results, is has a $CaO:SiO_2$ ratio that has made is possible to expect a new highly basic crystalline phase, C_3S (alite) in the fuel slag, which is not typical for such coal. This mineral is known as the most important phase component of Portland cement clinker, which provides superb engineering characteristics of the cement.

When combustion of Baltic oil shale fuel slag melt granulation appeared in other important for cement clinker crystalline phase β-S_2S (belite). Thus, not only the glass, but also fuel slags (Fig. 5–6) are crystallized, as studies have shown a great interest for the production of cement and other building materials.

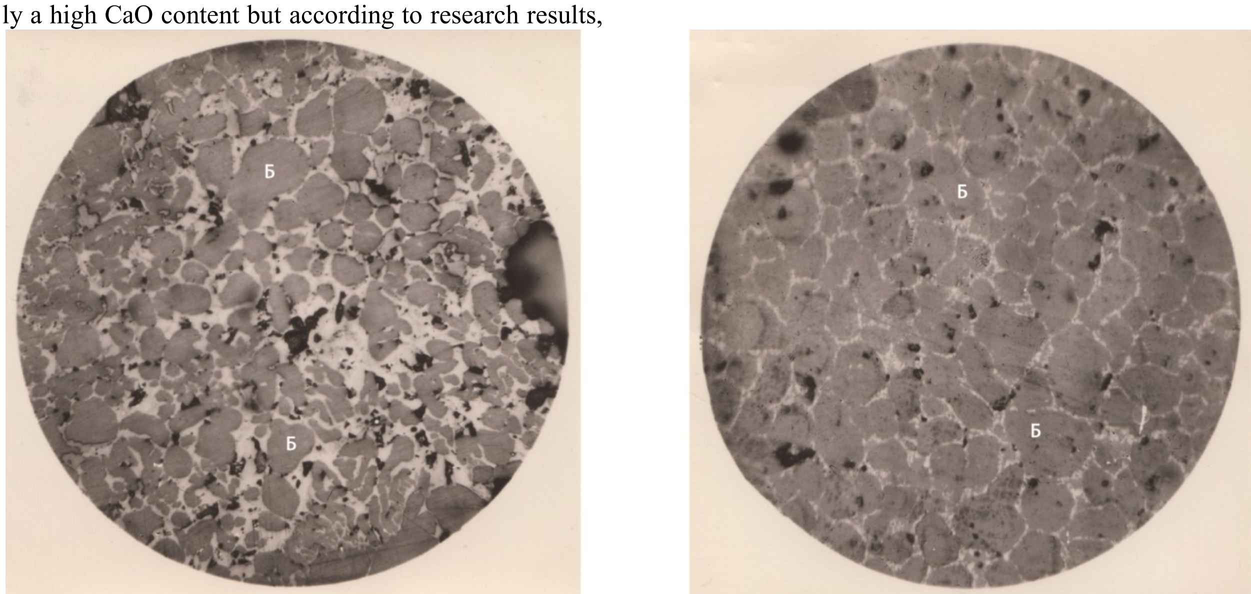


Fig. 5. Microphotographs of shale and ash granulated fuel slag

Б: belite (reflected light)

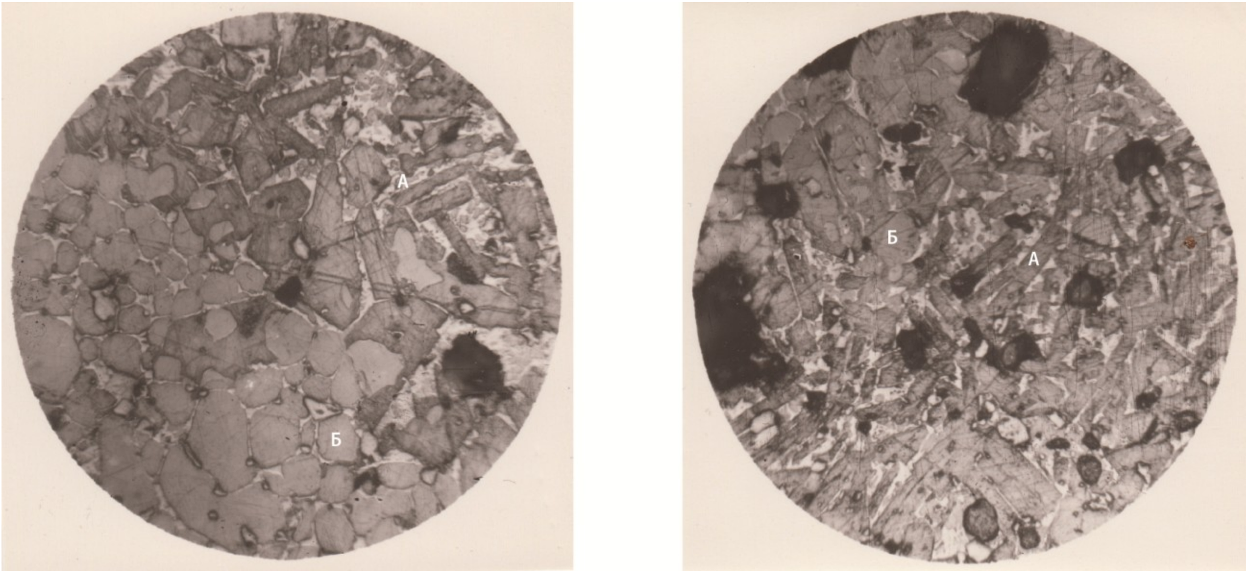


Fig. 6. Microphotographs of granulated fuel slag of coal from the Beryozovsky field of the Kansko-Achinsk basin (East Siberia) А: alite, Б: belite (reflected light)

In conclusion, the author considers it necessary to briefly mention issues related to physical properties and features of granulated fuel slag (ash and slag mixes) that have great significance for practical use. For example, when they are used for production of moist material (in this case, slag), their water-yielding capacity (ability to lose moisture at natural storage) and congelation during transportation, especially in harsh climates of Siberia, are very important. The results of the research have shown that granulated fuel slag is able to yield moisture much more intensively than blast furnace slag, even in the case of natural storage [7]. The Tomsk branch of Teploelektroproyekt Institute (currently Atomteploelektroproyekt Institute) with a contribution by Giprocement designed the principal concepts of facilities and devices for selection, dehydration, and shipment of granulated fuel slag with consideration of its specific physical properties. At Giprocement Institute, design studies were performed of principal process charts for application of such slag in cement production.

L.Y. Goldstein. The necessity and practicality of raising the quality and processing characteristics of ash and slag waste of thermal power plants for their successful use in production of cement and other construction materials // Proceedings of the V Conference "Ashes from TPPs: removal, transport, processing, storage", Moscow, April 24–25, 2014 — M.: MPEI Printing House, 2014. P. 159 – 164.